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FOR THE DEPARTMENT OF ENERGY

Establishing Specifications for Low Enriched Uranium Fuel Operations Conducted Outside the High Flux Isotope Reactor Site

September 2010

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ORNL/TM-2010/241

Research Reactors Division

ESTABLISHING SPECIFICATIONS FOR LOW ENRICHED URANIUM FUEL OPERATIONS CONDUCTED OUTSIDE THE HIGH FLUX ISOTOPE REACTOR SITE

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September 2010

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ABSTRACT

The National Nuclear Security Administration (NNSA) has funded staff at Oak Ridge National Laboratory (ORNL) to study the conversion of the High Flux Isotope Reactor (HFIR) from the current, high enriched uranium fuel to low enriched uranium fuel. The LEU fuel form is a metal alloy that has never been used in HFIR or any HFIR-like reactor. This report provides documentation of a process for the creation of a fuel specification that will meet all applicable regulations and guidelines to which UT-Battelle, LLC (UTB) – the operating contractor for ORNL - must adhere. This process will allow UTB to purchase LEU fuel for HFIR and be assured of the quality of the fuel being procured.

1.0 INTRODUCTION

The National Nuclear Security Administration (NNSA) has funded staff at Oak Ridge National Laboratory (ORNL) to study the conversion of the High Flux Isotope Reactor (HFIR) from the current, high enriched uranium (HEU) fuel to low enriched uranium (LEU) fuel. The LEU fuel form – a metal alloy composed of uranium and 10% molybdenum by weight (U-10Mo) - and a tentative production scheme have been documented in Ref. 1. The fuel will not be fabricated at ORNL (as the initial HEU fuel was) nor will the operating contractor for HFIR – UT-Battelle, LLC (UTB) – have any manufacturing role in the production of the LEU fuel. The UTB role will be limited to the purchase of the product.

The LEU fuel is a different physical form than the current HEU fuel; the HEU being a mixture of U_3O_8 and aluminum powders. The U-10Mo alloy has never been used in HFIR or any HFIR-like reactor. Furthermore, limited experience exists within the HFIR staff regarding the creation of fuel production processes since the HFIR HEU fuel specifications and production procedures are essentially unchanged since the HEU fuel fabrication process was created in the mid-1960s.

Reference 1 notes that the start of the LEU production process is the assignment of HEU to the production scheme. Thus the initial steps in LEU production will be in the secure area of the Y-12 National Security Complex. Subsequent to blend-down of HEU to LEU, economic considerations will lead to the remaining LEU plate production steps being outside the secure area. Thus there are at least two geographic locations for the LEU process and likely, but not necessarily, at least two vendors. By coincidence (and history), this same separation occurs in the current HEU process and results in two fuel specifications for HEU fuel. These two specifications are reproduced in Appendices A and B and it is the development of U-10Mo counterparts to Appendix A and the plate production processes in Appendix B that are the subjects of this study. As noted in Ref. 1, after HFIR fuel plates have been fabricated, the remainder of the LEU fuel production process will be the same as for the current, HEU fuel. The authors' goal is the establishment of a process for the creation of a fuel specification that will meet all applicable regulations and guidelines to which UT-Battelle, LLC must adhere.[*] This process will allow UTB to purchase LEU fuel for HFIR and be assured of the quality of the fuel being procured.

Operation of the Y-12 National Security Facility is the responsibility of the NNSA. LEU program management have informed HFIR staff that once a production process for LEU has been developed, the portions of the process following the blend-down of HEU would be in a facility that would be the responsibility of another entity in the Department of Energy (possibly Office of Nuclear Energy or Office of Science). The HFIR is a Department of Energy, Office of Science facility. Thus an established, LEU fuel cycle for HFIR will require cooperation among multiple entities within the Department of Energy.

[*] The authors recognize that the LEU fabrication process may have multiple vendors and multiple fuel specifications. For simplicity, references to vendors and specifications are made singular in tense.

2.0 PROCESS FOR THE CREATION OF FUEL SPECIFICATIONS

Research and development of the LEU, U-10Mo fuel (monolithic form) is the responsibility of the Global Threat Reduction Initiative (GTRI) Reduced Enrichment for Research and Test Reactors (RERTR) program. Responsibility for the research and development operations has been assigned to the Idaho National Laboratory. An assumption made for this study is that the research and development being conducted by INL is being performed in accordance with nuclear quality assurance standard, NQA-1 Subpart 4.2.

Production of reactor fuel is a joint responsibility of the reactor owner and the fuel vendor. The reactor owner is responsible for: creating and maintaining the fuel specification, being informed as to the procedures of the fuel vendor that are created by the vendor in order to produce a product that meets the specification, accepting responsibility that the quality assurance procedures created by the fuel vendor are adequate to assure that the fuel produced meets the specification, and for auditing the vendor to insure that the procedures are followed.

The operating contract for ORNL (including HFIR) between UT-Battelle and the United States Department of Energy (DOE) specifies rules and regulations that are applicable to HFIR operations and HFIR fuel procurement. The contracting requirement most applicable to the study presented here is the stipulation that "Contractors conducting activities, including providing items or services, that affect, or may affect, the nuclear safety of DOE nuclear facilities must conduct work in accordance with the Quality Assurance criteria in (Code of Federal Regulations, CFR) Sec. 830.122." In addition to 10 CFR 830, UTB is contractually obligated to DOE Order 414.1C (the quality assurance order). That Order requires that UTB adopt a consensus QA standard. UTB/HFIR staff have adopted NQA-1 2000 Part 1 through the Department of Energy process identified as "work smart standards." The work smart standards are incorporated into the UTB contract with the Department of Energy.

Adherence to fuel procurement regulations – those that are non-business related – is achieved via the quality assurance portions of the fuel specifications, i.e. the fuel specifications demonstrate adherence of UTB (HFIR) to NQA-1. The achievement of operation requirements is documented in the HFIR Safety Analysis Report (SAR).[2] That report will have to be updated for LEU fuel based on analyses performed by HFIR staff and data obtained from the NNSA LEU fuel development program.[3] In many instances, the sources of input to the analyses that are the basis for the HFIR SAR are the fuel specifications. Thus the new fuel specification to be developed for LEU fuel is one of the mechanisms for insuring the nuclear safety of HFIR as required by 10-CFR830 and the mechanism for insuring adherence to DOE Order 414.1C.

The Research Reactors Division at ORNL maintains an "internal" document, RRD Systems Engineering procedure SEP-0225, the stated purpose of which is "to control the initial development, and subsequent revisions to System Design Descriptions (SDD), Component Design Specifications (CDS), Material Specifications (MS) Job Specifications (JS), and General Procurement Specifications (GPS)." Note that fuel specification is not specified though could be considered as being a "component specification" or a "material specification." Review of this procedure showed that it presents, in general terms, the expected content of a specification but not the procedure for creating a specification, especially when outside organizations must be involved in specification development, nor does it specify the time in the development process at which a specification should be developed. The procedure seems based on the implicit assumption that a product, component, or material is available.

The creation of a fuel specification for HFIR U-10Mo should follow the process established by the International Organization for Standardization.[4] While the authors acknowledge that ref. 4 is intended for use among countries for established products, the philosophy employed in this process is applicable to the development of an LEU fuel cycle. The ISO process is described by an extensive set of references available from the link that is ref. 4. A brief summary of the process is presented below but with text modified to be applicable to LEU fuel for HFIR.

International standards are developed by ISO technical committees (TC) and subcommittees (SC) by a six-step process:

- Stage 1: Proposal
- Stage 2: Preparatory
- Stage 3: Committee
- Stage 4: Enquiry
- Stage 5: Approval
- Stage 6: Publication

Stage 1: Proposal Stage (unneeded, LEU is a new process so there must be a new standard).

Stage 2: Preparatory Stage — A working group of experts from or contracted to ORNL, the chairman (convener) of which is the project leader, is set up for the preparation of a working draft. The working group will also include representatives from the vendors. Successive working drafts may be considered until the working group is satisfied that it has developed the best technical solution to the problem being addressed.

Stage 3: Committee Stage — At this stage, the draft is forwarded to ORNL and vendor management for the consensus-building phase. Once consensus has been attained, the text is finalized for submission as a draft Research Reactors Division (RRD) specification.

Stage 4: Enquiry Stage — The draft RRD standard (DIS) is circulated to all Department of Energy (DOE) bodies including NNSA, Office of Science, and whichever office or entity is responsible for the fuel plate fabrication facility. Comments should be made within a period of five months. It is approved for submission as a final RRD standard if approved by the DOE Office of Science. If the approval criteria are not met, the text is returned to the originating Stage 2 for further study and a revised document will again be circulated for approval and comment as a draft RRD standard.

Stage 5: Approval stage (linked with stage 4 for the LEU process).

Stage 6: Publication Sage — Once a final draft RRD standard has been approved, only minor editorial changes, if and where necessary, are introduced into the final text. The final text is sent to RRD Document Control which publishes the specification.

The ISO process includes a useful “stage code table” that allows for tracking of the standard development process. The table is reproduced as Fig. 1. Certainly, many of the steps are unnecessary for LEU process development but the implied rigor of standard development should be adopted for the LEU process.

International harmonized stage codes

STAGE	SUBSTAGE						
				90 Decision Substages			
	00 Registration	20 Start of main action	60 Completion of main action	92 Repeat an earlier phase	93 Repeat current phase	98 Abandon	99 Proceed
00 Preliminary stage	00.00 Proposal for new project received	00.20 Proposal for new project under review	00.60 Close of review			00.98 Proposal for new project abandoned	00.99 Approval to ballot proposal for new project
10 Proposal stage	10.00 Proposal for new project registered	10.20 New project ballot initiated	10.60 Close of voting	10.92 Proposal returned to submitter for further definition		10.98 New project rejected	10.99 New project approved
20 Preparatory stage	20.00 New project registered in TC/SC work programme	20.20 Working draft (WD) study initiated	20.60 Close of comment period			20.98 Project deleted	20.99 WD approved for registration as CD
30 Committee stage	30.00 Committee draft (CD) registered	30.20 CD study/ballot initiated	30.60 Close of voting/ comment period	30.92 CD referred back to Working Group		30.98 Project deleted	30.99 CD approved for registration as DIS
40 Enquiry stage	40.00 DIS registered	40.20 DIS ballot initiated: *5 months*	40.60 Close of voting	40.92 Full report circulated: DIS referred back to TC or SC	40.93 Full report circulated: decision for new DIS ballot	40.98 Project deleted	40.99 Full report circulated: DIS approved for registration as FDIS
50 Approval stage	50.00 FDIS registered for formal approval	50.20 FDIS ballot initiated: *2 months*. Proof sent to secretariat	50.60 Close of voting. Proof returned by secretariat	50.92 FDIS referred back to TC or SC		50.98 Project deleted	50.99 FDIS approved for publication
60 Publication stage	60.00 International Standard under publication		60.60 International Standard published				
90 Review stage		90.20 International Standard under periodical review	90.60 Close of review	90.92 International Standard to be revised	90.93 International Standard confirmed		90.99 Withdrawal of International Standard proposed by TC or SC
95 Withdrawal stage		95.20 Withdrawal ballot initiated	95.60 Close of voting	95.92 Decision not to withdraw International Standard			95.99 Withdrawal of International Standard

Fig. 1. ISO stage codes used to track standard development (ref. 4).

3.0 ESTABLISHMENT OF INITIATION DATE FOR FUEL SPECIFICATION DEVELOPMENT

Obviously the process described in Section 2.0 would have to be completed prior to the production of the first HFIR LEU core. However the process cannot be initiated until an adequate amount of fuel research and development has been completed. That R&D is needed to enable the industrial process to be defined to the level of precision that will yield quantitative input on manufacturing tolerances and measurement uncertainties. A useful categorization of industrialization stages is presented Appendix C (ref. 5) though many other references provide similar discussion. Clearly many steps on the tables in Appendix C are not applicable to the LEU fuel development program but the stage definitions are useful.

Based on the "Key Questions" table in Appendix C for HFIR LEU fuel, the RERTR program is currently at Stage 2, Step 6, since a prototype of a HFIR LEU fuel plate has not yet been fabricated. Based on the "Activities Table" in Appendix C, the standards development process described in Section 2.0 should begin in Stage 4, Step 10.

Figure 2 is the LEU conversion schedule for high performance, United States reactors that was presented at NNSA and distributed in March 2010. While the designations in Fig. 2 do not map well to Appendix C, the date of January 2012 for commercial contract awarded would seem to match to Stage 4, Step 10 of Appendix C and thus should be the nominal starting time for fuel specification development.

A prototype, HFIR, U-10Mo fuel plate has not yet been constructed. Consequently it is not yet time to begin the fuel specification process. The process is expected to be initiated at the time that a commercial fabricator is selected. However, because initial LEU fabrication steps will involve HEU, that contractor (BWXT-Y12) is known and specifications for the "head end" of the process could be initiated prior to the selection of the commercial fabricator. Final approval of the "head end" fuel specification should await selection of and review by the commercial fabricator.

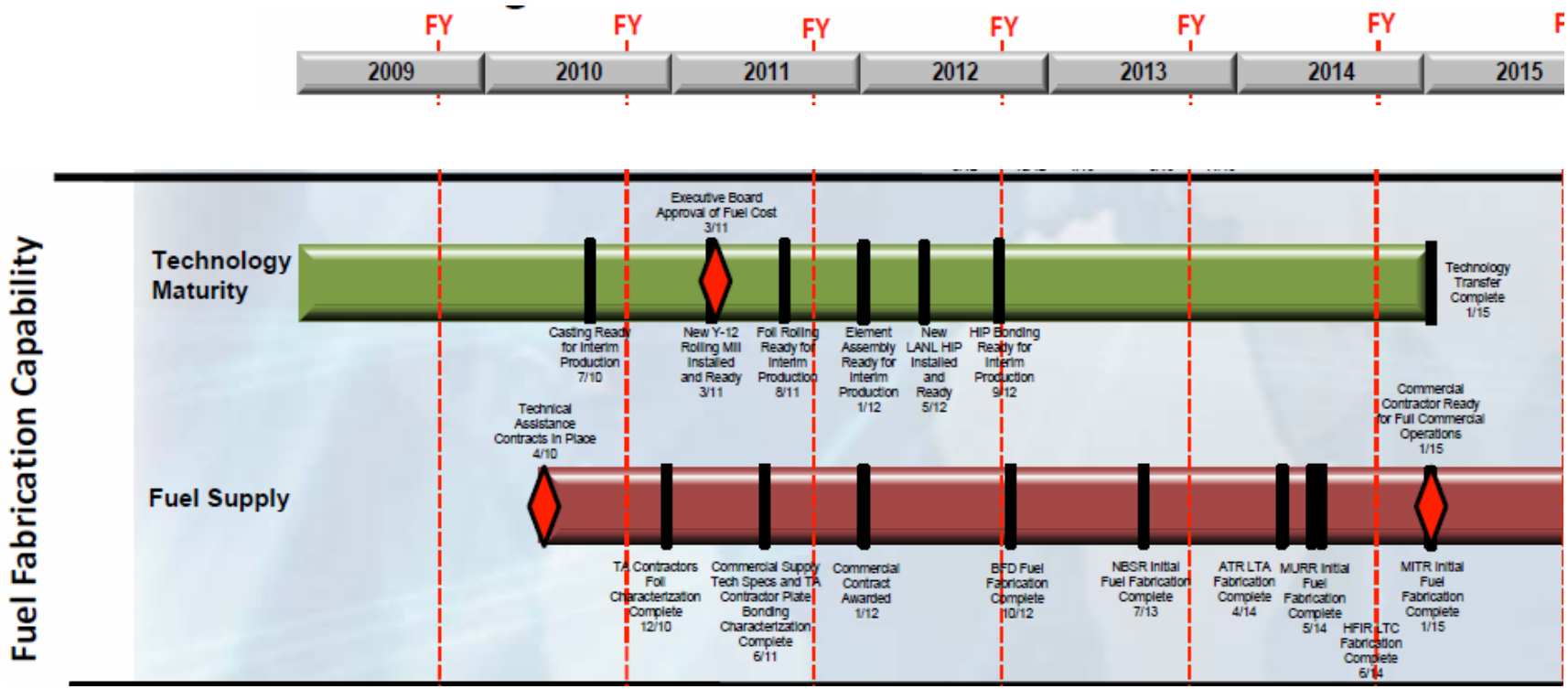

Fig. 2. Portion of NNSA, U.S. high performance reactor conversions schedule, March 2010.

4.0 CONCLUSIONS

Development of an LEU-10Mo fuel specification that corresponds to existing HEU fuel specifications is the mechanism for implementing quality assurance regulations to which the contractor for ORNL is obligated. Because the research and development (R&D) of the U-10Mo fuel is not the responsibility of UT-Battelle/ORNL, the assumption is made that all such work is in conformance with Nuclear Quality Assurance Standard 1 (NQA-1), Subpart 4.2. It is the responsibility of the LEU R&D contractor(s) to provide documentation to UT-Battelle of the validity of the assumption.

A prototype, HFIR, U-10Mo fuel plate has not yet been constructed. Consequently it is not yet time to begin the fuel specification process for fuel plates. However, a separate specification document could be prepared for the initial stages of the fuel production process. The contractor for the HEU stages will be BWXT-Y12 and a specification for the production step through the creation of U-10Mo foils could be initiated prior to the selection of the commercial fabricator for fuel plate and element production.

Creation of a fuel specification can be achieved by following a process similar to that endorsed by the international standards organization. A committee composed of staff from the reactor operator and the fuel vendors should be formed to create the specification. The specification will be the property of and maintained by the reactor operator.

5.0 REFERENCES

1. J. D. Sease, R. T. Primm III, and J. H. Miller, *Conceptual Process for the Manufacture of Low-enriched Uranium/Molybdenum Fuel for the High Flux Isotope Reactor*, ORNL/TM-2007/39, September 2007.

2. ORNL/HFIR/USAR/2344, HFIR Updated Safety Analysis Report, Revision 6.

3. D. M Wachs, *RERTR Fuel Development and Qualification Plan*, INL/EXT-05-01017, Rev. 4, August 2009.

4. http://www.iso.org/iso/standards_development/processes_and_procedures/stages_description.html, September 29, 2010.

5. http://www.bsutecenter.com/Tools___Links/ September 29, 2010.

APPENDIX A

FUEL SPECIFICATION FOR THE PRODUCTION OF U_3O_8 POWDER

ORNL RESEARCH REACTORS DIVISION
ENGINEERING STANDARDS AND SPECIFICATIONS
ORNL/RRD/INT-37, VOLUME 4

RRD-MS-106, REV. 1

SPECIFICATION FOR
U_3O_8 POWDER FOR MANUFACTURING HFIR FUEL PLATES

Prepared by:	RRD Fuels and Material Engineer	11/04/02 Date
Reviewed by:	RRD Systems Engineering	11/8/02 Date
Reviewed by: 11/13/02	RRD Safety Analysis	11-12-02 Date
Reviewed by:	RRD Quality Assurance	11/18/02 Date
Approved by:	RRD Plant and Project Management	11/18/02 Date

ORNL RESEARCH REACTORS DIVISION
ENGINEERING STANDARDS AND SPECIFICATIONS
ORNL/RRD/INT-37/V4
RRD-MS-106, R1

SPECIFICATION FOR U_3O_8 POWDER FOR MANUFACTURING HFIR FUEL PLATES

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ORNL RESEARCH REACTORS DIVISION
ENGINEERING STANDARDS AND SPECIFICATIONS
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SPECIFICATION FOR U_3O_8 POWDER FOR MANUFACTURING HFIR FUEL PLATES

1. INTRODUCTION

The revision to the specification is to provide more definitive requirements learned since the Rev. 0 was issued in 1998.

2. SCOPE

This specification will define the U_3O_8 powder containing 93% enriched uranium to be procured for use in the manufacture of fuel plates for the High Flux Isotope Reactor (HFIR). The U_3O_8 powder will be blended with aluminum powder to form the fuel sections in the fuel compacts used to make fuel plates for both inner and outer HFIR fuel elements. The U_3O_8 qualified under this specification will be used in the manufacture of U_3O_8 fuel elements for the NIST Reactor and may also be used in the manufacture of fuel elements for other research reactors.

3. REFERENCES

1. American Society For Testing and Materials (ASTM), *Standard Test Method for Sieve Analysis of Granular Metal Powder*, ASTM B 214-(latest revision).

2. ASTM:C 1462-00 "*Standard Specification for Uranium Metal Enriched to More Than 15% and less than 20% 235U*".

3. ASTM C 1233097 " Standard Practice for Determining Equivalent Boron Contents of Nuclear Materials".

4. W. J. Werner and J. R. Barkman, ORNL-4052, *Characterization and Production of U_3O_8 for the High Flux Isotope Reactor,* Oak Ridge National Lab., April 1967.

4. U_3O_8 POWDER SPECIFICATIONS

4.1 GENERAL REQUIREMENTS

The U_3O_8 powder shall contain 93% enriched uranium and shall be dense particles (>94% of theoretical density) of U_3O_8 with a nominal particle size of -170 + 325 US Standard mesh size. The powder particles shall be made by a precipitation and high temperature (i.e., 1400 C) air atmosphere sintering process. Particles produced in any other manner shall be determined to be equivalent based on homogeneity data from pre-production plate lots.

SPECIFICATION FOR U_3O_8 POWDER
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4.2 ENRICHED URANIUM

The enriched uranium contained in the U_3O_8 shall contain nominally >93% ^{235}U in total U with an allowable ^{235}U isotopic concentration of 92-94% in total U. The isotopic content of the uranium shall be measured to within +/- 0.1%.

4.3 CHEMICAL REQUIREMENTS

The powder shall be dry and free from volatiles, oil and grease.

4.3.1 CHEMICAL AND TRACE ELEMENTS REQUIREMENTS

		CONCENTRATION (trace elements parts per million)	
ELEMENT	Chemical Symbol	MINIMUM	MAXIUMUM
Aluminum	Al		100
Barium	Ba		10
Beryllium	Be		0.2
Boron	B		2
Cadmium	Cd		0.5
Calcium	Ca		50
Chromium	Cr		•
Cobalt	Co		3
Copper	Cu		20
Fluorine	F		20
Iron	Fe		•
Lead	Pb		10
Lithium	Li		5
Mangnesium	Mg		100
Manganese	Mn		5
Molydenum	Mo		100
Nickel	Ni		•
Phosphorous	P		100
Potassium	K		20
Silicon	Si		50
Sodium	Nd		20
Tin	Sn		100
Tungsten	W		100
Uranium	U	84.5 wt. %	
Vanadium	V		2
Zirconium	Zr		100
Rare Earths	Dy, Eu, Gd, Sm		3
Equivalent Boron Content*	EBC		4
	UO_2		1.0 wt. %

• The total of nickel, iron and chromium shall not exceed 150 ppm
*NOTE: EBC factor from ASTM C 1233-97, "Standard Practice for Determining Equivalent Boron Content of Nuclear Materials".

SPECIFICATION FOR U_3O_8 POWDER
FOR MANUFACTURING HFIR FUEL PLATES

4.3.2 HEALTH PHYSICS REQUIREMENTS

The gamma activity shall be <600 Bq/gU. The total alpha activity from transuranium elements shall be <250 Bq/gU.

4.4 PHYSICAL REQUIREMENTS

4.4.1 PARTICLE SIZE

The U_3O_8 powder shall consist of dense granular powder particles free from all foreign material. One hundred percent of the production sieved powder shall pass through a 170 mesh U.S. Standard screen and be retained on a 325 mesh U.S. Standard screen. The nominal particle size distribution (PSA) as determined by ASTM B 214 (latest revision) shall be as follows:

+170	<1%
-170 + 325	>90%
-325	<10%

4.4.2 SURFACE AREA

The surface area from the production sieved -170 + 325 product for a powder lot shall be <.05 m^2/g... as determined by the static krypton BET (see section 4.4.1). If –325 fines particles are added to a lot, the result surface area of the composite shall be <.05m^2/g.

4.4.3 PARTICLE DENSITY

The density of the -170 + 325 particles as determined by immersion density in toluene shall be >8.2 g/cc.

4.4.4 PARTICLE STRENGTH

The resistance of the production sieved -170 + 325 particles to degradation during subsequent fuel plate fabrication shall be determined by a particle size analysis per ASTM B 214. The maximum amount of -325 determined in the test shall be in compliance with Section 4.4.1.

4.4.5 PARTICLE SHAPE AND MICROSTRUCTURE

The particle shape from each batch shall be examined under a light microscope at 100X. The particle shape and aspect ratio shall be comparable with those shown in Y-12 photomicrograph Y-73834 (see Attachment 1, Page 1)(See W. J. Wermer and J. R. Barkam, ORNL-4052, Characterization and Production of U_3O_8 for the High Flux Isotope Reactor, Oak Ridge National Laboratory, April 1967, page 13).

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FOR MANUFACTURING HFIR FUEL PLATES

A random sample of sintered U_3O_8 particles from the first production batch in each lot shall be mounted and polished for microscopic examination. The sample shall be viewed at 200X and compared to Y-12 photomicrograph Y-73944 (see Attachment 2, Page 1) (See W. J. Werner and J. R. Barkman, ORNL-4052, *Characterization and Production of U_3O_8 for the High Flux Isotope Reactor,* Oak Ridge National Lab., April 1967, page 15). Any observable difference from the cited photomicrograph shall be called to the attention of the Buyer.

4.5 PROCESS REQUIREMENTS

The U_3O_8 powder particles shall be precipitated from a ~20gU/liter uranyl nitrate solution using hydrogen peroxide and ammonium hydroxide to control the pH at 2.0 +/- .1 to precipitate the uranium from solution. The U_3O_8 particles shall be formed by calcining the precipitated product at 850°C in nitrogen and subsequently sintered in air to a temperature >1350°C. If milling and sizing after sintering results in producing >25% -325 mesh particles, the remaining –170 +325 product shall be resintered to >1350 C. The buyer must approve the use of any other process.

A powder lot must represent one continuous production run of powder by the Supplier unless approved by the Buyer. The blending and dispensing of the batches used to constitute a powder lot shall be appropriate to minimize variations in the dispensed aliquots from each batch. The variations between individual containers used to constitute the lot shall be shown to be statistically insignificant.

5. TEST AND INSPECTION

5.1 SAMPLING

The sampling of the bulk product shall be by appropriate means to insure a representative sample for analysis.

5.2 URANIUM ISOTOPEIC CONTENT

The uranium isotopic analysis of enriched uranium feed materials that will be used to constitute a powder lot shall be determined by appropriate methods. The uranium isotopic content of each U_3O_8 powder lot shall be determined by the Supplier for conformance with Section 4.3.1 of this specification and reported to the Buyer.

SPECIFICATION FOR U_3O_8 POWDER
FOR MANUFACTURING HFIR FUEL PLATES

5.3 CHEMICAL COMPOSITION

5.3.1 CHEMICAL AND TRACE ELEMENTS REQUIREMENTS

The chemical composition of the uranium, other chemicals and materials used in the process shall be analyzed by the Supplier at a sufficient sampling level to insure with a high probability that the trace element requirements listed in Section 4.3.1. can be achieved in the finished U_3O_8 powder. The chemical composition requirements specified in Section 4.3.1 shall be performed on each powder batch produced for a powder lot. The Supplier shall report the actual values determined or the sensitivity of the test if the value is reported as less than (<) the required maximum value. For the analytical values reported, an estimate of the accuracy and precision of the values reported shall be provided.

5.3.2 HEALTH PHYSICS REQUIREMENTS

The gamma activity and total alpha activity from transuranium elements shall be reported for compliance with Section 4.3.2.

5.4 PHYSICAL PROPERTIES

A particle size distribution per ASTM B 214 (latest revision) shall be determined for the following particle sizes: +170; -170 +200; -200 + 230; -230 + 270; -270 + 325; -325 U.S. Standard Mesh for each powder lot. The particle size distribution, surface area, and immersion density shall be determined on each U_3O_8 power lot for compliance with Section 4.4. A 100X light microscope photomicrographs of powder samples for batches composing a lot shall be made as specified in Section 4.4.5 and a report prepared

The HFIR fuel fabricator shall make a 200X photomicrograph of a powder sample from each lot as specified in Section 4.4.5 for comparative historical purposes.

5.5 PROCESS REQUIREMENTS

An outline flow sheet that will be used to produce the U_3O_8 powder shall be provided to the Buyer prior to beginning of production operations.

A 1000 g sample of a candidate powder lot shall be submitted for evaluation and testing by the buyer prior to acceptance of the powder lot.

Before final acceptance of a U_3O_8 powder lot, at least one lot (24 fuel plates) of HFIR fuel plates

SPECIFICATION FOR U_3O_8 POWDER
FOR MANUFACTURING HFIR FUEL PLATES

(~500 g U_3O_8) shall be fabricated into flat roll bonded HFIR fuel plates and tested for compliance with the HFIR fuel dispersion homogeneity requirements. No more than 2 "spot defects" (+27%) shall be allowed in the pre-production plate lot.

6. SHIPPING REQUIREMENTS

6.1 SHIPPING ADDRESS

The shipping address for U_3O_8 shall be as follows:

BWX Technologies, Inc.
Naval Nuclear Fuel Division
Mt. Athos Road
Lynchburg, VA 24505-0785

6.2 PACKAGING REQUIREMENTS

The U_3O_8 powder shall be contained in ~2 liter polyethylene bottles with < 7kg's of U_3O_8 powder per bottle. Each plastic bottle shall be separately packaged in mild steel cans ~ 4 ¼ in. diameter by ~10 in. high with crimp lids sealed. The loaded cans shall be loaded into Department of Transportation (DOT) approved nuclear material transportation packages for transport to BWXT in Lynchburg, VA. The number of cans contained in each shipping package shall be as appropriate in compliance with the DOT requirements for shipping the packages. The type of shipping package to be used and the requirements for the transfer of inventory and other information in advance of a shipment shall be by mutual agreement of the Shipper and Receiver.

6.3 MARKING REQUIREMENTS

Each plastic bottle and can shall be clearly marked with the following. All weights shall be recorded in grams.

(a) Lot identification
(b) Container identification
(c) Gross, Tare and Net Weight
(d) Weight of Plastic
(e) Weight of Paper
(f) Percentage (Wt %) of ^{235}U (enrichment) in total uranium
(g) Net Weight of U
(h) Net weight of ^{235}U
(i) Percentage of total Uranium in U_3O_8 powder

SPECIFICATION FOR U_3O_8 POWDER
FOR MANUFACTURING HFIR FUEL PLATES

6.4 RADIATION LEVELS FOR SHIPPING

The contamination levels on the shipping container and inner containers (can and bottle) shall be <111dpm/100 cm^2 alpha and <1000 dpm/100 cm^2 beta.

6.5 PACKING SLIP DOCUMENT

A packing slip shall be attached to one of the shipping packages in the shipment and shall contain the following information:

(a) Name of individual responsible for Nuclear Material Receiving at BWXT
(b) Name of individual responsible for Nuclear Material Control at BWXT
(c) Radiological survey sheet with:

- indication of transport index
- individual survey of each can with the results in mr/hr.
- survey for loose surface contamination
- Hydrogen to X ratios

(d) Tabulation by can and bottle contained in each shipping package for information listed in 6.3.
(e) One copy of the certificate documentation for the material shipped.

7. QUALITY ASSURANCE

7.1 QUALITY SYSTEM/INSPECTION SYSTEM

The supplier shall document, implement, and maintain a quality system which complies with the a nationally recognized standard, such as, NQA-1, ISO-9000, 10CFR50, Appendix B, or 10CFR830 Subpart A.

7.2 CERTIFICATION

The supplier shall compile and maintain one (1) data package, which shall include copies of test reports and all other data pertaining to the manufacture and inspection as specified in Sections 4 and 5 of this document. Specific identity by serial number of the product process shall be noted on all charts and certifications. Three copies of the certification documents signed by an authorized official of the Supplier will be supplied to the Buyer before or upon delivery of the product.

The Supplier shall supply data to certify all requirements specified in Sections 4 and 5 have been achieved to include:

SPECIFICATION FOR U_3O_8 POWDER
FOR MANUFACTURING HFIR FUEL PLATES

(a) Supplier's manufacturing lot number,
(b) Isotopic Analysis of U_3O_8 powder as specified in Section 4.2,
(c) Chemical purity of U_3O_8 powder and trace element content as specified Section 4.3 of this document, and
(d) Physical properties per Section 4.4 of this document.

7.3 DOCUMENTATION

All handwritten manufacturing, test, and inspection records shall be in ink. All corrections, changes, or deletions will be done by drawing a single line through the item being changed. The change shall be signed (initials and last name) and dated by the person making the change. All documents furnished shall be an original or a reproducible copy.

7.4 MATERIAL TRACTABILITY

All end products and samples shall be traceable to parent material.

7.5 CLEANLINESS

The U_3O_8 powder shall be dry and free from volatiles, oil and grease.

SPECIFICATION FOR U_3O_8 POWDER FOR MANUFACTURING HFIR FUEL PLATES

ATT 1

Y-73834, Particle Shape and Microstructure

SPECIFICATION FOR U_3O_8 POWDER FOR MANUFACTURING HFIR FUEL PLATES

ATT 2

Y-73944, Particle Shape and Microstructure

APPENDIX B

SPECIFICATION FOR THE PRODUCTION OF HFIR HEU FUEL ELEMENTS

ORNL RESEARCH REACTORS DIVISION
ENGINEERING STANDARDS AND SPECIFICATIONS
ORNL/RRD/INT-37/V3

HFIR-SS-601

HFIR CORE COMPONENTS

RRD-FE-3, REV. 3

SPECIFICATIONS FOR
HIGH FLUX ISOTOPE REACTOR FUEL ELEMENTS

Prepared by:	RRD Fuels and Materials Engineer	6/29/2004 Date
Reviewed by:	RRD Engineering	6/29/2004 Date
Reviewed by:	RRD Reactor Safety	7/2/2004 Date
Reviewed by:	RRD QA	7/19/04 Date
Reviewed by:	Contract Officer, ORNL Procurement	7/28/04 Date
Approved by:	RRD Experimenter and Fabrication Interface Manager	7-29-04 Date

<u>Note:</u> Revision to this document may affect ORNL/TM-11656, *Safety Analysis Report for Packaging: The ORNL HFIR Unirradiated Fuel Element Shipping Container.*

ORNL/RRD/INT-37/V3
HFIR-SS-601, HFIR Core Components
RRD-FE-3, Rev. 3
Specification for High Flux Isotope
Reactor Fuel Elements

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1.0 SCOPE

This specification covers the process and material requirements for the fabrication of fuel assemblies for the High Flux Isotope Reactor (HFIR) at the Oak Ridge National Laboratory (ORNL). The aluminum-plate-type fuel for HFIR is contained in two separate cylindrical elements (inner and outer elements), which are nested inside each other during their operation in the reactor. The requirements for the manufacture of these separate fuel elements (inner and outer elements) are specified in this document. Included in this specification are the requirements for the materials; processes for the fabrication and inspection of components; processes for the assembly, welding, and inspection of elements; and the quality assurance requirements to produce these fuel elements. This specification is the controlling document for the fabrication of HFIR fuel elements and references the requisite ORNL engineering drawings. The specification also includes the preproduction vendor qualification requirements, if the Seller is not currently qualified.

2.0 DEFINITION OF TERMS

Average Coolant Channel Thickness. The normal distance between two adjacent fuel plates, measured in a plane perpendicular to the longitudinal axis of the element and averaged along a track (track average) or across the five tracks (station average).

Batch. A quantity of material that can be represented by a single sample.

Certification. A written statement of compliance with an individual requirement of this specification.

Compact. The cold pressed parallelepiped body containing a fuel and a filler section for one fuel plate.

Company. Oak Ridge National Laboratory, operated by current Department of Energy (DOE) contractor.

Company's Technical Representative (CTR). The individual identified by the Company as its representative for all technical issues related to the procurement of fuel elements.

Company's Contract Officer. The individual identified by the Company as its representative for all contractual issues related to the procurement of fuel elements

Coolant Channel. The region between two adjacent fuel plates in an assembled element.

Core Hump. The thickest portion (cross-sectional area) of the fuel section in a fuel core as located on the side of the plate containing the filler section.

Core Outline. The closed figure resulting from drawing a line connecting the outermost particles of U_3O_8, as on a radiograph of a flat plate or as revealed in X-ray fluoroscopic examination of a flat fuel plate.

Cover Plate. The aluminum plate components of a billet that will make up the cladding or protective portion of the fuel plates.

Dummy Fuel Element. A prototype of a HFIR fuel element that is identical to a HFIR fuel element in materials and dimensions except the fuel plates are replaced with simulated fuel plates made from aluminum sheet stock.

End Adapters. Cylindrical tube-shaped sections welded on the side plate ends to provide a bearing surface for the fuel elements in the reactor.

Frame. The billet component that will provide the aluminum surrounding the fuel core.

Fuel Assembly. The complete fuel loading for HFIR, consisting of an inner and an outer fuel element.

Fuel Core. The rolled formed rectangular parallelepiped section of a fuel plate that is comprised of the fuel and aluminum filler sections.

Fuel Element. A term for either the inner or outer fuel element.

Fuel Plate. The individual uranium-bearing aluminum plate used in either the inner or outer fuel elements.

Fuel Section. The contoured portion of a fuel compact or core containing the U_3O_8 particles mixed with aluminum powder.

Filler Section. The aluminum portion of the fuel compact or core that is added to maintain the fuel contour in the cold pressed fuel compact. For the inner element, it contains the burnable poison.

Grooves. The circumferential channels cut into the side plates in which weld metal is deposited to join fuel plates to the side plates.

Lot. Material from a single ingot, or from other comparable starting material (for example, a single group of fuel cores), fabricated successively to a given size by identical procedures.

Pack Assembly. The assembly of two fuel compacts, frame, and cover plates prepared for hot rolling (i.e., billet).

Qualification. A demonstration of the Seller's ability to successfully conduct an operation or test in accordance to this specification and to the satisfaction of the Company.

Reactor. The High Flux Isotope Reactor (HFIR) at the Oak Ridge National Laboratory.

Safety-Related Component. Any HFIR component related to the safety of the reactor as identified in the HFIR Safety Analysis Report. The HFIR fuel elements are safety-related components.

Seller. The successful out-source bidder for the manufacture of HFIR fuel elements.

Side Plates. Cylindrical tubes in which the fuel plates are assembled.

Slot. The longitudinal channels cut parallel and uniformly spaced into the surface of the side plates to receive the fuel plates.

Surface Density. The total quantity of uranium or boron contained in a specified volume of a fuel plate that includes both the cladding and the fuel core.

Wall Assurance Groove. Circular grooves cut in the side plates that are used to measure the wall thickness of the side plates after final machining of a fuel element.

Welder. One who performs a manual or semiautomatic welding operation.

Welding Operator. One who operates a machine or automatic welding equipment.

3.0 REFERENCES

This specification supersedes HFIR-FE-3 issued in August 1984. The order of precedence of the documents referenced in this specification shall be follows: (1) this document, (2) ORNL engineering drawings, (3) other ORNL/Research Reactors Division (RRD) specifications and procedures, and (4) military and industry standards and specifications.

3.1 Engineering Drawings

The engineering drawings listed below are an integral part of this specification. The Company will maintain all listed ORNL engineering drawings. If there is a recognized conflict between this document and an engineering drawing(s), the Company shall be informed in writing by the Seller and the engineering drawing(s) and/or this document revised by the Company. The Seller is encouraged to use the applicable revision of the listed drawings for working drawings. If the Seller elects to produce and use working drawing comparable to the listed engineering drawings for use on the shop floor, these working drawings and their revisions shall be approved by the CTR and RRD Engineering for configuration control purposes.

A listing of the applicable ORNL engineering drawings with a cross reference to the comparable approved BWX Technologies, Inc. (BWXT) working drawings currently in use are tabulated in Appendix A. The revision level and issue date of these drawings in effect at the beginning date of a new contract or a later revision of these drawings as agreed to by the Buyer and Seller shall be used. See Appendix A.

	ORNL
ASSEMBLY DRAWINGS	
HFIR inner fuel element—assembly	E-42118
HFIR outer fuel element—assembly	E-42126
COMPONENT DETAILS	
HFIR inner fuel element—fuel plate loading details	D-42114
HFIR outer fuel element—fuel plate loading details	D-42122
HFIR inner fuel element fuel plate—true involute curvature design details	D-42113
HFIR outer fuel element fuel plate—true involute curvature design details	D-42121
HFIR inner fuel element—inner side plate #1	E-42112
HFIR inner fuel element—outer side plate #2	E-42117
HFIR outer fuel element—inner side plate #3	E-42120
HFIR outer fuel element—outer side plate #4	E-42125

3.2 Materials Specifications

The following materials specification shall be used to procure fuel that will be contained in the finished fabricated HFIR fuel elements:

- RRD-MS -106, Specification for U_3O_8 Powder for Manufacturing HFIR Fuel Plates. Revision in effect on issue date of new contract or later revisions as agreed to by Buyer and Seller.

3.3 Applicable Military and Industry Standards and Specifications

The applicable portions of the following documents, as defined herein, form a part of this specification. Where there is conflict between the documents cited and the revisions thereof, the Seller shall notify the Company of the conflict and use the latest revision, in effect at the signing of the contract, unless otherwise directed by the Company.

- 10 CFR 830.10, "Quality Assurance Requirements."
- MIL-C-45662, "Calibration System Requirements."
- EPRI-NP- 5652 "Guideline for the Utilization of Commercial Grade Items in Nuclear Safety Related Applications."
- ASTM-B-209, "Aluminum and Aluminum-Alloy Sheet and Plate."
- ASTM-B-241, "Aluminum and Aluminum-Alloy Seamless Pipe and Seamless Extruded Tube."

- AWS A5.10, "Specification for Bare Aluminum and Aluminum Alloy Electrodes and Rods."
- ANSI/AWS D1.2, "Structural Welding Code—Aluminum."
- ASME Boiler and Pressure Vessel Code, Section VIII, "Pressure Vessels."
- ANSI/ANS-8.21—1995, "Use of Fixed Neutron Absorbers in Nuclear Facilities Outside Reactors."
- SNT-TC-1A, "American Society for Nondestructive Testing (ASNT) Recommended Practice."

3.4 Reference Materials

These reference materials are intended to provide the Seller with general guidance and overview of the HFIR fuel fabrication processes, but are not to be considered as approved procedures or a part of this specification:

- ORNL-TM -11809, "Observations in the Manufacture of Aluminum-Based Research Reactor Fuel Elements," R. W. Knight, July 1993.
- ORNL-TM-6852, "Fabrication Procedures for the Manufacturing of High Flux Isotope Reactor Fuel Elements," R. W. Knight and Ray Morin, December 1999.
- RRAP-4110, "ORNL Research Reactors Division Administrative Policies and Procedures (RRAP) Dedication of Commercial Grade Items," Rev. 0, June 9, 2000.

4.0 GENERAL DESCRIPTION

4.1 Reactor

The HFIR is a research-type nuclear reactor that was designed and built in the early 1960s and has been in continuous operation since its initial criticality in 1965. Its primary function is to produce neutrons for the production of radioisotopes, materials irradiation, and research. Under current modernization plans, the HFIR is expected to continue in operation until 2035.

The HFIR is a compact (51-L core) flux-trap-type reactor that is light-water moderated and designed to operate at 100 MW(t). The reactor is currently being operated at 85 MW(t). The very high-power- density core (~2000 kW/L) uses two nested, cylindrical aluminum (Al) plate-type fuel elements and a beryllium reflector that surrounds the core. The power of the high-neutron-leakage core is controlled by a reflector control system. The maximum unperturbed thermal neutron flux in HFIR is ~ 5×10^{15} neutrons/(cm^2 - s).

The inner and outer fuel elements, which comprise the HFIR core, consist of annular arrays of fuel plates contained in slotted sections of aluminum tubing (side plates). The inner element contains 171 identical fuel plates and the outer 369, which are also identical but differ slightly from those contained in the inner element.

4.2 Fuel Plates

The aluminum fuel plates are made by the "picture frame" hot roll bonding process. The loading of the highly enriched (93% ^{235}U) U_3O_8 fuel powder is continuously varied across the width of the fuel plates (graded) by pressing a duplex powder compact. In this duplex compact, the fuel-bearing powder is contoured by using a sweep template and pure aluminum filler powder added

on top of the contoured fuel powder before pressing. These compacts are loaded into aluminum frames with covers for hot roll bonding. In the rolled plates, the maximum fuel loading is approximately along the longitudinal centerline with reduced fuel loading along the edges to reduce powder peaking. In the fuel plates for the inner elements, a burnable poison (^{10}B) contained in natural boron as B_4C powder is included with the aluminum filler powder during the compacting operation. The fuel plates are formed into an involute configuration to provide the maximum fuel volume with the graded fuel distribution, uniform metal-to-water ratio, and high heat transfer surface-to-core-volume ratio, while maintaining a constant channel spacing.

4.3 Fuel Element Assembly

Each fuel element is assembled by inserting the formed fuel plates into machined slots in two concentric cylindrical side plates. The fuel plates are attached along both edges in 1-in. intervals to the side plates by depositing weld metal by the gas metal arc welding (GMAW) process in a circumferential groove machined into the side plates. After welding, the outside and inside surfaces of the end attachment area on the elements are rough machined and cylindrical end adapters attached by a GMAW process before final machining.

5.0 MATERIALS

5.1 Safety-Related Components

HFIR fuel elements are safety-related components and must meet all RRD requirements for such components. The procurement by the Seller of any commercial-grade raw materials that will be incorporated in the final element assembly must be procured and controlled in a manner similar to the requirements as outlined in EPRI-NP- 5652, "Guideline for the Utilization of Commercial Grade Items in Nuclear Safety Related Applications." The dedication program as presented in RRAP-4110 or the Seller's equivalent program shall be used for the procurement of all commercial materials used in the fabrication of HFIR fuel elements.

5.2 Process Materials

All materials used in the fabrication of the HFIR fuel elements that are not part of the final fuel element shall be procured with the Seller's specifications. This shall include welding gases, all cleaning materials, cutting fluids, lubricants, solvents, or fixture materials that come in contact with any component used in the fuel element during manufacturing. The shielding gases for welding aluminum shall conform to the requirements as specified in ANSI/AWS-D1.2, Section 1.3.3 (welding-grade argon shall have a minimum purity of 99.998% with a dew point of −76°F or lower), and it shall be certified by the Seller that the gases used conform to these requirements.

5.3 Aluminum Plate and Sheet

The aluminum plate and sheet shall be procured as commercial aluminum alloy 6061-T0 and be certified to meet the requirements of ASTM B-209. Additional analysis shall be performed and reported on the following list of elements. These elements are the only ones to be included in the "others each" category referenced within the material specification. The "others total" category shall be simply reported as the calculated sum of the analytical results reported on the

following list of elements and shall be considered acceptable when less than or equal to the "others total" limit. The trace elements to be analyzed for and the maximum values allowed are listed below:

- Boron, ≤ 10 ppm
- Cadmium, ≤ 30 ppm
- Lithium, ≤ 80 ppm
- Gallium, ≤ 400 ppm
- Cobalt, ≤ 10 ppm

The material may be procured in the T-6 temper and heat treated as appropriate by the Seller.

5.4 Aluminum Tubing

The aluminum tubes shall be procured as commercial extruded aluminum alloy 6061-T6511 tubes and be certified to meet the requirements of ASTM B-241. Additional analysis shall be performed and reported on the following list of elements. These elements are the only ones to be included in the "others each" category referenced within the material specification. The "others total" category shall be simply reported as the calculated sum of the analytical results reported on the following list of elements and shall be considered acceptable when less than or equal to the "others total" limit. The trace elements to be analyzed for and the maximum values allowed are listed below:

- Boron, ≤ 10 ppm
- Cadmium, ≤ 30 ppm
- Lithium, ≤ 80 ppm
- Gallium, ≤ 400 ppm
- Cobalt, ≤ 10 ppm

The T-6511 temper is required for the side plate tubes to meet final machining tolerances in the fuel elements and may not be waived.

5.5 Aluminum Weld Wire

The aluminum weld wire used in the attachment of fuel plates and end adapters shall be procured as commercial aluminum alloy 4043 and be certified to meet the requirements of AWS A5.10. The diameter of the weld wire shall be nominally 0.030 in. Additional analysis shall be performed and reported on the following list of elements. These elements are the only ones to be included in the "others each" category referenced within the material specification. The "others total" category shall be simply reported as the calculated sum of the analytical results reported on the following list of elements and shall be considered acceptable when less than or equal to the "others total" limit. The trace elements to be analyzed for and the maximum values allowed are listed below:

- Boron,≤ 10 ppm
- Cadmium, ≤ 30 ppm
- Lithium, ≤ 80 ppm

- Gallium, ≤ 400 ppm
- Cobalt, ≤ 10 ppm

5.6 Aluminum Powder

The aluminum powder shall be atomized particles of 101 aluminum. One hundred percent of the powder shall pass through a 100 mesh U.S. standard screen with 75–85% passing through a 325 mesh U.S. standard screen. The referenced micron sizes as determined by Fisher Sub-Sieve Sizer (F.S.S.S.) are as follows:

- < 10 microns (D10) 10.8%
- < 50 microns (D50) 30.6%
- < 90 microns (D90) 82.8 %

Aluminum powder manufactured by Toyal America, Inc., (ATA 101 aluminum powder or equivalent) is the type powder required. The aluminum powder shall be dry and free from volatiles, oil, and grease and meet the chemical requirements listed below.

Element	Weight percent
Aluminum (metallic)	99.30 minimum
Cadmium	0.002 maximum
Copper	0.200 maximum
Lithium	0.008 maximum
Silicon and iron	0.250 maximum
Zinc	0.100 maximum
Other (single)	0.050 maximum
Al_2O_3	0.700 maximum
Boron	0.001 maximum

An aluminum powder lot shall represent one continuous production run and variations between individual containers shall be minimal. An aluminum powder lot shall not be accepted for production use until the Seller has demonstrated that the candidate powder lot will perform satisfactorily in the fuel plate fabrication process by meeting the requirements of this specification.

5.7 Enriched Uranium

The enriched uranium feed material shall contain 92–94% ^{235}U in total U. The Seller shall have a nuclear criticality safety program approved by the Nuclear Regulatory Commission (NRC) or DOE to prevent the possibility of a nuclear criticality accident during manufacture and storage of all fuel powders, components, assemblies, and scrap. As a part of this program, the Seller shall

ensure that an assembled inner fuel element at any stage in manufacture or storage is never inserted into the annulus of an outer fuel element.

5.8 Uranium Oxide Powder

The special U_3O_8 powder used in the compacts is a -170 mesh (U.S. standard mesh size) powder procured to meet the requirements as specified in RRD specification RRD-MS-106, "Specification for U_3O_8 for Manufacturing HFIR Fuel Plates." The physical properties of this powder is extremely important to the homogeneity inspection of fuel plates and must be precisely controlled.

5.9 Boron Carbide Powder

The boron carbide powder shall have the chemical composition of B_4C produced from natural boron and be 100% -325 U.S. standard mesh size or equivalent powder. The boron carbide powder shall be dry and free from volatiles, oil, and grease and meet the chemical requirements listed below.

Element	Concentration (weight %)	
	Minimum	Maximum
Boron	76.5	
Carbon	20	22
Boron plus carbon	98	99.5
B_2O_3		0.2
Soluble boron		0.5
Iron		0.5
Aluminum		0.2
Calcium		0.1
Magnesium		0.05
Moisture		200 ppm
^{10}B	18.22	18.78

A powder lot shall represent one continuous production run, and variations between individual containers shall be minimal. The analytical laboratory and test methods used to certify the boron and ^{10}B content shall satisfy the requirement of ANSI/ANS-8.21, Section 5.3.1.3, for B_4C purchased subsequent to June 30, 1999.

6.0 FUEL PLATES REQUIREMENTS

6.1 General

The fuel plates shall be manufactured to the requirements as specified in the following ORNL engineering drawings:

- D-42114, "HFIR Inner Fuel Element—Fuel Plate Loading Details."
- D-42113, "HFIR Inner Fuel Element Fuel Plate—True Involute Curvature Design Details."
- D-42122, "HFIR Outer Fuel Element—Fuel Plate Loading Details."
- D-42121, "HFIR Outer Fuel Element Fuel Plate—True Involute Curvature Design Details."

The applicable revision levels for these drawings are shown in Section 3.1.

6.2 Fuel Loading and Distribution

The ^{235}U contained in U_3O_8 powder particles shall be loaded in each compact as follows:

- Inner—15.18 g ± 0.150 g ^{235}U
- Outer—18.44 g ± 0.180 g ^{235}U

The relative concentration of fuel across the width of each plate shall be varied as specified in the fuel contour diagrams and accompanying tables in the following ORNL engineering drawings:

- D-42114, "HFIR Inner Fuel Element—Fuel Plate Loading Details."
- D-42122, "HFIR Outer Fuel Element—Fuel Plate Loading Details."

Straight-line interpolation of the values shown the tables in the referenced drawings may be used for additional "*Y*" values.

The ^{235}U surface density shall be calculated by multiplying the relative "*Y*" values shown in the tables by the following factors:

- Inner—0.0459
- Outer—0.0683

The fuel homogeneity requirements are specified in Section 8.2.4.

6.3 Poison Loading and Distribution

The ^{10}B contained in natural boron carbide powder shall be loaded in each inner fuel plate as follows:

- Inner—0.0164 g ± 0.0016 g –^{10}B
- Outer—None required

The relative concentration of the boron across the width of each inner fuel plate shall be varied as specified in the fuel contour diagram and accompanying table shown in ORNL engineering drawing D-42114, "HFIR Inner Fuel Element—Fuel Plate Loading Details." Straight-line interpolation may be used for additional "Z" values.

The boron surface density shall be calculated by multiplying the relative "*A*" values shown in the table in the referenced drawing by the following factor: 2.27×10^{-5}.

The boron homogeneity requirements are specified in Section 8.2.5.

6.4 Fuel Compacts

Fuel compact shall be made by a powder metallurgical process to meet the fuel core configuration as specified in the following engineering drawings:

- D-42114, "HFIR Inner Fuel Element—Fuel Plate Loading Details."
- D-42122, "HFIR Outer Fuel Element—Fuel Plate Loading Details."

6.5 Fuel Plate Pack Assembly

The pack assembly for roll forming shall be fabricated to meet the fuel plate configuration as specified in the following engineering drawings.

- D-42114, "HFIR Inner Fuel Element—Fuel Plate Loading Details."
- D-42122, "HFIR Outer Fuel Element—Fuel Plate Loading Details."

6.6 Fuel Plate Forming

The fuel plates shall be formed as specified in the following ORNL engineering drawings:

- D-42113, "HFIR Inner Fuel Element Fuel Plate—True Involute Curvature Design Details."
- D-42121, "HFIR Outer Fuel Element Fuel Plate—True Involute Curvature Design Details."

6.7 Process

The picture frame hot-roll bonding process shall be employed to fabricate the fuel plates.

6.7.1 Compacts

1. A sequential number including lot number shall be assigned to each fuel compact, and this number shall be used to identify an individual plate throughout manufacturing.

2. The aluminum, U_3O_8, and boron carbide (inner only) powder contents for each compact shall be separately dispensed by weight using calibrated scales capable of measuring to ± 0.01 g for the aluminum and U_3O_8; to ± 0.001 g for the boron carbide. The actual weight dispensed shall be recorded to 0.01 g for the aluminum and U_3O_8; and to 0.001 g for the boron.

3. After pressing, the weight of each compact before annealing shall be separately measured using calibrated scales capable of measuring to ±0.01 g and recorded.

6.7.2 Pack Assembly

1. The compacts shall be inserted into the frames with clean stainless steel tongs to avoid the introduction of any foreign materials on the bonding surfaces of the frame and covers.

2. The compact identification numbers shall be transferred to the pack assembly by vibra-tool marking on the top cover plate. The placement of this number shall also be used to establish the reference edge and top and bottom ends of the finished fuel plates.

3. The clamping pressure of the pack assembly for welding shall be sufficient to minimize gaps between the frame and covers prior to and during pack welding.

4. The welding parameters for welding the covers to the frame shall be established to provide a structural weld that will minimize the relative movement of the covers with the frame during hot bonding.

6.7.3 Roll Bonding

1. The hot rolling shall be performed at 490°C ±10°C (914°F ±18°F). A hot rolling schedule shall be established to ensure that the packs/plates are at the specified temperature prior to each hot rolling pass. The thickness after hot roll (nominally 0.063 in.) shall be within ±0.001 in.

2. After hot rolling, each plate shall be heat treated (blister anneal) at 490°C ±10°C (914°F ±18°F) for a minimum of 2 hours at the specified temperature to enhance the visual detection of blisters that may be present.

3. The cold rolling shall be at room temperature and provide a roll reduction of nominally 20%. The final thickness shall be adequate to allow for final etching per Section 6.7.5. After cold rolling, the thickness variation in a plate lot of 24 plates shall not exceed 0.001 in.

4. After cold rolling, each plate shall be program annealed between aluminum flattening platens at 490°C ± 10°C (914°F ± 18°F) for a minimum of 2 hours (time the plates are at the specified temperature) and then cooled at a rate not to exceed 10°C/min (18°F/min) to 200°C (392°F). The stack shall be allowed to cool to < 60°C (<140°F) before removing the platens. The plates shall be annealed with a minimum of 48 and maximum of 144 plates in a single furnace load (maximum of six lots in two stacks).

6.7.4 Flat Fuel Plate

The configuration of the fuel core for compliance with the applicable engineering drawings shall be determined during fabrication using a template that will outline the maximum and minimum dimensions of the fuel core when examined under a fluoroscope or digital radiographic examination.

The location of the "hump" or line of maximum fuel content in the fuel core to the referenced edge shall be verified by a nondestructive testing method approved by the Company.

6.7.5 Formed Fuel Plates

The fuel plates shall be formed to the required involute contour as specified in ORNL engineering drawings by a rubber-pad forming process.

After forming and prior to assembly, each fuel plate shall be etched in a cold solution of HNO_3-HF followed by a deionized water rinse to remove the oxide film formed during processing (see Section 10 for cleaning requirements). Based on the etching of coupons (prepared from the scrap generated when the HFIR fuel plates are blanked) to establish the etching time, each fuel plate shall be etched to remove a minimum of 0.0001 in. per side and to meet the thickness requirements of drawing D-42114 for the outer plates and drawing D-42122 for the inner plates. Pickle and etch baths shall be tested at the beginning of each working day by placing a coupon in the solution to check the strength of the bath. All pickled and etched assemblies shall be handled with clean nylon, cotton, or vinyl gloves.

7.0 FUEL ELEMENT REQUIREMENTS

7.1 General

The fuel elements shall be manufactured to the requirements as specified in the following ORNL engineering drawings:

- E- 42118, "HFIR Inner Fuel Element—Assembly."
- E- 42126, "HFIR Outer Fuel Element—Assembly."

The handling of plates and assembled elements shall be with clean nylon, cotton, or vinyl gloves. No liquid other than deionized water or clean alcohol may be used in assembly, machining, or cleaning of assembled fuel elements during fabrication and storage. During handling and storage, fuel plates and elements shall be protected from dust, dirt, shop grease, moisture, and other similar contaminants. Elements and fuel plates shall be stored at room temperature.

7.2 Side Plates

Side plates for elements shall be machined and inspected in accordance with the following ORNL engineering drawings:

- E-42112, "HFIR Inner Fuel Element—Inner Side Plate #1."
- E-42117, "HFIR Inner Fuel Element—Outer Side Plate #2."
- E-42120, "HFIR Outer Fuel Element—Inner Side Plate #3."
- E-42125, "HFIR Outer Fuel Element—Outer Side Plate #4."

7.3 Insertion of Fuel Plates

1. The number and location of each fuel plate shall be verified before insertion.

2. Clean isopropyl or ethyl alcohol shall be used as a lubricant during the insertion of a plate into the side plates.

3. A fuel plate that does not slide freely into a slot shall be removed and replaced with another fuel plate that will slide freely. Force other than the slight hand pressure necessary to slide a plate into a lubricated slot is not permitted during the insertion of a fuel plate.

4. As assembled, each plate shall protrude into the weld groove to meet the plate protrusion requirements at welding specified in section 7.4.2.3.

5. Teflon spacers shall be inserted into each channel after assembly to aid in maintaining the coolant channel spacing during welding.

7.4 Welding

The attachment of fuel plates and end fittings shall be as specified in ORNL engineering drawings:

- E- 42118, "HFIR Inner Fuel Element—Assembly."
- E- 42126, "HFIR Outer Fuel Element—Assembly."

Welds shall be machine-made welds by the GMAW process using fixtures, a positioner for holding and rotating the element during welding, a programmable welding power supply, and automatic filler wire feeder head. A welding procedure specification (WPS) in accordance with ANSI/AWS D1.2-9, Section 4, Part C, or other qualified procedure specifications may be used with the approval of the Company. The weld parameters of voltage, current, rotation speed, wire feed rate, and cover gas flow rate shall be controlled to the extent practical by automatic machine functions. The actual welding parameters used for each weld shall be recorded. The real-time recording of weld parameters is desirable but not mandatory. The Company shall approve the welding equipment, procedures, and inspection methods.

7.4.1 Weld Test Samples

1. Weld test samples shall be prepared from sections of each type of side plate; and weld and tensile test plates shall also be prepared. The side plate sections used shall be ~ 3 in. wide and contain three weld grooves, with one weld groove in the center of the section. The arc length of the side plate weld test sections shall be as follows: Side Plate 1, ~180°; Side Plate 2, ~180°; Side Plate 3, ~120°; Side Plate 4, ~72°. The weld

and tensile test plates, which will simulate the heat dissipation of actual fuel plates during welding, shall be made from the scrap generated when HFIR fuel plates are blanked to size. The weld test plates shall be ~ 2 1/2 in. wide and 1 in. long with the wide side parallel to the rolling direction in the scrap. The tensile test plates shall be ~ 2 in. wide and 1 3/4 in. long, with the wide side parallel to the rolling direction in the scrap; a hole shall be drilled or punched in one end for attachment to a tensile testing device.

2. In the assembly of a weld test sample, the wide side of the test plates shall be inserted into the slots and bottomed. A minimum of three tensile test plates shall be used in each weld test sample, one in the center slot of the section and with the other two approximately equal distances from the center and the ends. The design of the components for weld test samples is to be approved by the CTR.

3. For each fuel element, a weld test sample representative of either an inner or outer side plate weld shall be made and tested before and/or after (from preceding element) welding the plates into the side plates. Weld test samples shall be welded in the center weld groove with the weld parameters used in the actual welding of the fuel elements. These samples shall contain the start/overlap area and termination point of the weld. Evaluation of a weld test sample shall include visual and pull testing to determine the attachment strength of the weld tensile test plates.

4. Metallographic examination of a section along the centerline of the weld bead of each weld test sample shall be made to evaluate possible variations in the weld penetration that could result from subtle changes in the welding machine/wire feed functions over time. The section for metallographic examination shall be polished and etched as required for reviewing.

5. The "after" weld sample from the preceding element of the same type may be used for the "before" weld sample for the next element provided there is not a delay of over 30 working days between welds.

7.4.2 Welding of Fuel Plates

1. Welding of a fuel element shall not begin until the before-weld test sample meets the visual and tensile strength requirements in Sections 8.3. 4.1 and 8.3.4.2.

2. Before welding, each element shall be visually inspected for alignment of plates, excessive oxidation, and cleanliness.

3. Before welding, the protrusion of the fuel plates into the weld grooves of the side plates shall be determined by measuring the plate penetration at a minimum of three locations: in the middle weld groove and weld grooves on both ends. For outer side plates, the penetration shall be ≥0.035 in; inner side plates ≥0.015 in. During the entire welding operation, the fuel plate penetration shall be a minimum of 0.025 in. for outer side plates and 0.010 in. for the inner side plates.

4. Assembled elements shall be dried at 121°C ± 6°C (250°F ± 10°F) for a minimum of 4 hours to remove residual alcohol or moisture before welding.

5. The welds shall be made in a specified sequence starting in the middle and working toward each end.

6. During welding, the direction of the rotation of a fuel element when mounted on the element positioner as observed from the non-geared end of the positioner shall be as follows: (a) inner element, counterclockwise and (b) outer element, clockwise.

7. Adjacent welds shall be started at least 30° displaced from the overlap area of the previous adjacent weld.

8. The welds shall not extend into the water channels. The water channels shall be visually inspected for weld "drop-through" and a Supplier Nonconformance Report (SNR; Section 9.6) submitted if any weld "drop-through" extends into the water channel more than 0.010 in.

9. Weld filler metal deposits in the weld grooves shall be sufficient to provide a smooth surface after final machining.

10. The face side of each weld shall be free of defects such as cracks, incomplete fusion, or voids. The weld beads shall have a uniform contour and be free of oxidation, and the termination craters shall have a depth less than that required to provide a smooth surface on the fuel element after final machining.

11. To examine the quality of an as-welded external weld bead, it is permissible to machine, grind, or file (using carbon steel tooling) a weld below the surface of the as-welded tubing provided a smooth surface can be achieved after final machining.

12. Repair of surface weld defects such as craters or underfill is permissible by approved procedures. Weld defects that may require removal of weld metal to the weld root shall be submitted on an SNR. The SNR shall include the proposed weld repair procedure and shall be approved by the CTR and RRD QA.

13. The root side of each weld shall be free of gross oxidation, sagging, or warpage.

7.4.3 Welding of End Fittings

1. Before welding, each joint shall be visually inspected for alignment, excessive oxidation, and cleanliness.

2. The end fitting welds shall penetrate the full thickness of the side plate.

3. Weld filler metal in the weld grooves shall be sufficient to provide a smooth surface after final machining.

4. The face side of the weld shall be free of defects such as cracks, incomplete fusion, or voids. The weld bead shall have a uniform contour and be free of oxidation, and the

termination craters shall have a depth less than that required to provide a smooth surface after final machining.

5. To examine the quality of an as-welded external weld bead, it is permissible to machine, grind, or file (using carbon steel tooling) a weld below the surface of the as-welded tubing provided a smooth surface can be achieved after final machining.

6. Repair of surface weld defects such as craters or underfill is permissible by approved procedures. Weld defects that may require removal of weld metal to the weld root shall be submitted on an SNR. The SNR shall include the proposed weld repair procedure and shall be approved by the CTR and RRD QA.

7.5 Channel Spacing

The coolant channel spacing shall be measured before the welding of the end fittings and final machining.

7.6 Element Identification

Each element shall be marked as specified on the element assembly drawings.

8.0 TEST AND INSPECTION

8.1 General

All dimensions noted with hexagonal boxes on the reference engineering drawings shall be inspected with calibrated gages and documented in accordance with RRD-JS-24 or with the equivalent Seller's procedures and reporting forms approved by the CTR.

8.2 Fuel Plates

The test and inspection requirements for HFIR fuel plates are contained in the following sections.

8.2.1 Fuel Loading

The ^{235}U loading in each fuel plate for compliance with the quantity specified in Section 6.2 shall be determined from the weight of constituents dispensed, corrected for the weight loss during compacting (weight of compact), and the chemical and isotopic analysis of the constituents. The correction for weight lost shall be determined and documented based on the quantitative analysis of fuel plates. Semi-quantitative verification of the plate fuel loading in each fuel plate shall be determined by gamma scanning. Verification of the uranium loading may require periodic destructive analysis of randomly selected fuel plates.

8.2.2 Fuel Core Configuration

As a flat plate, configuration of the fuel core in each fuel plate for compliance with the applicable engineering drawings shall be inspected using either:

(1) a template that will outline the maximum and minimum dimensions of the fuel core when examined under a fluoroscope, or
(2) digital radiography

If the fuel core falls outside the prescribed outlines, the plate shall be radiographed and any nonconformance reported on an SNR in accordance with Section 9.6 of this specification.

To verify the above inspection, a sample from acceptable fuel plates fabricated shall be radiographed and the core dimensions measured. If the core configuration of the sample is found to be in violation, 100% of the fuel plates in the group shall be radiographed and the fuel core configuration for compliance redetermined from the radiographs.

8.2.3 Fuel Distribution

The fuel distribution in each fuel plate shall be quantitatively determined by scanning the entire surface of each plate through a collimated X-ray beam that covers a 0.080-in.-diameter area on the plate and comparing the attenuation of the X-ray beam with calibration standards.

Two scanners (one digital and the other analog) for measuring fuel distribution in HFIR fuel plates are provided by the Company for use by the Seller. When funds are available, the analog scanner will be converted to digital operation. In the interim, the analog scanner may be used by the Seller for the acceptance of fuel plates for homogeneity. Fuel plates rejected by the analog scanner shall be rescanned by the Seller on the digital scanner and submitted on an SNR for disposition by the Company. The functional requirements of the two scanners are as follows.

1. The calibration standards supplied by the Company are contoured to match the X-ray attenuation of the fuel distributions in ORNL engineering drawings D-42114 and D-42122 and of fuel plates containing the specified U_3O_8 fuel particles (RRD-MS-106).

2. The longitudinal scanning of the fuel distribution in each plate shall be done in 0.080-in.-wide track increments across the width of each plate with a 0.020-in.-overlap between tracks. The standards shall be scanned on each track.

3. For the digital scanner, data shall be digitized and recorded in 0.060-in. increments along the length of the plate and calibration standards. The digitized data shall be recorded in two tables as follows:

   Average. The average data shall be calculated as the arithmetic means of at least seven data inputs acquired during a 0.060-in. track movement ("LOC" data file).

   Maximum spot. The maximum spot data shall be recorded as the maximum fuel density from the data inputs points acquired during each .060-in. track movement ("MAX" data file).

4. During scanning of fuel plates on the analog scanner, deviations from the specified homogeneity requirements shall be recorded in a manner that shows the calibration standards and the location of the defect(s) in a fuel plate on paper strip charts.

5. For the digital scanner, an exponentially weighted running average fuel density is used to simulate the operation of the analog scanner's existing RC circuit. It is calculated by the following recursion relation, which gives the exponentially weighted running average at axial point n, $Y(n)$, in terms of the exponentially weighted running average at $n-1$, $Y(n-1)$, and the averaged fuel density (from the "LOC" data file) at point n, $X(n)$, as follows:

$$Y(n) = A * Y(n-1) + (1-A) * X(n)$$

The value of A = 0.91393 best simulates the operation of the analog scanning equipment when operating at a speed of 300 in./min.

8.2.4 Fuel Homogeneity

1. The fuel distribution shall be determined by measuring the X-ray attenuation in the fuel plates compared to the Company supplied calibration standards.

2. The maximum fuel concentration in any 0.080-in. diameter spot over the entire surface of a fuel core shall not exceed the attenuation of the +27% calibration standard for that track's location on the fuel distribution contour.

3. The maximum average density as determined internally by the analog scanner or with the exponentially weighted average function described in Section 8.2.3.5 shall not exceed the attenuation of the +12% calibration standards for any integration area along any 0.080-in.- wide track and that track's location on the fuel distribution contour.

4. Any fuel plate that does not meet the specified requirements in Section 8.2.4.2 shall be rejected.

5. Any fuel plate that does not meet the specified requirements in Section 8.2.4.3 shall be submitted as a supplier nonconformance request (SNR) per Section 9.6 and shall include details as to the location and magnitude of the deviated condition(s) for disposition by the Company.

6. In lieu of Section 8.2.4.5, the Company can approve a method of disposition at the Seller's facility of any fuel plate that does not meet the specified requirements in Section 8.4.2.3. This method shall be submitted as a supplier deviation request (SDR) per Section 9.6 and shall be approved by the Company.

8.2.5 Boron Distribution

The boron distribution across the width of the inner fuel plates (as specified in Section 6.3) shall be verified by the destructive sampling and analysis of one randomly selected plate from the

group of fuel plates selected for each inner fuel element. A rejected plate from a lot of plates contained in the group may be used for this destructive examination.

1. This plate shall be sampled by punching fifteen 1/2-in.-diameter specimens in three rows with equal boron concentration randomly along the length of the plate. One row of holes shall be on or near the fuel hump.
2. Each sample shall be analyzed by a laboratory and methods as appropriate in conformance with ANSI/ANS-8.21, Section 5.3.1.3.

3. The distribution of boron from the sample plates shall be as follows:

   - Samples within minimum fuel core outline: ±35% of calculated value.
   - Samples along edges of core outline: +35 - 100% of calculated value.

4. If any sample value falls outside the specified range, three additional plates from the group shall be sampled and analyzed. If any sample value from these three additional plates falls outside the specified range, all the plates from the group shall be rejected.

8.2.6 Nonbond

Fuel plates shall be inspected for presence of any nonbonded areas or blisters by ultrasonic scanning of the entire surface of each fuel plate.

1. The ultrasonic test shall be conducted with sufficient sensitivity to detect a nonbonded area or blister of <0.063 ± 0.005-in. diameter.

2. Within the maximum core outline plus a 1/4-in. margin, any indication >0.063 ± 0.005 in. shall be cause to reject the plate.

3. Outside the core outline and margin, any indication >0.125 ± 0.005 in. shall be cause to reject the plate.

4. Calibration standards shall be scanned before and after scanning a group of plates.

8.2.7 Clad Thickness and Bonding

The clad thickness and bonding shall be determined by destructive examination of one randomly selected fuel plate from the group selected for each fuel element. A rejected plate from the lot of plates contained in the group may be used for this destructive examination.

1. This plate shall be transversely sectioned in the middle and equidistant from the middle to each end. The end transverse sections shall be further sectioned along their centerline and samples prepared to allow examination from approximately 1/2 in. beyond the core and extending 1-1/2 in. into the core.

2. The clad thickness shall be determined by measuring the clad thickness on both sides of the fuel core in each of the prepared sections. The minimum clad thickness shall be >0.007 in.

3. Bonding shall be evaluated by metallographic examination of the interfaces in polished and etched sections of all the interfaces. Acceptable bonding is defined as (1) no visible separation between the layers when viewed under 10 X magnification and (2) ≥ 50% grain growth evenly distributed across the aluminum-to-aluminum interfaces as viewed under polarized light at 50 X.
4. If any value falls outside the specified range, three additional plates from the group shall be sampled and analyzed. If any sample value from these three additional plates falls outside the specified range, all the plates from that group shall be rejected.

8.2.8 Radioactive Surface Contamination

The radioactive surface contamination shall be determined by smearing the surfaces of flat fuel plates and counting these smears with appropriate radiation measuring equipment. The radioactive surface contamination of a flat fuel plate shall be < 5 disintegrations per minute (dpm) per 100 cm^2 alpha (equivalent to ~1 μ ^{235}U per 100 cm^2). Statistically appropriate sampling of fuel plates may be used to ensure that the radioactive contamination level is maintained below the specified level.

8.3 Fuel Element Assembly

The test and inspection requirements for the assembly of HFIR fuel elements are contained in the following section.

8.3.1 Uranium Loading

The total loading of ^{235}U in each fuel element shall be determined by the summation of the ^{235}U contents (as determined in Section 8.2.1) in each plate contained in the element.

8.3.2 Boron Loading

The total loading of ^{10}B in each inner element shall be based on the summation of dispensed weights of boron carbide contained in each plate and the certified ^{10}B content in the B_4C material used.

8.3.3 Coolant Channel Spacing

Each coolant channel in each fuel element shall be continuously measured along the entire length of each coolant channel at the following radial locations. Locations are in inches ±1/8 in. from the centerline of the elements.

	Gage position number				
	1	2	3	4	5
Inner fuel element	3.10	3.56	4.05	4.40	4.80
Outer fuel element	6.20	6.64	7.22	7.61	7.90

The device for measuring the channel spacing shall be furnished by the Company.

The coolant channel spacing tolerances along the length of the fuel elements are given in Table 8.1.

Table 8.1. Coolant channel spacing tolerances (in.)

A. Inner element

Axial Region 1: Top 21 inches of channel

Gage position number	1	2	3	4	5	Row average
Local minimum	0.040	0.040	0.040	0.040	0.040	
Local maximum	0.060	0.060	0.060	0.060	0.060	
Station (row) avg. min.						0.044
Station (row) avg. max.						0.056
Track avg. min.	0.040	0.040	0.040	0.040	0.040	
Track avg. max.	0.060	0.060	0.060	0.060	0.060	
Axial Region II: Bottom 3 inches of channel						
Gage position number	1	2	3	4	5	Row average
Local minimum	0.040	0.040	0.040	0.040	0.040	
Local maximum	0.060	0.060	0.060	0.060	0.060	
Station (row) avg. min.						0.044
Station (row) avg. max.						0.056
Track avg. min.	0.040	0.040	0.040	0.040	0.040	
Track avg. max.	0.060	0.060	0.060	0.060	0.060	

Overall average of entire length of all channels, all tracks: min. 0.049 in., max. 0.051 in.

B. Outer element

Axial Region 1: Top 21 inches of channel

Gage position number	1	2	3	4	5	Row average
Local minimum	0.040	0.040	0.040	0.040	0.040	

Table 8.1. Coolant channel spacing tolerances (in.)

Local maximum	0.060	0.060	0.060	0.060	0.060	
Station (row) avg. min.						0.044
Station (row) avg. max.						0.056
Track avg. min.	0.040	0.040	0.040	0.040	0.040	
Track avg. max.	0.060	0.060	0.060	0.060	0.060	
Axial Region II: Bottom 3 inches of channel						
Gage position number	1	2	3	4	5	Row average
Local minimum	0.040	0.040	0.040	0.040	0.040	
Local maximum	0.060	0.060	0.060	0.060	0.060	
Station (row) avg. min.						0.044
Station (row) avg. max.						0.056
Track avg. min.	0.040	0.040	0.040	0.040	0.040	
Track avg. max.	0.060	0.060	0.060	0.060	0.060	

Overall average of entire length of all channels, all tracks: min. 0.049 in.; max. 0.051 in.

8.3.4 Welding

1. Fuel Plates

The quality of the attachment welds for fuel plates cannot be practically examined by nondestructive means and must be controlled by strict adherence to the welding materials requirements, the welding procedures, evaluation of weld test samples before and after the welding of each element, visual inspection of the as-welded weld surfaces, and visual inspection of the finished machined surfaces of the welds.

(a) Weld Test Samples

(1) **Visual examination.** The surfaces of the weld bead on the weld test samples shall be free of defects such as cracks, incomplete fusion, or voids. The weld beads shall have a uniform contour and be free of oxidation, and the termination crater(s) shall have a depth less than would be required to provide a smooth surface on a fuel element after final machining.

(2) **Tensile strength**. The pull strength of the attachment of the tensile test plates, with the force applied normally to the bottom surface of the slot, shall be >100 pounds.

(3) **Metallographic examination**. A minimum of 95% of the dummy weld test plates shall be welded to the side plate across the entire surface of the fuel plate; the other 5% shall be joined over at least 75% of the thickness of the fuel plate. The penetration of weld metal into the weld groove shall be > 10% except for the first 2 in. at the weld start. Full penetration of the slide plate slots is not desirable and shall be avoided.

(4) Welding of a fuel element shall not begin until the before-and/or-after (from preceding element) weld test sample meets visual and tensile strength requirements listed in (1) and (2) above.

(5) If the before-and/or-after (from preceding element) weld test sample does not meet the visual and tensile strength requirements listed above, welding of additional test samples shall continue until two consecutive samples meet all the requirements of this specification.

(6) If an after weld sample does not meet the requirements of this section, an SNR shall be submitted to the CTR for disposition.

(b) Visual Inspection As-welded

All as-welded weld beads and adjacent heat-affected surfaces shall be visually inspected. The face side of each weld shall be free of defects such as cracks, incomplete fusion, or voids. The weld beads shall have a uniform contour and be free of oxidation, and the termination crater(s) shall have a depth less than that required to provide a smooth surface on the fuel element after final machining. Any deficiency noted in this inspection shall be repaired and reinspected before final machining.

(c) Visual Inspection after Machining

After final machining, all weld surfaces shall be visually inspected. Porosity in the GMAW cannot be avoided and is permissible if it does not exceed that specified for radiographic inspection in the ASME Boiler and Pressure Vessel Code, Section VIII, Appendix IV, "Porosity Charts for Plate 1/4 in. or Less." The amount of large porosity shall be < 1/2 the amount shown in the figure. The presence of cracks or voids extending into the side plate thickness or porosity exceeding those permitted in this section shall be submitted on an SNR. The SNR shall include the proposed weld repair procedure, if applicable.

2. End Fittings

(a) **Visual inspection as welded**. The face side of each weld shall be free of defects such as cracks, incomplete fusion, or voids. The weld beads shall have a uniform contour and be free of oxidation, and the termination crater(s) shall have a depth less than that

required to provide a smooth surface on the fuel element after final machining. Any deficiency noted in this inspection shall be repaired and reinspected before final machining.

(b) **Radiographic examination**. Each end fitting weld shall be inspected by radiography. Welds shall be unacceptable if the radiograph shows any cracks or any of the types of discontinuities as specified in ANSI/AWS D1.2, Sections 9.15.2.1 through 9.15.2.4. If a defect is noted in the radiographic inspection of an end fitting weld, an SNR shall be submitted for disposition.

(c) **Visual inspection after machining**. After final machining, any reportable weld defects shall be submitted on an SNR. The SNR shall include the proposed weld repair procedure, if applicable.

9. 0 QUALITY ASSURANCE AND DOCUMENTATION

9.1 Quality Assurance Plan

The Seller shall document and maintain quality systems that address Company requirements (10 CFR 830.120). Measurement equipment used for tests and inspection shall be calibrated in conformance with MIL-C-45662 or Company-approved equal. A description of the quality assurance program and the procedures to maintain adequate control and quality shall be furnished to the Company.

9.2 Process Control

The Seller shall establish a process control program whereby checks are made on manufacturing processes, operational procedures, intermediate product characteristics, and equipment to demonstrate that the process stability during production is at least equal to that demonstrated during qualification. The Seller shall develop and implement plan for providing process control through statistical trend analysis of key attributes. The plan, including the list of key attributes and appropriate measures of process stability or yields to be used for comparison, will be submitted to CTR for concurrence.

If process yields fall significantly below historical values over a 3-month period, as defined within the plan, the specific production tasks affecting these yields shall be evaluated by the Seller and this evaluation shall be provided to the CTR in writing. Depending upon the findings and recommendations of this evaluation, the process and/or personnel associated with this task(s) may be disqualified for continued HFIR production.

9.3 Procedures

Work activities shall be performed, controlled, and documented in accordance with written procedures approved by the CTR. The operators and inspectors shall be trained to these written procedures for their specific tasks and shall perform their HFIR production tasks in strict accordance with these written procedures. The Seller shall monitor the conformance of the

operators and inspectors to the written procedures and inform the Company of any nonconformances. The written procedures shall be reviewed at least every 5 years by the Seller to ensure that the procedures are clear. The Seller shall maintain a record of the review and submit all procedures that have been revised for all non-administrative changes.

Administrative changes to procedures do not require the approval of the CTR. Administrative changes shall be defined as (1) clerical changes — e.g., spelling, grammar, punctuation, and typographical errors; (2) restructuring/retyping document without altering the technical contents; (3) additions or changes not relative to manufacturing/inspection/testing procedures — i.e., personnel/ nuclear safety, labor reporting, inventory tracking and production scheduling, security, work center/department number; and (4) verbatim compliance of contract specifications.

9.4 Requalification

Requalification for any fuel plate or fuel element attribute to the requirements of this specification shall be required when the processes, materials, fuel loading, equipment, or personnel, which had been previously qualified, are changed. The Seller shall notify the Company of any proposed process change and then must document on an SDR to the satisfaction of the Company that the change will have no detrimental effect on the product. Engineering evaluation and/or proof tests will be required to justify a major process change. A proposed major process change cannot be used in production until all the qualification requirements specified in this document have been met, documented, and approved by the Company in writing. Minor process changes or refinements shall be submitted on an SDR for approval by the CTR and RRD QA before implementing in production. The CTR and RRD QA will determine what procedure changes constitute major changes. Editorial or wording changes for clarification in procedures are not considered changes as defined in this section.

9.5 Personnel Qualification

Personnel performing work activities shall demonstrate technical proficiency and shall be trained in the use of applicable procedures. Personnel performing radiographic and ultrasonic NDE examinations shall be certified to ASNT procedure SNT-TC-1A, and certification documentation shall be available to the Company. Specific qualifications are required for operating personnel performing powder compacting and welding. These requirements are contained in Sections 9.5.1 and 9.5.2. Operating personnel performing pack assembly, hot rolling, and cold rolling shall be qualified to procedures developed by the Seller. Documentation shall be maintained by the Seller that all operating and inspection personnel are qualified to perform their identified tasks.

9.5.1 Powder Compacting

Candidate personnel for powder compacting shall be instructed by the Seller's process engineering department in the proper powder handling, die loading, and powder sweeping techniques. For qualification, the candidate operator shall demonstrate a proficiency in satisfactorily making at least 20 out of 24 compacts from each of the two consecutive outer plate lots. A satisfactory compact is one that has passed all visual and dimensional inspection requirements and the fuel distribution has been determined to be acceptable in the finished

rolled plate. Separate qualification on inner compacts is not required. The qualification of a compacting operator shall be based only on defects directly related to the powder compacting operation(s).

9.5.2 Welding

General qualifications. Welding operators who perform machine welds on HFIR fuel elements shall be qualified for the welding of aluminum tubes of the same diameter and thickness of tubes used on HFIR fuel elements with single "V" groove weld preparation in the 1G position (tube horizontal, rotated) using the HFIR welding equipment or other comparable equipment. The qualification shall be based on the satisfactory completion and documentation of the welds in accordance with the general qualification requirements outlined in ANSI/AWS D1.2, Section 4, Part D. Welders who make hand repair welds on HFIR fuel element and welder(s) used in pack assembly shall be qualified for the appropriate weld type in accordance with the general qualification requirements outlined in ANSI/AWS D1.2, Section 4, Part D. If a Seller has welding operators or welders who are currently qualified for welding on HFIR fuel elements under different criteria, these welding operators or welders shall be considered qualified.

Fuel plate welding. In addition to the general personnel qualification requirements, a candidate welding operator for HFIR fuel elements shall demonstrate the successful welding of at least two consecutive weld test samples of each type in accordance with the requirements in Section 8.3.4. A candidate welding operator shall be supervised by a welding engineer or qualified HFIR fuel element welding operator during qualification. The results of this qualification test shall be documented and reviewed with the Seller's process engineer before approval of the candidate welding operator for production welding of HFIR fuel elements. A requalification of a HFIR welding operator shall be required if more than 12 months has elapsed since the operator welded a HFIR element.

End fitting welding. In addition to the general personnel qualification requirements, a candidate replacement welding operator for end fitting welding shall be supervised by a welding engineer or a qualified HFIR end fitting welding operator for at least two end fitting welds of each type. The results of this qualification shall be documented and reviewed with the Seller's process engineer before approval of the candidate welding operator for production welding of HFIR fuel elements. A requalification of a HFIR welding operator shall be required if more than 12 months has elapsed since the operator welded a HFIR element.

9.5.3 Radiography

The preparation of radiographs shall be performed by ASNT/SNT-TC-1A Certified Level 1 or higher level radiographer. The interpretation of radiographs shall be performed by ASNT/SNT-TC-1A Certified Level II or higher level radiographer.

9.6 Supplier Deviation and Nonconformance

The Company shall have the sole authority for determining the acceptability of a proposed deviation or the disposition of a proposed nonconformance. A supplier deviation request (SDR)

form and a supplier nonconformance request (SNR) form shall be supplied to the Seller by the Company.

Any proposed deviation from this specification shall be documented on a SDR and approved by the Company before proceeding.

In the event that any component, part, work operation, or fuel element does not meet the specified requirements of this specification and a deviation has not been granted by the Company as identified in the previous paragraph, a SNR may be submitted to the Company for approval. This SNR shall be completed by the Seller up to and including the technical justification of the recommended disposition. A copy of the repair/rework procedure shall be submitted if applicable.

9.7 Audits and Surveillance

9.7.1 Audits and Source Inspection

The Seller shall permit the Company to conduct pre-award audits and continuing evaluation of his quality system. The Seller shall be subject to source inspection by the Company, both at the Seller's facility and also at subtier suppliers' facilities if deemed necessary. The Company will identify hold points to the Seller to be witnessed by the Company's representative. The Company's source inspection does not constitute final acceptance of a fuel element. The Company may perform physical inspection of the finished fuel element at the Seller's facility prior to shipment. The Company may review all delivery submittals listed in Section 12.6 of this specification prior to the shipment of a finished fuel element, and the Company may also witness the final packaging of fuel elements before shipment.

9.7.2 Surveillance

As a part of the Company, Research Reactors Division's Quality Assurance Program source surveillance activities may be conducted at the Seller's facility as deemed necessary by the Company to ensure that quality objectives are met. Such surveillances will include, but not be limited to, auditing and monitoring any work in progress, processes, chemical/physical certifications, final inspection and testing, preparation for shipment, and review of certification data. The Seller shall provide the Company's representative(s) access to all data and operating areas that are pertinent to the contract. Source surveillance by the Company's representative(s) shall not constitute product acceptance by the Company and in no way shall relieve the Seller of the responsibility to furnish acceptable items.

9.8 Preproduction Qualification

Before production, the Seller, if not currently qualified, shall demonstrate that the fabrication and inspection techniques used to fabricate both inner and outer fuel elements are capable of conforming to this specification. Before production of reactor-grade fuel plates the results of the preproduction qualifications shall be approved in writing by the Company.

9.8.1 Fuel Plate Qualification

The fuel plates procedures shall be qualified by satisfactorily producing consecutively in a single operation a minimum of 24 fuel plates for each type of HFIR fuel element in accordance with this specification. These plates shall be identical to the expected production plates.

Flat plates. The Seller will have met the process qualification requirements if at least 80% of the flat plates of each plate type produced in the qualification run meet the requirements of this specification and the following additional inspections and tests.

Remeasurement of fuel core. After blanking and inspection and before forming, every qualification plate shall be radiographed and the core measured on the radiographic film to show that the core outline and minimum edge conform with the drawing specifications.

Clad thickness and bonding. Three flat plates from the qualification batch for each element type shall be destructively examined for clad thickness and bonding. These plates shall be transversely sectioned in the middle and equidistant from the middle to each end. The end transverse sections shall be further sectioned along their centerline and samples prepared to allow examination from approximately 2 in. beyond the core and extending 12 in. into the core. Each of these sections shall be examined for conformance to the requirements of Section 8.2.7 of this specification.

Boron content and distribution. The boron loading in inner fuel elements shall be verified by the Seller to demonstrate his ability to control the boron content in fuel plates. Evidence of this control shall be by analysis of three randomly selected fuel plates for total boron content. Each plate shall be dissolved and analyzed by a laboratory and methods as appropriate (ANSI/ANS-8.21, Section 5.3.1.3). The total ^{10}B content determined shall be within the range as specified in Section 6.3 (0.0164 ± 0.0016 ^{10}B).

The boron distribution across the width of each inner fuel plate shall be verified by destructive sampling and analysis of three randomly selected plate from the inner fuel plate qualification lot. The sample analysis shall be as prescribed in Section 8.2.5 of this specification.

Retesting. If any of the accepted qualification test plates fails any one of the additional destructive test and inspection requirements for preproduction qualification, another lot of plates shall be produced and tested. In addition, twice the number of plates shall be examined for the attribute that failed in the first test to meet the preproduction qualification requirements.

Homogeneity scanner. The precision and accuracy of the digital homogeneity scanner shall be determined during preproduction inspection of fuel plates by the scanning of a special test plate to be supplied by the Company at least three times and statistically analyzing the data. The variance of this data shall be within agreed limits to be established by the Company.

Surface contamination. The fabrication processes involving in handling of fuel powders, the pressing and handling of fuel compacts and pack assembly shall be contained to the extent necessary to consistently fabricate fuel plates with a surface contamination of < 5 dpm per 100 cm^2 alpha. During startup the Seller shall demonstrate that the process can consistently

produce flat plates with a surface contamination below the level specified by smearing all fuel plates produced in the first 5 production lots of fuel plates of each type.

9.8.2 Fuel Elements

Prior to the beginning of production operations, draft welding procedure specifications (WPS) for the welding of the fuel plates and end fittings shall be prepared and documented in accordance with the general requirements outlined in ANSI/AWS D1.2, Section 4, Part C, or another procedure specification if approved by the Company.

During preproduction operations, the Seller shall demonstrate that the channel spacing is not altered during subsequent welding of the end fittings and the final machining operations.

Dummy Fuel Elements

1. To qualify the fabrication process for HFIR fuel assemblies, a minimum of one inner and one outer dummy fuel element shall be fabricated and shipped to the Company for approval.

2. These elements shall be made to the identical engineering drawings and fabrication, test, and inspection procedures planned for producing HFIR fuel elements by the Seller in compliance with this specification except for the fuel plates.

3. The simulated fuel plates in these dummy fuel elements shall be dimensionally identical to those specified for the actual fuel elements except that they shall be made of 6061-0 aluminum sheet stock. The dummy shall be conspicuously marked as such.

4. The Seller shall certify the conformance of these dummy fuel elements to this specification.

Destructive Examination—Fuel Plate Welds

1. A single dummy fuel element (either inner or outer element) shall be assembled as described Section 9.8.2 (dummy fuel element) for destructive examination.

2. A minimum of four complete circumferential welds on both the inner and outer side plates shall be welded as specified in Section 7.4.2 by each welding operator for preproduction qualification.

3. These welds shall meet all the requirements of Section 8.3.4.

4. As welded, the element diameter and plate spacing shall meet the requirements of Sections 8.1 and 8.3.3.

5. One inner and one outer weld shall be sectioned along the centerline of the weld and prepared for examination as described for weld test samples.

6. The sectioned welds shall meet the requirements of the weld test samples, Section 8.3.4.

7. If any weld fails to meet the requirements previously described, a complete weld requalification shall be required.

8. The successful completion of the weld preproduction requirements shall constitute the qualification of the welding procedure specification and the production welding operator(s).

Destructive Examination—End Fitting Welds

1. One end fitting on a dummy inner and outer element shall be welded as specified in Section 7.4.3 for destructive examination.

2. These welds shall meet all the requirements of Section 8.3.4.

3. Each weld shall be sectioned and examined.

4. The sections shall be crack free and show a full penetration weld with defects such as slag inclusions and porosity no larger than as specified for radiographic acceptance of the weld.

5. If any weld fails to meet the requirements previously described, a complete weld requalification shall be required.

6. The successful completion of the weld preproduction requirements shall constitute the qualification of the welding procedure specification and the production welding operator.

Qualification Elements

One complete inner fuel element and one outer fuel element certified to meet the requirements of this specification shall be furnished the Company for approval before full production operation.

10.0 CLEANLINESS

10.1 General

The aluminum used for fuel cladding in the HFIR fuel elements is subject to pitting corrosion from the presence of many foreign materials that may be left on the aluminum surfaces during fabrication. Also, the completed fuel elements will be operated in a high-purity water environment. To protect the completed fuel plates and elements from pitting corrosion, and to avoid the introduction of ionic and foreign materials into the HFIR water systems, the Seller shall not use any process or material (including packaging or shipping materials) that has the possibility of leaving a residue of certain detrimental materials on the surface of any fuel plate after the final fuel plate cleaning step and after the final cleaning of the completed fuel element.

The detrimental materials are chlorine, fluorine, copper, lead, nickel, silver, thorium, tin and carbon. If the Seller's processes, whether inadvertent or not, cause any of these detrimental materials to contact the surface of a component, the Seller shall establish cleaning and inspection procedures subject to approval by the CTR for cleaning and maintaining the cleanliness of all fuel plates and completed fuel elements to comply with this requirement. Because trace amounts of these materials are found in cleaning fluids such as alcohol and water, the procedures shall identify the specifications for all cleaning fluids or identify acceptable levels of these impurities that shall be verified through testing of the purchased lot.

Mercury in any form can cause catastrophic corrosion of aluminum and shall be specifically precluded in the procurement of aluminum raw materials and in all processing and manufacturing operations used by the Seller for HFIR fuel elements.

10.2 Fuel Plates

1. The use of any abrasive or any procedure that removes >0.001 in. from a surface of a fuel plate shall not be used. A fine aluminum wool or "Scotch Bright" containing fine aluminum oxide as the abrasive may be used to remove surface defects <0.001 in.

2. The Seller shall establish and demonstrate that the production process flow and isolation of radioactive contamination consistently produces flat fuel plates with radioactive surface contamination of <5 dpm per 100 cm^2 alpha.

10.3 Fuel Elements

1. The interior and exterior surfaces of the fuel elements and fuel channels shall be free of weld splatter, slag, dirt, oil, scale, paint, marking ink, or any other foreign materials.

2. Pickling or similar cleaning in any stage of fabrication of an assembled fuel element shall not be permitted.

11.0 PACKAGING AND SHIPPING

1. Before shipping, each fuel element shall be individually wrapped in green colored polyethylene plastic wrap or bag (0.004 in. minimum thickness) to protect the element from dust and moisture. Clear plastic wrap is not allowed in the Company's reactor building.

2. The Seller shall load each completed fuel element into an individual shipping container supplied by the Company.

3. After loading, each shipping container shall be provided with a tamper-proof seal as required for the shipment of special nuclear materials.

4. The Company will be responsible for shipping the fuel elements from the Seller's facilities to the Company's facilities in Oak Ridge, Tennessee.

12.0 RECORDS, SAMPLES, AND INFORMATION TO BE SUPPLIED

The Seller shall perform regular statistical trend analysis for process control and provide the data to the CTR semi-annually.

12.1 Engineering Drawings and Material Specifications

The Company will maintain all reference drawings and material specifications referenced in this specification. All other engineering drawings and process materials specifications shall be maintained by the Seller. A copy of all proposed changes to an approved drawing or specification shall be submitted on a deviation request form for Company approval and incorporation into an engineering drawing or specification. The Seller is encouraged to use the applicable revision of the reference engineering drawings for working drawings. If the Seller elected to produce and use working drawing comparable to the referenced engineering drawings for use on the shop floor, these working drawings and their revisions shall be approved by the Company for configuration control.

12.2. Procedures

A copy of procedures and route cards approved by the Seller for use in fuel element fabrication shall be submitted to the Company for approval. These shall include procedures for fuel plate fabrication, fuel element fabrication, inspection and testing, cleanliness, packaging and shipping, quality assurance, and preproduction qualification. All copies of approved procedures and route cards used in production shall be numbered and controlled. Any proposed modification of an approved procedure or route card shall be submitted on a deviation request for approval by the Company.

12.3 Production Records

Production records including route cards, quality deficiency notices, temperature strip charts, radiographs, inspection data, and materials inspection and identification data that are not included in certification packages shall be retained by the Seller until the HFIR element(s) related to this information is used in the HFIR. The Company will inform the Seller when a specific fuel element has been used in the HFIR. Alternatively, if the Seller is not notified that the HFIR element has been used in the HFIR within two years after delivery of the HFIR element, the Seller may ship the production records to the Company at its discretion.

12.4 Safety-Related Materials Certification and Archive Samples

1. For each lot of material, certified copies of the test and inspection results shall be retained by the Seller along with certifications that the materials comply with the requirements of this specification until the HFIR element(s) related to this information is used in the HFIR.

2. One properly identified archive sample from each material lot of (1) uranium oxide, (2) boron carbide, (3) aluminum powder, (4) aluminum weld rod or wire, (5) aluminum plate and sheet, and (6) aluminum tubing shall be retained by the Seller until the HFIR elements containing the materials are used in the HFIR.

3. The Company will inform the Seller when a specific fuel element has been used in the HFIR.

4. Alternatively, if the Seller is not notified that the HFIR element has been used in the HFIR within two years after delivery of the HFIR element, the Seller may ship the Safety-Related Materials Certifications and Archive Samples to the Company at its discretion.

12.5 Preproduction Procedure Qualification Results

A copy of all preproduction qualification test results and a certification that the preproduction qualification tests have met the requirements of this specification shall be furnished to the Company. The Seller does not need to meet this requirement if the contract is a continuation of HFIR element work from a previous contract. These tests results, if required to be submitted, shall include the following:

1. **Fuel plates**. Prequalification test data to be furnished for both inner and outer type fuel plates shall include visual, dimensional, radiographic, destructive, and uranium homogeneity and boron distribution and content.

2. **Fuel elements**. Prequalification test data to be furnished for both inner and outer fuel elements shall include, visual, dimensional, channel spacing, welding qualification, and welding test and inspection results.

12.6 Data Furnished with Each Element

A certification package for each fuel element shall be supplied to the Company before shipment of the element. The certification package shall contain the following information:

1. A certification that the fuel element complies with the requirements of this specification.

2. Identification number of the fuel element.

3. Lot number and weight of total uranium and ^{235}U in each fuel plate and total in fuel element.

4. Lot number and weight of boron carbide in each inner element.

5. Measured values of dimensions indicated on the assembly drawing for each fuel element.

6. Fuel plate weld test samples and inspection report.

7. Radiographic analysis report of end-fitting welds.

8. Destructive examination inspection report on bond quality and clad thickness.

9. Analytical report from destructive examination for boron content from fuel plate samples.

10. Identification of all welding machine operators and welders.

11. A listing of all SNRs and deviation requests issued and approved for any component or process affecting this element.

12. A report indicating that the following inspections have been made, and by whom, and summarizing the results:

    (1) fuel plate dimensions (for control fuel plates only)
    (2) fuel channel spacing data
    (3) side plate thickness

Appendix A
Cross Reference to BWXT Working Drawings (July 2004)

ASSEMBLY DRAWINGS	ORNL	Rev.	Date	BWXT/TI	Rev.	Date
HFIR inner fuel element—assembly	E-42118	Q	Jul-98	DG-8-7213	U	Mar-96
HFIR outer fuel element—assembly	E-42126	M	Jul-98	DG-8-7214	X	Mar-96
COMPONENT DETAILS						
HFIR inner fuel element—fuel plate loading details	D-42114	H	Apr-91	DG-8-7146	T	Feb-94
HFIR outer fuel element—fuel plate loading details	D-42122	H	Apr-91	DG-8-7148	S	Feb-94
HFIR inner fuel element fuel plate—true involute curvature design details	D-42113	G	Apr-91	DG-8-7147	F	Oct-68
HFIR outer fuel element fuel plate—true involute curvature design details	D-42121	H	Apr-91	DG-8-7149	F	Oct-68
HFIR inner fuel element—inner side plate #1	D-42112	H	Apr-91	DG-8-7218	J	Aug-75
HFIR inner fuel element—outer side plate #2	D-42117	H	Apr-91	DG-8-7217	J	Aug-75
HFIR outer fuel element—inner side plate #3	D-42120	H	Apr-91	DG-8-7216	M	Aug-75
HFIR outer fuel element—outer side plate #4	D-42125	J	Apr-91	DG-8-7215	M	Aug-75

APPENDIX C

BOISE STATE TECENTER TECHNOLOGY COMMERCIALIZATION MODEL

PHASES, STAGES, & STEPS

	TECHNICAL	MARKET	BUSINESS
CONCEPT PHASE			
Stage 1 **Investigation**	TECHNICAL ANALYSIS STEP 1	MARKET NEEDS ASSESSMENT STEP 2	VENTURE ASSESSMENT STEP 3
DEVELOPMENT PHASE			
Stage 2 **Feasibility**	TECHNICAL FEASIBILITY STEP 4	MARKET STUDY STEP 5	ECONOMIC FEASIBILITY STEP 6
Stage 3 **Development**	ENGINEERING PROTOTYPE STEP 7	STRATEGIC MARKET PLAN STEP 8	STRATEGIC BUSINESS PLAN STEP 9
Stage 4 **Introduction**	PRE-PRODUCTION PROTOTYPE STEP 10	MARKET VALIDATION STEP 11	BUSINESS START-UP STEP 12
COMMERCIAL PHASE			

Stage 5 **Growth**	**PRODUCTION** **STEP 13**	**SALES AND DISTRIBUTION** **STEP 14**	**BUSINESS GROWTH** **STEP 15**
Stage 6 **Maturity**	**PRODUCTION SUPPORT** **STEP 16**	**MARKET DIVERSIFICATION** **STEP 17**	**BUSINESS MATURITY** **STEP 18**

THE TECHNOLOGY COMMERCIALIZATION MODEL

KEY QUESTIONS

	TECHNICAL	MARKET	BUSINESS
CONCEPT PHASE			
Stage 1 **Investigation**	**TECHNICAL ANALYSIS** **STEP 1** **Is this product new, unique, and technically feasible?**	**MARKET NEEDS ASSESSMENT** **STEP 2** **Does this product meet a clear market demand or solve a problem?**	**VENTURE ASSESSMENT** **STEP 3** **Will this product or venture opportunity make a profit?**
DEVELOPMENT PHASE			
Stage 2 **Feasibility**	**TECHNICAL FEASIBILITY** **STEP 4** **What are the total costs associated with producing the product?**	**MARKET STUDY** **STEP 5** **Who will buy the product, how many will be bought and at what price?**	**ECONOMIC FEASIBILITY** **STEP 6** **Does this opportunity generate sufficient returns to justify investment?**
Stage 3 **Development**	**ENGINEERING PROTOTYPE** **STEP 7** **Do you have a prototype that exactly represents the product?**	**STRATEGIC MARKET PLAN** **STEP 8** **Have you profiled and finalized the target market?**	**STRATEGIC BUSINESS PLAN** **STEP 9** **Have you finalized your business model, identified total financial needs, and secured seed capital?**
Stage 4 **Introduction**	**PRE-PRODUCTION PROTOTYPE** **STEP 10** **Have you completed a limited production and tested for performance and reliability?**	**MARKET VALIDATION** **STEP 11** **Have you made sales?**	**BUSINESS START-UP** **STEP 12** **Is the management team operational?**
COMMERCIAL PHASE			

Stage 5 **Growth**	**PRODUCTION** **STEP 13** **Is production process dependable, reliable and optimized?**	**SALES AND DISTRIBUTION** **STEP 14** **Are you growing market share?**	**BUSINESS GROWTH** **STEP 15** **Are you on course to achieve your business plan objectives?**
Stage 6 **Maturity**	**PRODUCTION SUPPORT** **STEP 16** **Are you supporting the product?**	**MARKET DIVERSIFICATION STEP** **Have you identified your next generation of products?**	**BUSINESS MATURITY** **STEP 18** **Are you generating and/or maximizing a return on investment?**

Activities

CONCEPT PHASE			
Stage 1 **Investigation**	**TECHNICAL ANALYSIS** **STEP 1** • Define concept • Confirm critical assumptions • Survey state of the art • Id critical barriers • Evaluate applicability • Determine technology	**MARKET NEEDS ASSESSMENT** **STEP 2** • Conduct market overview • Id pricing structure • Id market barriers • Id risks • Id distribution channels • Id trends and competitors	**VENTURE ASSESSMENT** **STEP 3** • Estimate profit potential • Conduct self, enterprise and commercialization assessments • Id professional needs • Id capital needs
DEVELOPMENT PHASE			
Stage 2 **Feasibility**	**TECHNICAL FEASIBILITY** **STEP 4** • Develop working model • Test technical features • Assess preliminary producibility • Conduct manufacturing assessment • Assess safety & environmental features • Finalize designs	**MARKET STUDY** **STEP 5** • Id and quantify: • Market size • Customers • Volume • Prices • Distribution • Competitors	**ECONOMIC FEASIBILITY** **STEP 6** • Formulate financial assumptions • Develop pro forma • Id seed capital • Form advisory team
Stage 3 **Development**	**ENGINEERING PROTOTYPE** **STEP 7** • Develop prototype • Id materials and processes • Conduct tests • Develop manufacturing methods	**STRATEGIC MARKET PLAN** **STEP 8** • Id marketing team • Define target market • Select market channels • Field test	**STRATEGIC BUSINESS PLAN** **STEP 9** • Decide venture or license • Finalize intellectual property • Id management team • Select organization structure • Write business plan
Stage 4 **Introduction**	**PRE-PRODUCTION PROTOTYPE** **STEP 10** • Develop production prototype • Determine production process • Select manufacturing equipment • Design field support system • Demo product features	**MARKET VALIDATION** **STEP 11** • Establish market relationships • Conduct limited sales • Analyze sales • Survey customers • Refine marketing plan	**BUSINESS START-UP** **STEP 12** • Establish business function • Hire staff • Execute contracts • Secure first-stage financing
COMMERCIAL PHASE			

Stage 5 **Growth**	**PRODUCTION** **STEP 13** • Prepare commercial design • Establish quality control • Construct facilities • Conduct full production • Finalize internal distribution system	**SALES AND DISTRIBUTION** **STEP 14** • Expand distribution • Analyze competitor response • Assess customer satisfaction • Assess distributorsatisfaction • Refine product features	**BUSINESS GROWTH** **STEP 15** • Monitor enterprise position • Hire and train personnel • Execute contracts • Arrange financing • Institute vision, mission and management policies
Stage 6 **Maturity**	**PRODUCTION SUPPORT** **STEP 16** • Maximize production • Establish after market support, repairs and spares • Warrantee service • Implement training program	**MARKET DIVERSIFICATION** **STEP 17** • Develop market retention • Establish market scan • Id new markets • Id new products	**BUSINESS MATURITY** **STEP 18** • Establish SWOT process • Invest profits • Monitor product life cycle • Monitor business trends • Monitor mgmt. technologies • Implement innovations

DELIVERABLES

	TECHNICAL	MARKET	BUSINESS
CONCEPT PHASE			
Stage 1 **Investigation**	TECHNICAL ANALYSIS STEP 1 Provisional patent, patent, copyright, patent scan, license agreement	MARKET NEEDS ASSESSMENT STEP 2 Background research materials	VENTURE ASSESSMENT STEP 3 Preliminary cost and revenue estimate
DEVELOPMENT PHASE			
Stage 2 **Feasibility**	TECHNICAL FEASIBILITY STEP 4 A working model of the product	MARKET STUDY STEP 5 Primary market research	ECONOMIC FEASIBILITY STEP 6 A financial model accurately representing the business opportunity
Stage 3 **Development**	ENGINEERING PROTOTYPE STEP 7 An accurate prototype representing the materials and functionality of the end product	STRATEGIC MARKET PLAN STEP 8 The final marketing plan based upon discussions with suppliers, market representatives, and customers	STRATEGIC BUSINESS PLAN STEP 9 The business plan
Stage 4 **Introduction**	PRE-PRODUCTION PROTOTYPE STEP 10 A limited production	MARKET VALIDATION STEP 11 Sales	BUSINESS START-UP STEP 12 An Enterprise
COMMERCIAL PHASE			
Stage 5 **Growth**	PRODUCTION STEP 13 Production	SALES AND DISTRIBUTION STEP 14 Growing sales	BUSINESS GROWTH STEP 15 Increasing revenues
Stage 6 **Maturity**	PRODUCTION SUPPORT STEP 16 Maximum production	MARKET DIVERSIFICATION STEP 17 New products	BUSINESS MATURITY STEP 18 Profits

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