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DDE-NBSR Status Report of Conceptual Design Activities

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September 2012

Idaho National Laboratory

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Abstract

The Design Demonstration Experiment for the National Bureau of Standard Reactor (DDE-NBSR) is intended to facilitate Low Enriched Uranium (LEU) conversion of the NBSR by demonstrating the performance and fabrication of the LEU fuel element design through an irradiation test in the Advanced Test Reactor center flux trap. At the time this report was prepared the resources for furthering DDE design work were expected to be postponed. As such, the conceptual design effort to date is summarized herein in order to provide the status of key objectives, notable results, and provisions for future design work. These demonstrate that the DDE-NBSR design effort is well on the path to producing a suitable irradiation experiment. This report also exhibits several recommendations in order to facilitate success of the irradiation campaign.

DDE-NBSR Status Report of Conceptual Design Activities

1. Introduction

The National Nuclear Security Agency Global Threat Reduction Initiative Convert (GTRI-Convert) program employs the Reduced Enrichment for Research and Test Reactors (RERTR) Fuel Development (FD) pillar to facilitate maturation of Low Enriched Uranium (LEU) fuel technology in order to enable conversion of High Power Research Reactors (HPRR) to these fuels. The RERTR FD pillar has overseen design, fabrication, irradiation, and examination of numerous tests on small to medium sized specimens containing these fuels. To enable three HPRR conversions, including the Massachusetts Institutes of Technology Reactor (MITR), University of Missouri Research Reactor (MURR), and National Bureau of Standard Reactor (NBSR), the FD pillar is currently focused on qualification of the "Base Monolithic Design". The Base Monolithic Design consists of uranium-10 wt% molybdenum alloy (U-10Mo) in the form of a monolithic foil, with thin zirconium interlayers, clad in aluminum by hot isostatic press as seen in Figure 1. [1] [2] [3]

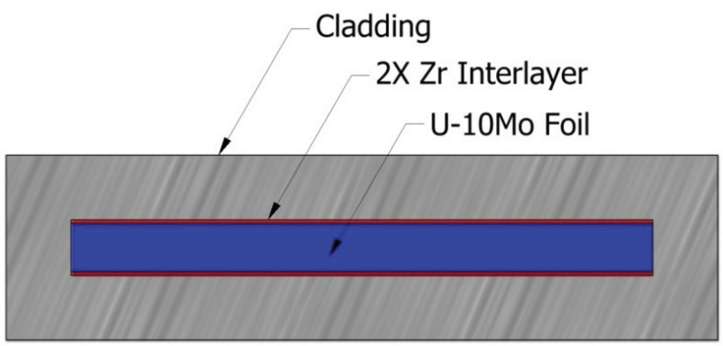

Figure 1: Base Monolithic Design

The licensing basis of the three aforementioned HPRR's restricts them from testing lead test elements of their respective LEU fuel element designs [4]. In lieu of the lead test assembly methodology, one Design Demonstration Experiment (DDE) for each of the three NRC licensed reactors will be irradiated elsewhere using prototypic fuel plate geometries under prototypic conditions (i.e. "end use application" in a "design environment" [5]). In terms of the technology life cycle, execution of the DDE campaign will represent a significant level of maturity as a "Development Work" activity and will be subject to all pertinent "Part I and applicable Part II" quality assurance requirements [6].

1.1 Objectives

While absolute prototypic conditions may not be achievable in any reactor except the one for which the LEU element is designed, the DDE campaign is intended to accomplish several critical functions. The following list constitutes the core goals for the DDE campaign:

- **Confirm Performance** under stringent prototypic parameters (e.g. heat flux, fission density)
- **Show Resistance** to worrisome failure modes (e.g. fission gradients, thin-clad structural stability)
- **Demonstrate Fabrication** by producing the plates/elements as demonstration products [7]
- **Give Confidence** in the LEU fuel designs prior to conversion

1.2 NBSR Reactor Description

The NBSR is cooled and moderated with D_2O and the fuel elements are placed in a “loose” configuration, i.e. with significant space between each fuel element, in order to achieve design objectives. Each fuel element has a 7-inch gap at the mid-core. This arrangement allows for beam tubes to point directly to the gap (and not to fuel) in the core [8] as seen in Figure 2.

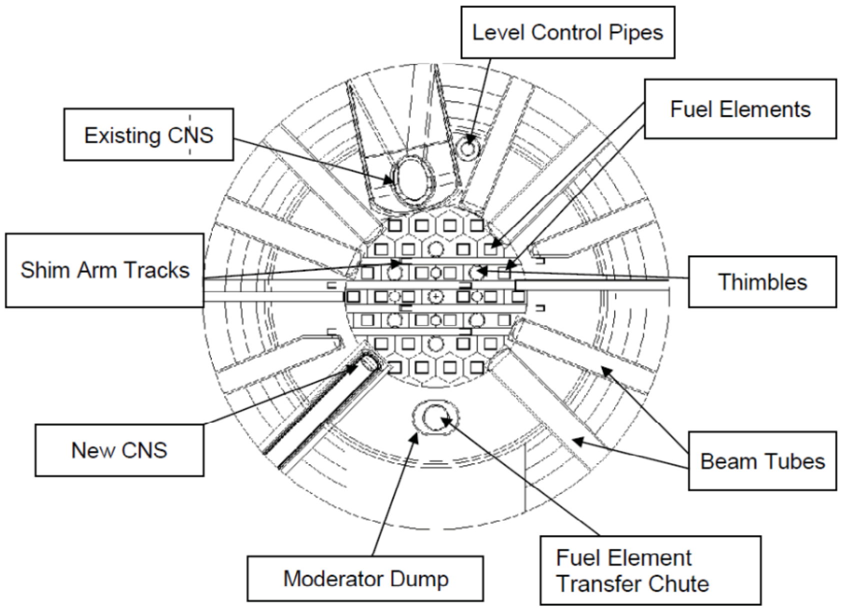

Figure 2: NBSR Core Layout (reference [9])

2. Design Inputs

NBSR critical geometry and irradiation parameters were established based on forthcoming conversion analyses provided by the GTRI-Convert Reactor Conversion (RC) pillar. Each fuel element is constructed of 17 plates in each upper and lower half (34 plates per fuel element), with one full-length dummy plate on each of the exterior sides, in a curved plate geometry as seen in Figure 3. Nominal fuel plate dimensions can be seen in Figure 4, Figure 5, and Figure 6. Irradiation parameters are summarized in Table 1.

Figure 3: LEU NBSR Fuel Element Design

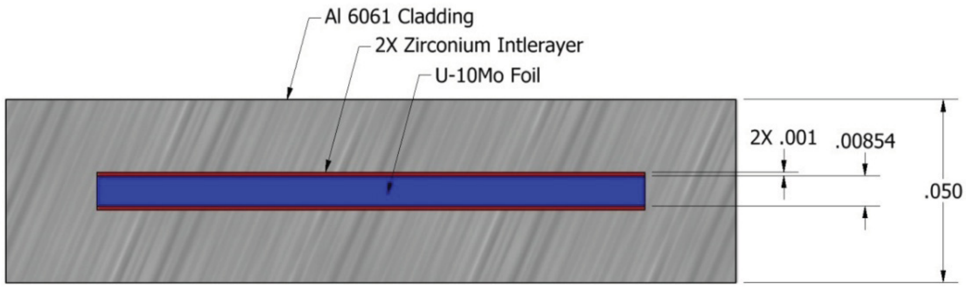

Figure 4: NBSR LEU Fuel Plate Nominal Cross Section (dimensions in inches)

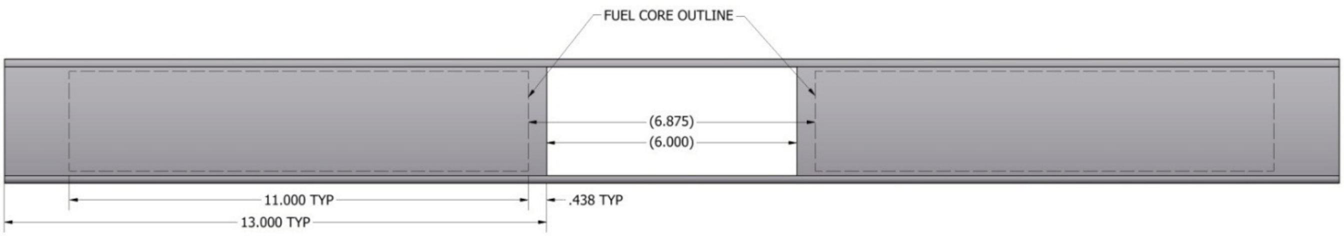

Figure 5: NBSR LEU Fuel Plate Nominal Lengths (dimensions in inches)

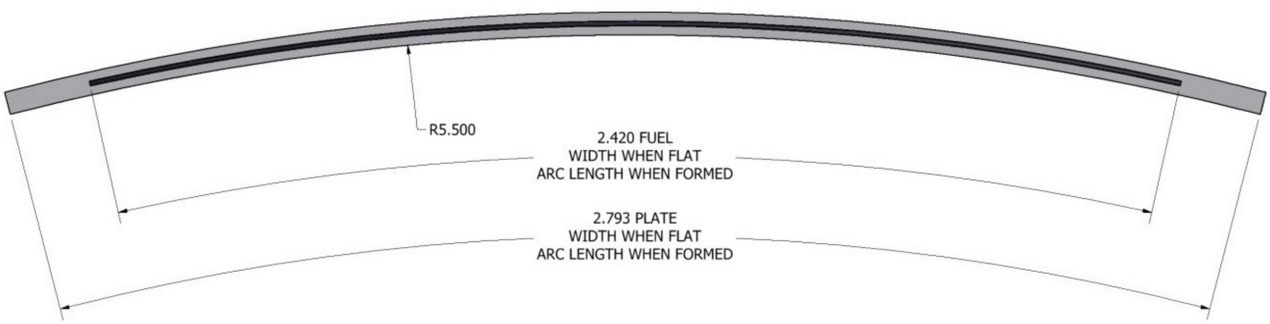

Figure 6: NBSR LEU Fuel Plate Nominal Widths (dimensions in inches)

Table 1: NBSR Operating Conditions and Reactor Parameters

Parameter	LEU Core Nominal	DDE Target
Coolant Velocity (m/s) [9]	3.0	3.0
Peak Local Heat Flux (W/cm^2) [10]	139	>139
Peak Plate Surface Temp (°C) [10]	103	~103
Peak Fuel Meat Centerline Temp (°C) [10]	113	~113
Peak Fission Density (fissions/cc)	7.75E+21*	>7.75E+21*

* Peak fission density represents full LEU burn-up

While the above geometries and parameters were subject to change, they were assumed based on the best information available at the onset of the DDE-NBSR effort and were used for scoping analysis activities. A formalized submission of the experiment's critical characteristics was requested from the RC pillar with the intent of including these, among other requirements, in a Functional and Operational Requirements (F&OR) document. Receipt of this submittal was delayed. As a result, the above parameters were also assumed as the key inputs for the conceptual design work. The F&OR document was not approved as a final document, but the draft document is included in this report for reference purposes and can be seen in Appendix A.

2.1 Alternatives and Selection

Several irradiation locations within the ATR, as well as within other reactors, were considered and it was determined that DDE-NBSR would be best suited for irradiation in the Advanced Test Reactor (ATR) Center Flux Trap (CFT) position. This is documented elsewhere [11].

3. Design Status

The DDE design effort was commenced in mid 2010 for three distinct campaigns; one for each MITR, MURR, and NBSR. This was premised around the original proposal to irradiate each in an ATR Medium I position. As a result, the efforts primarily concerned designing an experiment, consisting of LEU fuel meat, which would fit in to the Medium I position geometry, which can accommodate just over three inches of useable test geometry with the existing liner cans removed, while meeting the ATR TSR requirement of <365g U-235 per experiment position [12].

Resources for designers and analysts were difficult to ascertain until the effort was better funded in Fiscal Year 2011 (FY11). It was at this point that analysts identified that the low fluence of ATR I positions gave fission rates which failed to approach the irradiation conditions of each reactor. Budget cuts in March of 2011 caused suspension of further investigations until June of that year when a small budget was allocated to evaluate DDE designs with increased fuel meat enrichment (i.e. HEU). While scoping analysis indicated that HEU fuel meat could give fission rates representative of the MITR, these efforts were unsuccessful for the DDE-MURR and DDE-NBSR experiment. As a result, alternate experiment positions were evaluated and the CFT of the ATR was selected for DDE-NBSR [11].

The DDE work languished somewhat due to inadequate funding in FY11, but was revived in FY12 with meaningful funding and allocation of designers and analysts. This is the general timeframe when the conceptual design work is considered to have been commenced. Design efforts in early FY12 were accelerated in order to accommodate an HPRR conversion schedule which would require completion of the DDE's irradiation around 2015. In order to facilitate this timeline, experiment plans were drafted and called for formal submission of the aforementioned Critical Characteristics, as well as another set of inputs referred to as the Technical Tolerances, from the RC pillar in spring of FY12. These were intended to facilitate completion of the safety analysis and preliminary design work just prior to close of FY12 with completion of DDE coupon and element specifications as INL PEMP milestones. INL held regular conference calls with key personnel from the RC and Fuel Fabrication Capability (FFC) pillars as well as representatives from the each reactor in order to define experiment parameters, discuss design options, and foster communication between the design team and stakeholders.

Formal submission of both the Critical Characteristics and Technical Tolerances was postponed due to re-prioritization of GTRI-Convert personnel resources which was caused, to some extent, by emergent PIE blister threshold results from the RERTR-12 and AFIP-4 campaigns [13]. These prompted reduction of the DDE funding level in mid FY12 with the intent to complete conceptual design work only. At this time it was acknowledged that the aforementioned coupon and element specifications, if completed, would represent a maturity level less than originally planned (i.e. conceptual design vs. preliminary design). Regardless, these were produced primarily in the interest of good documentation and milestone accomplishment. These specifications are considered to be inadequately mature for fabrication of final DDE products, are discussed in greater detail in section 3.6, and are included in Appendices B and C for reference purposes

Toward the latter end of FY12, and corresponding with what should have been the close of the DDE conceptual design work, several factors drove a new HPRR conversion schedule to be proposed. This invalidated some the original DDE design assumptions, particularly those pertaining to schedule constraints, and also gave way to a suspension of DDE-related funding in FY13. As a result, the DDE design team endeavored to use the remaining FY12 resources to finalize a few important activities and document the results in preparation for a hiatus in DDE design work; resulting in the preparation of this document. However, funding overruns in another project which shared the DDE control account forced abandonment of some critical DDE design activities. As a result, the DDE conceptual design work was not considered entirely complete at the time this report was prepared. Recommendations, concerns, risk, incomplete activities, and other useful information are presented in section 4 for the purpose of facilitating future DDE design work.

3.1 Experiment Design

The DDE-NBSR experiment was designed to accommodate full size NBSR plates in accordance with the objective to irradiate prototypic plate geometry. Three such plates per row could fit into the CFT diameter if the Loop 2A facility were to be removed. The relatively short length of the NBSR plate geometry allowed for 3 total rows to fit easily within with the active core length of the ATR. This gave a total of 9 plate specimens in the experiment. Designs which held four plates per row were investigated, but were determined to be less desirable from a hardware design and structural standpoint (hardware design is discussed in greater detail in section 3.2).

Unlike other flux traps in the ATR, which were either too small to house the DDE-NBSR fuel plate or were unavailable for RERTR use during the original schedule window, the CFT's power level was known to lack direct adjustability via control drums. As a result, the primary parameter used to control the DDE-NBSR fission rate was fuel meat enrichment. The target peak heat flux for DDE-NBSR was 139 W/cm^2. Scoping analyses showed that predicted peak heat fluxes for designs with 20% and 25% enriched fuel meat were ~160 W/cm^2 and ~200 W/cm^2, respectively. While the fission rates, and resultant heat fluxes, for the 20% enriched design better matched the projected NBSR conversion core, the fuel meat was eventually designed at 25% enrichment in order to accommodate the original DDE schedule constraints in achieving fission density targets within six normal ATR cycles (~50 days irradiation each) prior to the 2015 ATR Core Internal Change-out (CIC). This schedule constraint was invalidated shortly before this report was written, but after the neutronic design was performed. As a result, the 25% was the most complete design concept at the time this report was written and is reported hereafter. Alternate design options are discussed in greater detail in the context of future recommendations in section 4.3. The relatively small fuel meat volume in the NBSR plate did not challenge the <365 total U-235 safety limit at 25% enrichment with 9 plate specimens. Constituent compositions can be seen in Table 2. The ATR CFT position can be seen in Figure 7.

Table 2: DDE-NBSR Nominal Plate Volumes and Masses

		Constituent Volumes			Constituents Masses					
Row	Plate	Fuel Meat	Interlayer	Cladding	Fuel Meat				Interlayer	Cladding
		U-Mo Volume (cm^3)	Zr Volume (cm^3)	Al-6061 Volume (cm^3)	U-Mo Mass (g)	Total U Mass (g)	U-235 Mass (g)	Mo Mass (g)	Zr Mass (g)	Al-6061 Mass (g)
A (top)	A1	3.73	0.87	25.15	63.33	57.00	14.25	6.33	5.70	67.91
	A2	3.73	0.87	25.15	63.33	57.00	14.25	6.33	5.70	67.91
	A3	3.73	0.87	25.15	63.33	57.00	14.25	6.33	5.70	67.91
B (mid)	B1	3.73	0.87	25.15	63.33	57.00	14.25	6.33	5.70	67.91
	B2	3.73	0.87	25.15	63.33	57.00	14.25	6.33	5.70	67.91
	B3	3.73	0.87	25.15	63.33	57.00	14.25	6.33	5.70	67.91
C (bot)	C1	3.73	0.87	25.15	63.33	57.00	14.25	6.33	5.70	67.91
	C2	3.73	0.87	25.15	63.33	57.00	14.25	6.33	5.70	67.91
	C3	3.73	0.87	25.15	63.33	57.00	14.25	6.33	5.70	67.91
				Mass Totals (g)	**569.98**	**512.98**	**128.25**	**57.00**	**51.27**	**611.20**

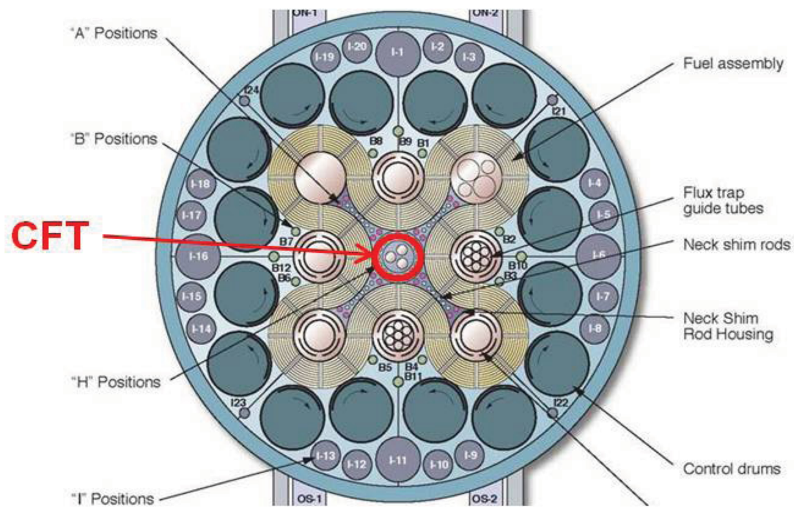

Figure 7: CFT Position

A challenge unique to the DDE-NBSR campaign was achieving a neutronic design which approximated the pronounced edge peaking effects seen in NBSR's D_2O moderated environment. Since it was infeasible to use D_2O as a coolant in the CFT, which must operate within ATR light water coolant when the loop facility is removed, other features of neutronic significance were designed for this purpose. The most notable feature was two hafnium rods placed in the irradiation vehicle with proximity to the fuel plates as seen in Figure 8. These rods, aided slightly by strategically designed water volumes in the annulus region (between irradiation assembly outer profile and CFT inner profile), produced a fission gradient map comparable to that of the NBSR LEU design. This was compared to a 3 X 14 mesh "hottest plate" heat flux map that was provided by the NBSR LEU conversion analysis team. These demonstrated fair agreement between the overall 2D fission rate maps in terms of Local to Average Ratios (L2AR's), particular in regards to the exterior plates in the top and bottom rows (A and C) where the ATR's "chopped cosine" axial power profile gave axial asymmetry as well. See Figure 9.

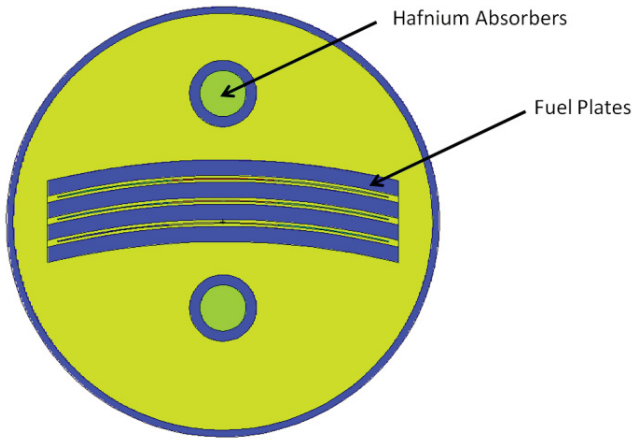

Figure 8: Hafnium Absorbers and Fuel Plates MCNP Cross Section

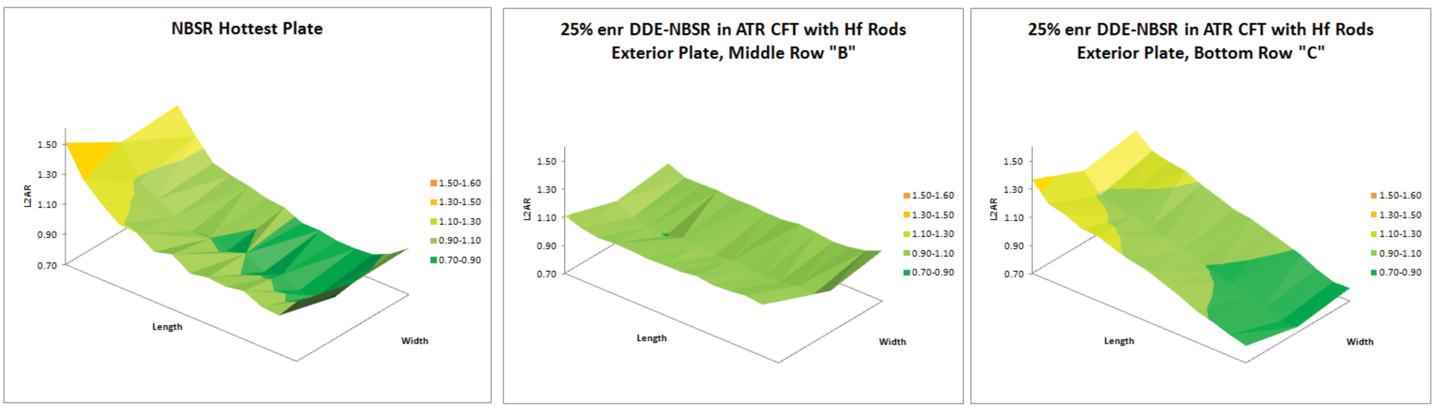

Figure 9: Fission Rate L2AR Contour Plots

ATR safety assumptions require flux trap experiments to impart minimal perturbation of the axial symmetry in the reactor's flux distribution. Consequently, the DDE-NBSR design placed the fuel meat of plate row "B" centered about the ATR core mid-plane. Because the distribution of flux within the experiment is axially symmetric there was little concern with ATR down-flow coolant direction in relation to NBSR's up-flow coolant direction. Analysis showed that the exterior plates of row "B" had the greatest average fission rates while the exterior plates of rows "A" and "C" had the most pronounced fission gradients in the axial direction. The interior plates exhibited slightly reduced average fission rates due to shielding from the exterior plates. The physics analyses of this experiment are discussed in greater detail in section 3.3.

The 6 inch gap between fuel plate ends in the NBSR facilitates the reactor beamline mission but was not necessarily seen as a critical parameter of the DDE-NBSR design. Scoping analyses showed that the end-to-end spacing had little effect on the fuel end-peaking fission rates. Eventually a gap of 1 inch was selected in order to give an adequate coolant mixing region, to keep the hot ends of the row "A" and "C" plates nearer to the ATR axial midplane (where the flux is higher), and to facilitate ATR canal channel gap probe gap insertion.

The experiment was designed to be irradiated within the CFT with the same rotational configuration throughout. The flow outlet path in the DDE-NBSR irradiation vehicle was designed via RELAP analysis in order to control the flow rate. The increased fission rates seen in the 25% enriched design drove a design which "overcooled" the experiment (i.e. provided coolant flow-rates beyond that of the NBSR core). This thermal hydraulic design effort helped to reduce fuel plate constituent temperatures (e.g. fuel meat centerline, clad surface) so that they were more prototypic of the NBSR environment, but these were offset somewhat by the higher inlet temperature of the ATR coolant as a fixed boundary condition. This is discussed in greater detail in section 3.4.

Detailed hardware design, structural analyses, and fuel element specification were also produced and the summarized in sections 3.2, 3.5, and 3.6, respectively. The INL's procedures for design control [14], irradiation experiment life cycle [15], and research and development quality assurance [16] were followed insofar as they pertained to conceptual design activities.

3.2 Hardware Design

Drawings of hardware designs can be found in Appendix D. Engineering Job number EJ-7.9.15-145 was initiated to track design control activities for the DDE-NBSR campaign. The design requirements of prototypic conditions, center flux trap irradiation, handling and measurement in the canal, and shipping constraints were considered in the design below and resulted in some departures from precedent CFT designs. The primary design constraint for the NBSR DDE was that it must demonstrate satisfactory performance in prototypic conditions. These conditions included fuel plate width, thickness, length, and curvature. They also included channel gaps between the fuel plates, flux profile, and the swaging method used to create assemblies from the individual fuel plates.

The irradiation vehicle design was designed as three main components that can be connected with a D-shaped pin:

- Retriever: This top portion was designed approximately four feet long and three inches in diameter with a lifting bail on top and an attachment mechanism on the bottom to attach to the body. This design makes the lifting bail available from the top of the center flux trap, which is recessed in the ATR neck shim housing.
- Body: The body portion was designed to contain the fuel plates and hafnium rods with a total length slightly less than four feet.
- Bottom: The bottom was designed with approximately 14 inches in length. It was designed to locate the test in the CFT lower support and provide a throttled flow outlet path.

In previous large plate experiments (e.g. AFIP-6, AFIP-7), the plates were swaged into a set of side rails, or a frame; allowing them to be removed from the main body for examination and shipping. This method was problematic for the NBSR plates due to their large size in the width direction (~2.75") in relation to the CFT inner diameter, which allowed insertion of a vehicle with outer diameter of 3.125. With appropriate clearances, the wall thickness at two locations on each side would have been ~0.03 inches thick. This would have be very susceptible to damage and distortion during irradiation and handling and would create high risk for the irradiation campaign.

Consequently, the Body was designed for fuel plate swaging directly to its structure. This gave several advantages such as a fixed datum surfaces from which the channel gap probe could measure, fuel plate protection by thick sidewalls during handling evolutions in the canal and during shipment, and a robust thermal bridge to a large thermal mass in contact with the primary coolant (direct path for decay heat removal). However, drawbacks of the body-element integral design include handling and shipping of the whole body, rather than just the fueled portion, and lack of fuel plate surface visibility during in-canal visual examinations. The body was designed with appropriate features for handling in the canal and channel gap probe characterization, the latter of which would require suitable fixturing. The fuel-containing body portion was designed for post-irradiated shipment within currently-used spent-fuel shipping casks. These length requirements mandated a removable bottom component.

D -pins were designed to be inserted from the side in order to connect the bottom to the body and to connect the body to the retriever. These were designed for removal/insertion when the assembly is at a 45 degree angle in the canal floor where a tool threads into the D-pin and facilitates it removal/insertion. D-pins were intended for replacement each cycle. To ensure vibration would not cause the D-pin to fall out, leaf type springs were used in the pin. These leaf springs were designed to press lightly against a ramp upon insertion, and because withdrawal increases force on the spring, vibration would cause the pin to move inward. Two leaf springs were included to ensure redundancy.

Finally, a special ATR-canal hook tool was designed to facilitate in-canal handling. It was designed to be more robust than the small hook tool used for previous AFIP in-canal manipulations while exhibiting the appropriate overall length for projected DDE-NBSR handling activities as any existing tools, which were thought to be adequately robust, did not exhibit the needed overall length.

Fabrication:

The hardware was designed for tight tolerance fabrication within the current capabilities of INL machine shops. The four aluminum pieces that make up the body were designed for fabrication on an extended-travel computer controlled milling machine at the Materials and Fuel Complex. The holes for the hafnium rods were designed to be gun drilled at the North Holmes Laboratory. Other parts were designed for fabrication with wire EDM and common machine tools. These were intended for fabrication and shipment to the plate fabricator (Babcock and Wilcox) for final swaging and assembly. Swaging experts at Babcock and Wilcox reviewed this concept and concurred with its feasibility, but noted that some special-use fixtures may need to be developed.

3.3 Physics Analysis

MCNP [17][18], a general purpose Monte Carlo N-Particle transport code, was used to model and evaluate the heat generation profile, and reactivity worths of the DDE-NBSR as designed with nine full-sized NBSR fuel plates arranged into three columns of three plates (3x3) and two hafnium rods in the CFT of the ATR (see Figure 10). The depletion methodology MCWO, Monte Carlo with ORIGEN2 [19], was used to model and evaluate the fission density and depletion the DDE-NBSR assembly, providing the fission power density and burnup versus Effective Full Power Days (EFPD) for the DDE-NBSR experiment. ORIGEN2 was used within MCWO to model the buildup, decay, and activation radioactive materials within the DDE-NBSR material compositions [20].

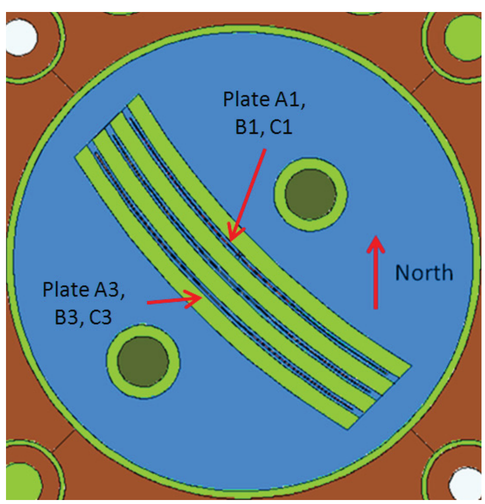

Figure 10: Cross Sectional View of DDE-NBSR Experiment in Center Flux Trap

The experiment was analyzed with regard to the experiment objectives to represent the conditions of the NBSR, of which a main objective was to achieve full LEU equivalent burnup. Since a nominal LEU plate at 19.75% U-235 enrichment has 7.74E+21 U-235 atoms per cc, full LEU equivalent burnup was interpreted to mean that the total fission density (fissions/cc) to be at least to 7.74E+21. Another objective of the experiment was to mimic the NBSR plate power profile without grossly overshooting the heat flux target while still achieving the burnup objective in 6 cycles. Two hafnium rods were incorporated into the design to both hold down the beginning of life power of the experiment and to enhance the edge peaking in the plates.

The following assumptions were used in the physics analysis such that the primary objective of the experiment, achieving full LEU equivalent burnup, was achieved:

- Nominal lobe powers of 18.0-14.0-21.0-23.0-23.0 MW (NW-NE-C-SW-SE) were used to evaluate the heat generation rate and depletion analyses.
- A constant cycle length of 42.5 days was used under the assumption that ATR will operate for 85% of a planned 50 day cycle.
- A maximum irradiation time of 6 cycles was assumed so that the irradiation of the experiment would be complete before the ATR CIC.

In order to accurately capture the detailed power distribution and associated power peaks within each plate, all nine plates of the experiment were split into 14 axial and 15 azimuthal stripes. The average heat flux for each plate was calculated as well as the peak heat flux within this 14 x 15 division. For depletion purposes this 14 x 15 division was reduced to 14 x 3 in order to reduce the computational time for the analysis while only minimally impacting the accuracy of the results. Table 3 shows the beginning of life average and peak heat fluxes, as well as the end of life peak fission density for each of the 9 plates in the experiment.

Table 3: Summary Data from Physics Analysis

Row	Plate	Avg Heat Flux (W/cm^2)	Max Heat Flux (W/cm^2)	Peak Fission Density (Fissions/cc)
Top	A1	115.31	180.55	7.64E+21
	A2	113.42	178.87	7.73E+21
	A3	115.94	177.24	7.74E+21
Mid	B1	171.71	201.28	8.23E+21
	B2	169.89	204.99	8.25E+21
	B3	173.98	206.20	8.32E+21
Bot	C1	127.17	189.66	7.97E+21
	C2	125.52	191.83	8.00E+21
	C3	128.48	191.88	8.03E+21

3.4 Thermal Analysis

The flow rates through the experiment were evaluated using the RELAP5 plant code. The experiment geometry for the entire irradiation assembly was modeled in RELAP, and the reactor operating conditions for inlet temperature/pressure and outlet pressure were included as boundary conditions. The size of the assembly outlet orifices was based on the RELAP analysis results with the intent to “overcool” the experiment and obtain fuel and clad temperatures similar to those of the NBSR. Flow through each of the fuel plate channels was found to be 12.2 m/s. Greater confidence in the flow rates should be obtained by physical flow testing in the future. The flow rates through the experiment channels and around the experiment holder were input to an ABAQUS finite element model. The flow rates were also used to compute heat transfer coefficients for each channel and input to the ABAQUS model.

The ABAQUS model assumed nominal dimensions from the aforementioned conceptual drawings. To maintain consistency with similar analyses for ATR driver fuel and other experiments, a 0.001 inch oxide layer was included on both sides of the fuel plates. Three heating cases were assumed. The first heating case was developed to evaluate the experiment's performance with regard to the ATR safety requirements, and was used to evaluate the Departure from Nucleate Boiling Ratio (DNBR) and Flow Instability Ratio (FIR) results for both steady state full flow and flow coastdown cases. A center lobe power of 30 MW was assumed for this heating case. This power bounded typical center lobe powers and resulted in over-estimated experiment heating. The second heating case eliminated an uncertainty associated with localized fuel loading variations. The slightly lower heat rate was used to determine the temperatures for use in the structural analysis. The final heating case was for nominal heat loading and did not apply any uncertainty factors to the heat loads generated by the physics analysis. Improved accuracy in the nominal case results should be obtained when the DDE-NBSR schedule is revisited and the corresponding ATR cycles/predicted powers are ascertained. Heating rates for the fuel plates were obtained from the physics analysis and scaled as described above. Non-fueled material heating rates were obtained from a nuclear analysis of various materials in the south flux trap. Table 4 summarizes the plate temperatures for the three heating cases evaluated:

Table 4: Thermal Results Summary

Analysis Description	Peak Fuel Meat Temperature (^oC)	Average Fuel Meat Temperature (all plates) (^oC)	Peak Clad Temperature (^oC)	Average Clad Temperature (all plates) (^oC)
Maximum heating case (30 MW lobe) full uncertainties applied – full flow	234	156	210	125
Maximum heating case (30 MW lobe) full uncertainties applied – coastdown flow	249	168	226	135
Structural temperature evaluation, (30 MW lobe), limited uncertainties	213	143	191	116
Nominal Case (21 MW lobe), no uncertainties	160	113	145	95

Figure 11 shows the temperature profile in the coolant for the flow coastdown case. Figure 12 shows the heat flux from the plate surfaces for the flow coastdown case. These results were used to determine the Critical Heat Flux and resultant DNBR value. For the flow coastdown, the minimum DNBR and FIR were 5.2 and 4.2, respectively (must be greater than two to meet ATR safety requirements). For the full flow case, these values were 6.5 and 5.3, respectively. More details are available in the thermal analysis report [21]. This was a small part of the safety analyses that will be required for the final experiment analyses package. Additional analyses should include reactivity insertion accidents, including the effect of cascading reactivity, horizontal in air and water evaluations for storage and handling evolutions, and a natural circulation evaluation to determine coolability during plant shutdown. Additionally, an oxide spallation analysis should be performed to evaluate expected fuel performance characteristics.

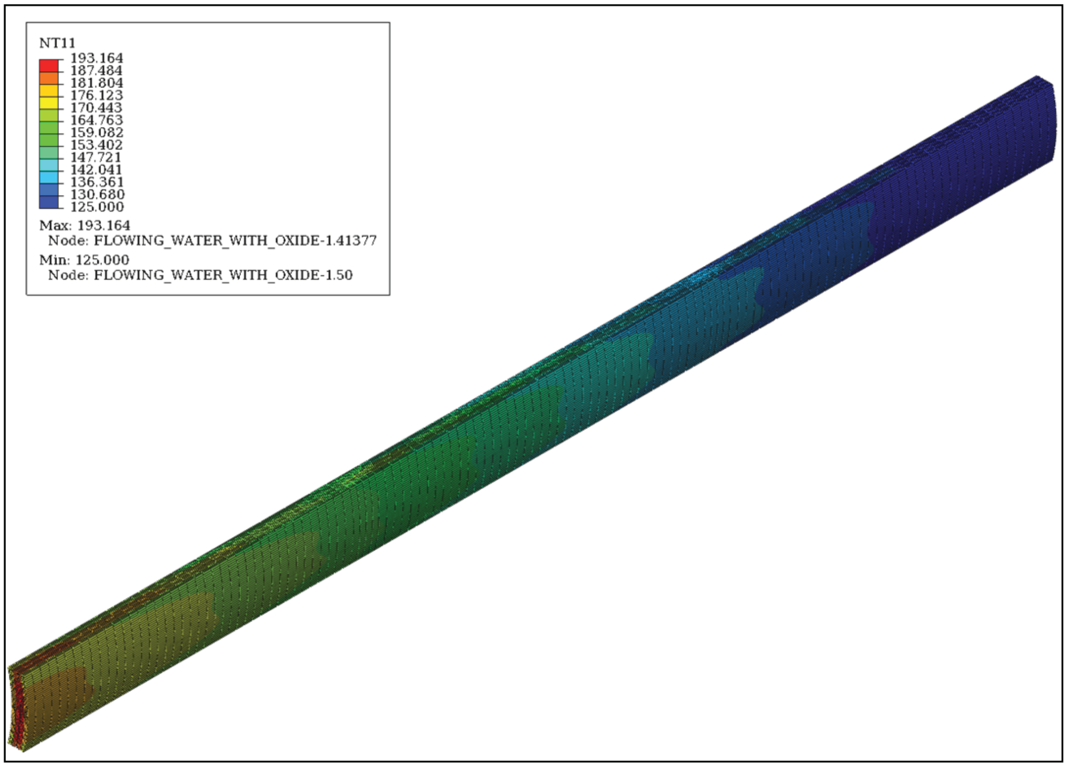

Figure 11: NBSR Experiment Flow Coastdown Coolant Temperatures (^{o}F)

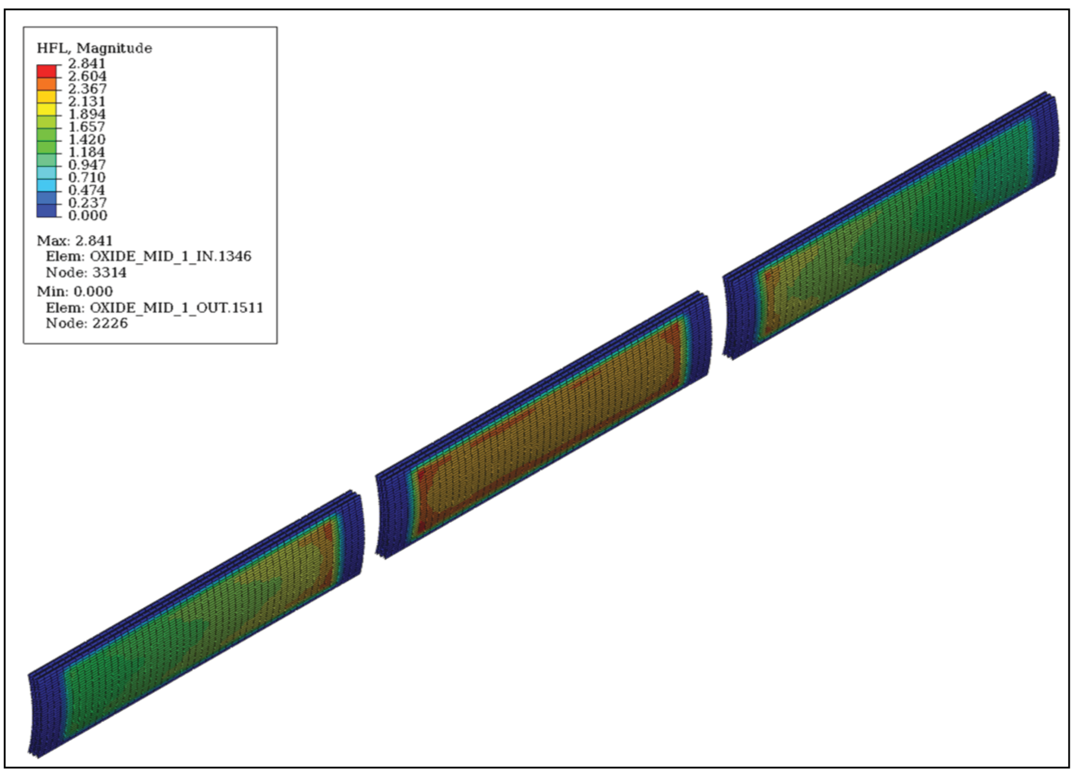

Figure 12: NBSR Experiment Flow Coastdown Plate Surface Heat Flux (BTU/s-in^2)

3.5 Structural Analysis

An ABAQUS finite element structural analysis was used to evaluate the NBSR irradiation assembly for stresses incurred through thermal temperature expansion, flow drag, dead weight, reactor pressures, flow-induced vibration, and handling for normal CFT operation. The analysis showed that the majority of the stresses occurred in fuel plate body region due to thermal temperature expansion. Seismic loading was analyzed for short durations and showed little affect on the irradiation assembly or reactor core structure. Dead weight, flow-induced loading, and reactor pressures also added to structural stresses. Two structural plots illustrate von Mises stress on the element assembly sides and fuel plates due to thermal expansion and dead weight as seen in Figure 13 and Figure 14, respectively. More details can be found in reference [22].

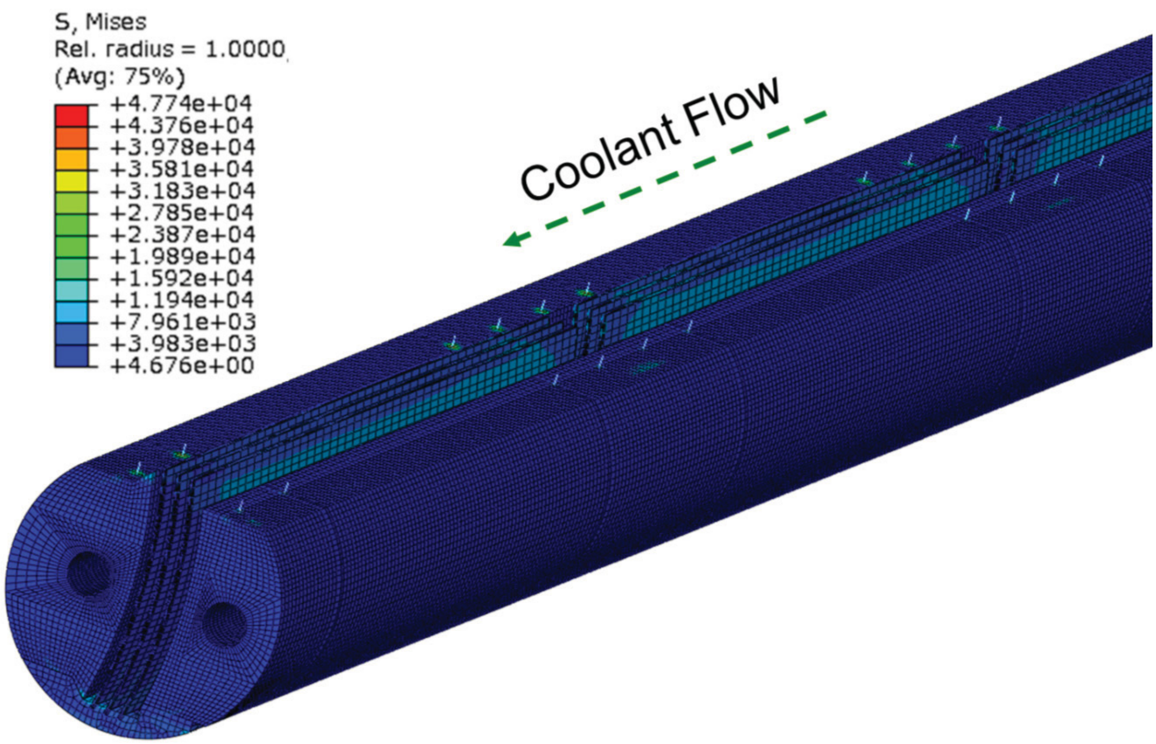

Figure 13: Assembly Body FEA Stress Plot (one side plate hidden to show stresses at screw locations)

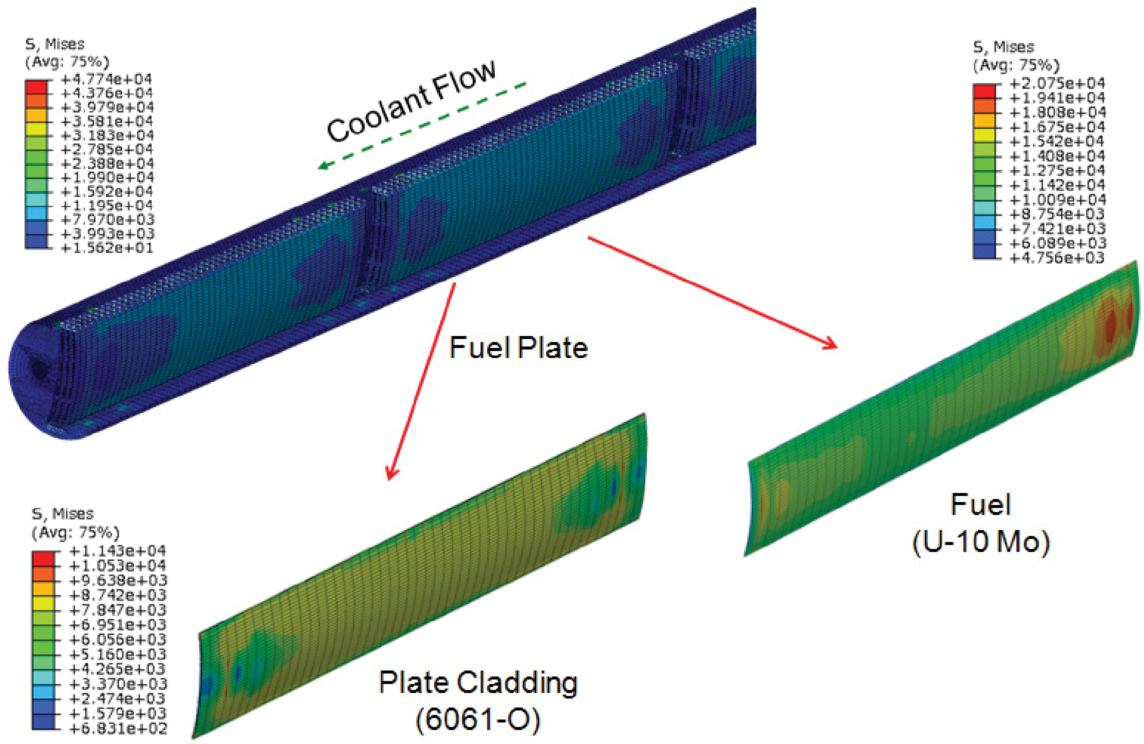

Figure 14: Fuel Plate FEA Stress Plots

3.6 Fuel Specifications

As discussed in section 3, draft specifications were produced for the DDE-NBSR U-Mo coupons and fuel element and can be seen in Appendices B and C, respectively. These specifications represent a design maturity level commensurate with conceptual design only and are considered to be inadequately mature for fabrication of final DDE products. The element specification corresponds with fuel plate and fuel element assembly drawings 603876 and 603878, respectively, as seen in Appendix D.

These specifications were based, to the level possible, upon a quality control and quality assurance requirements in existing specifications. The chemical and isotopic requirements of U-Mo materials were based upon existing standards for HEU metal [23], Y-12 specifications for LEU metal [24] and LEU-Mo [25], ASTM standards for LEU-metal [26], and U-Mo foil specifications for the RERTR-FE campaign [27]. These were tabulated and the appropriate compositional limits were selected. Equivalent Boron Content (EBC) limits were derived by comparing the sum total max EBC of each plate constituent in the existing HEU designs to the proposed EBC limit for U-Mo. In the case of DDE-NBSR, where the fuel material was > 20% enriched, the other isotopic limits (i.e. ^{234}U and ^{236}U) and ^{235}U enrichment tolerances were modified slightly based on the increased ^{235}U enrichment. These limits were compared to historical analyses of U-Mo materials. These tabulations, calculations, and comparisons can be found in the Coupon Specification Composition Worksheet as denoted in Table 5 of section 5.2.

The composition and isotopic limits explained above were specified based primarily on existing requirements and equivalency to currently accepted designs and/or standards. Consequently, these limits represent a proposed base for nuclear safety and LEU reactor operation of the MITR, MURR, and NBSR, but do not represent any requirements that the manufacturer wish to impose in order to facilitate greater yield rates or ease in fabrication. Intermediate product specifications [28], sampling plans, manufacturing procedures, etc. should be incorporated into the DDE coupon specifications, or related documents, as their effects on fabrication processes becomes known during the FFC pillar's ongoing fabrication studies.

Like the coupon specifications, DDE element specifications were based, to the level possible, on existing specifications and standards. Specifically, the MITR HEU [29] element and MURR HEU [30] element specifications were chosen as “templates” to work from. These were selected based on their succinct structure and experience base with the fuel procurement group at the INL. As a result, much of the specification verbiage was taken from the MITR and MURR HEU specifications, except those specific requirements pertaining to the LEU elements, DDE specific design features, and other requirements taken from the the existing NBSR HEU element specification [31] and element drawings [32].

This was intended to facilitate one of the core DDE goals to demonstrate fabrication. Unlike the current HEU element procurement structure, the final NBSR LEU elements were proposed to be accomplished by the INL fuel procurement group. Furthermore, quality assurance requirements for irradiation within the ATR were known to require that the supplier with whom the INL contracts be evaluated and qualified in order to provide these services. For example, if the INL were to contract with Oak Ridge National Laboratory (ORNL), whom currently procures the NBSR fuel, to provide the DDE-NBSR fuel element for irradiation in the ATR, then the INL must to qualify ORNL for these services, who would then in-turn do the same for the commercial fabricator (i.e. Babcock and Wilcox). Rather than encumbering the process in this way, the DDE element specifications were written in accordance with maintaining a procurement structure which is prototypic of that for the final LEU element.

Other specification adaptations include differences innate to the DDE design such as the absence of end box casting requirements and plate/element U-235 limits based on a total quantity of nine fuel plates at 25% enrichment. Requirements that were based on upon the precedent HEU dispersion fuel (e.g. stray fuel particles and provisions for “dogbones”) were eliminated or modified. Additional inspections and requirements which pertain to the monolithic base fuel design and respective fabrication process are also included such as bend testing of clad croppings and zirconium interlayer thickness inspection. Finally, some specification adaptations were necessary based on the DDE’s end use including references to the NBSR as the “stakeholder” rather than the “user”, designation of the ATR as the shipping destination, and mandatory boehmite prefilm treatment of the fuel plate cladding for use in the ATR primary coolant.

4. Future Recommendations

4.1 Experiment and Hardware Design Recommendations

Reduction of the scope and budget during mid FY12 to “conceptual work only” caused certain features of the hardware design to be incomplete. Their maturation is recommended for future efforts. These include:

- Fabricate full-size mock-ups of the DDE-NBSR irradiation assembly for the purpose of functional handling in the ATR canal, channel gap probe, and other applicable handling evolutions. This effort would substantially reduced the risk of hardware based failure in providing “hands-on” experience regarding fabrication of the hardware, ability to assemble underwater and perform channel gap measurements, and likelihood of damage during handling. Completion of this work is strongly recommended. These should give way to training and procedures for handling of the assembly with particular attention given to mitigating the risk of damaging the fuel plates.
- Development of any special purpose tooling for canal and ATR vessel handling such as storage buckets, handling tools, and fixturing. These should also be fabricated and handled in a prototypic effort as described above early enough in the design process to facilitate modifications if necessary. Storage buckets and similar fixtures should also endeavor to allow for natural circulation removal of decay heat. These should give way to training and procedures for handling of the assembly with particular attention given to mitigating the risk of damaging the fuel plates.

- Design of a suitable location in the irradiation assembly and selection of an appropriate dosimetry material (e.g. flux wires) for the purpose of benchmarking cycle-to-cycle as-run depletion analysis in order to reduce the risk of "over-burning" or "under-shooting" the actual experiment during irradiation. This effort may also make use of the to-be-installed ATR fuel element burn-up monitoring system.
- Complete design and installation of a channel gap probe sensor which can measure channel gap distance and water temperature concurrently.
- The DDE-NBSR design was originally designed to use the existing hafnium absorbers (originally fabricated for AFIP-7 campaign), but it was recently discovered that one of the hafnium absorbers had cracked in the region near the handling hole. The remaining four hafnium absorbers should be investigated for damage and, if they are unusable, the DDE-NBSR should endeavor to design new hafnium absorbers. As lead-time to obtain nuclear grade hafnium can be considerable, it is recommended that this effort is undertaken in a timely manner.
- The DDE-NBSR will be characterized by the ATR in-canal channel gap probe before irradiation, between each cycle (during outage) and after irradiation. The channel gap probe has two "cradles", one will likely be dedicated to ATR fuel element geometry. The remaining cradle must accommodate both the DDE-MITR and DDE-NBSR experiments. Further design work to develop suitable guide blocks and locating fixtures common to both DDE-MITR and DDE-NBSR. These should also be fabricated and handled in a prototypic effort as described above early enough in the design process to facilitate modifications if necessary.

4.2 Analytic Recommendations

Several analytic efforts were not completed due to reduction of the scope and budget during mid FY12 to "conceptual work only" and the belated Critical Characteristics submittal. Their maturation is recommended for future efforts. These include:

- Upon ascertainment of a more mature design, which may only be possible following receipt of the Critical Characteristics and development of a new experiment schedule (and resultant ATR cycle lobe power projections), a full suite of safety analyses should be performed and reviewed by nuclear safety personnel.
    - Physics: source term, void worth, and axial flux perturbations
    - Thermal: reactivity insertion accidents, including the effect of cascading reactivity, horizontal in air and water evaluations for storage and handling evolutions, and natural circulation evaluation to determine coolability during plant shutdown
    - Structural based on more mature inputs from the thermal safety analysis and all anticipated service levels
- Further design analyses should include:
    - An analysis "round robin" where the DDE-NBSR heat loads, flow rates, etc. would be provided to the RC team for input into their NBSR LEU models and vice-versa for the purpose of comparing analytic results between the DDE-NBSR and NBSR LEU methods, models, codes, etc.
    - Since the DDE experiments, compared to previous RERTR-FD irradiations, have more specific fission density goals which must be confidently met prior to post irradiation shipment, as-built equivalent boron content of non-fueled components

(e.g. aluminum stock used to fabricate the irradiation vehicle) should be investigated for it contribution to the final fission densities via physics analyses.

- Fluid Structure Interaction (FSI) analysis performed in order to evaluate the risks for flow induced failure modes. This should be performed in conjunction with physical flow testing of dummy hardware.
- Analysis to determine the risk for an oxide spallation failure. Since the DDE-NBSR experiment will reside in the ATR canal under decay heat conditions for greater lengths of time than previous RERTR-FD fuel development experiment these calculations should also consider including “canal-time”, if significant, in the oxide spallation analysis.
- Analysis regarding fuel plate performance and its impact on potential failure modes. This should be done with the most pertinent tools, including multiphysics codes where applicable, to evaluate effect of fuel swelling, material properties evolution, fuel creep, thermal conductivity degradation, and other pertinent and predictable fuel performance phenomena.

4.3 Design and Engineering Process Recommendations

A Process Focused on Risk and Failure Modes

The DDE-MURR campaign is considered an engineering scale demonstration test with significant maturity in the technology life cycle. As such, this campaign constitutes less of a “scientific” interest compared to other GTRI-FD irradiations (e.g. RERTR and AFIP series tests) where fuel is often driven to extreme conditions in order to amplify fuel performance phenomena. Rather, DDE-MURR constitutes a demonstration of engineering design scale performance. As a result, the campaign is likely to have lower probability of scientific-scale type failures, but constitutes a large consequence of failure in precluding regulatory approval of reactor conversion.

Consequently, the campaign should be treated as a high risk effort and handled appropriately. This should include design efforts strongly focused on failure modes in regards to concept generation, analysis, evaluations, design reviews, and other pertinent arenas. Furthermore, project management strategies should work to this end through use of campaign-focused risk management plans and an emphasis on stable funding in order to foster design team continuity and propensity to identify failure modes. In this regard, stable “modest” funding should be considered superior to sporadic “aggressive” funding.

A Process Founded in Structured Design-Phases

In the context of the original assumptions, the DDE-NBSR design exhibits a high level of detail for a “conceptual” design. However, some of the original schedule assumptions (which were intrinsically linked to the selected irradiation location) have already been invalidated and the experiment’s key inputs were based on scoping assumptions rather than official Critical Characteristic submittals. Combined with the possibilities of a redefined base fuel design (driven largely by emergent PIE results), the potential for design modifications of the proposed final LEU conversion element, and prospective design modifications based on forthcoming fabrication studies, it is apparent that the existing DDE-NBSR design outputs (i.e. those summarized in this report) should be evaluated and updated for their applicability at such time as the design work is recommenced. This should include:

- Final approval of the rev 0 Functional and Operational Requirements document with the Critical Characteristics incorporated
- Re-evaluation of the decision to use the ATR CFT in the context of future schedule constraints and key risks to the campaign. For example, the ATR North East Flux Trap (NEFT) and other reactors such as OSIRIS or BR2 may pose benefits to the design, but were originally excluded from consideration due to schedule assumptions [11] which are now invalid. Performing of this evaluation prior to the ATR 2015 CIC would also pose some benefit in terms of determining if and when the ATR CFT will be used, which may have some bearing on the post-CIC ATR loop configuration and potential cost savings for experiment installation. This decision should be made in the context of the trade-offs for each option. For example, the NEFT would allow for more-direct adjustability of experiment power while giving give more prototypic interior plate powers and edge peaking L2AR's by accommodating larger fuel plate arrays, but could potentially complicate the CGP common cradle fixturing as the NEFT, unlike the CFT, has a larger diameter than Medium I positions.
- If the ATR CFT is still found to be the preferred option, then the following should be considered:
    - Longer irradiation option (~7-8 cycles) with more prototypic fission rates. Such an option could conceivably reduce technical risk while posing some promise for a 20% enriched option in order to facilitate fabrication. This should be examined in the context of the fission rate, heat flux, and fission density information in the final critical characteristics submittal. Activities to compile the critical characteristics submittal should give particular attention to the fission density target in this regard with detailed depletion calculations for the projected LEU NBSR fuel cycle. The ultimate fission density target should account for ^{235}U captures without fission, contribution from ^{239}Pu fission, and local "burn-out" of the highly peaked edge regions with eventual redistribution of fissions towards the interior fuel meat.
    - Use of fixed shims in ATR H-positions (or other modular features of nuclear significance) which may be used to adjust the CFT neutron flux in order to compensate for uncertainties in future lobe powers or belated changes of such as determined by other irradiation users.
- Updating and final approval of rev 0 Experiment Control Plan
- Producing a detailed DDE-NBSR schedule, project execution plan, and other deliverables needed for project management
- Revising, if needed, of applicable engineering deliverables (analyses, drawings, QLD's, etc.)
- Performance of a conceptual design evaluation with key stakeholders from the GTRI-Convert program to ensure that the concept is appropriately engineered to meet the campaign objectives

Completion of the conceptual design work should give way to completion of the more detailed preliminary work per the experiment control plan and should include the following recommendations:

- Completion and approval of the Technical and Functional Requirements with updating of the F&OR as needed
- Flow testing of a physical mock-up irradiation assembly combined with FSI structural analysis to experimentally determine flowrates and potential for flow induced failure modes

- Functional handling and operation of a physical mock-up irradiation assembly in the ATR canal and, if needed, ATR vessel. These should verify that the assembly can be manipulated underwater through all expected handling evolutions including characterization in the channel gap probe.
- Performance of the full suite of safety analyses required for physics, thermal, structural, and oxide growth/spallation calculations
- Receipt of the official Technical Tolerances submittal and finalization of the coupon and element specifications
- Initiation of PIE design activities
- Evaluation of the emerging design in the context of potential failure modes and effects
- Performance of a preliminary design evaluation with key stakeholders from the GTRI-Convert program to ensure that the concept is appropriately engineered to meet the campaign objectives

Completion of the preliminary design work should give way to completion of final design per the experiment control plan and should include the following recommendations:

- Finalization of all engineering deliverables
- Compilation and approval of the Experiment Safety Assurance Package
- Fabrication of the final DDE-NBSR irradiation vehicle hardware, fuel element, and ancillary tools/fixtures with the appropriate quality assurance measure and incorporation of any as-built features, if needed, into the original engineering deliverables
- Performance of a final design evaluation with key stakeholders from the GTRI-Convert program to ensure that the concept is appropriately engineered to meet the campaign objectives
- Performance of a final design review by INL experiment engineering personnel as the design verification necessary to close-out the overall design control package

5. Provisions for Future Work

5.1 Design Team

The following personnel made up the DDE-NBSR conceptual design team:

- Bruce Nielson – Experiment Manager
- Nicolas Woolstenhulme – Irradiation Testing Lead and Specification Author
- Brian Durtschi – Lead Engineer and Hardware Designer
- Chris Glass – Physics Analyst
- Glenn Roth – Thermal Analyst
- Tom Clark – Structural Analyst

5.2 Document and Hardware Location

The following items were produced during this design campaign and, at the time this report was prepared, were stored as seen in Table 5.

Table 5: Document and Hardware Location

Item	Status	Location
DDE Design Status Report Nov 2011	Final rev 0	INL external report INL/EXT-11-23991
Drawings	Draft	Appendix D of this report DDE design file path (\\fserob1\projects\rertr\Design Demonstration Experiments\DDE-NBSR) CAD and solid model files reside with ATR Experiment Drafting and are stored on their server
Experiment Control Plan	Draft	DDE design file path (\\fserob1\projects\rertr\Design Demonstration Experiments\DDE-NBSR)
Fuel Specifications	Draft, awaiting Technical Tolerances submittal and Preliminary Design work	Appendices B and C of this report DDE design file path (\\fserob1\projects\rertr\Design Demonstration Experiments\DDE-NBSR)
Coupon Specification Composition Worksheet	In-process worksheet "Origin of DDE Coupon Spec Limits.xlsx"	DDE design file path (\\fserob1\projects\rertr\Design Demonstration Experiments\DDE-NBSR)
F&OR	Draft, awaiting Critical Characteristics	Appendix A of this report DDE design file path (\\fserob1\projects\rertr\Design Demonstration Experiments\DDE-NBSR)
T&FR	Draft	DDE design file path (\\fserob1\projects\rertr\Design Demonstration Experiments\DDE-NBSR)
EJ	Initiated EJ-7.9.15-145	Will reside with ATR configuration control coordinator until it is either cancelled or resumed
QLD's	MSA-000198 Specifications for DDE's ATR Comp-000074 AFIP and DDE Non-Fueled Hardware	INL's QLD system, likely to require revision up resumption of DDE work (must revise every two years [33])
Critical Characteristics Submittal	Not yet received Requested information outlined in experiment control plan Requested information further	n/a

	outlined in F&OR	
Technical Tolerances Submittal	Not yet received Requested information outlined in experiment control plan	n/a
Partially complete irradiation vehicle mock-up components and materials	Fabrication started per NHL WR-12-333, suspended before completion	Useable components and materials stored as shop stock at INL North Holmes Laboratory
Prototyping Mock-up Drawings	Final rev 0	Available on INL EDMS dwg numbers 604121, 604122, 604123, 604124, 604125, 604126, and 604127
Rapid Prototype Mock-up	Some items produced	Physical item stored in Brian Durtschi's office

6. References

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[11] N.E. Woolstenhulme, R.B. Nielson, "DDE Design Status Report Nov 2011", November 2011, INL/EXT-11-23991.

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[16] INL Document LWP-13016, "The Graded Approach to Research and Development Product Assurance", rev 3, 10/14/2011.

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[21] INL Document ECAR-2045, “Thermal Analysis of the Conceptual Design for the NBSR DDE Experiment”, rev 0, September 2012.
[22] INL Document ECAR-2061, “Structural Evaluation of the DDE-NBSR Test Train Conceptual Design”, rev 0, September 2012.
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[33] INL Document LWP-13014, “Determining Quality Levels”, rev 5, 12/14/2011.

Appendix A (Draft F&OR)

Document ID: FOR-117
Revision ID: 0 (DRAFT)
Effective Date: XX/XX/XX

Functional and Operational Requirements

DDE-NBSR Irradiation in the ATR

Idaho National Laboratory

The INL is a U.S. Department of Energy National Laboratory operated by Battelle Energy Alliance.

CONTENTS

1. INTRODUCTION

1.1 Description of Engineering Task

This engineering task will facilitate maturation of Low Enriched Uranium (LEU) fuel technology in order to enable conversion of High Power Research Reactors. To enable conversion of the national Bureau of Standards Reactor (NBSR), whose licensing basis restricts them from testing lead test elements of its LEU fuel element design [1], a Design Demonstration Experiment (DDE) will be irradiated elsewhere using prototypic fuel plate geometries under prototypic conditions (i.e. “end use application” in a “design environment” [2]) in lieu of the lead test element methodology. NBSR intends to convert using the Base Monolithic Design which consists of uranium-10 wt% molybdenum alloy (U-10Mo) in the form of a monolithic foil, with thin zirconium interlayers, clad in aluminum by hot isostatic press as seen in Figure 1. [3] [4] [5]

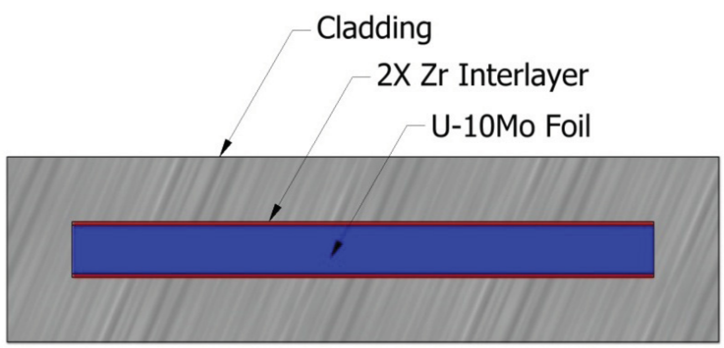


Figure 1: Base Monolithic Design

1.2 Description of the End-Use for the Engineered Item or Activity

The following list constitutes the core goals for the DDE campaign:

- Confirm Performance under stringent prototypic parameters (e.g. heat flux, fission density)
- Show Resistance to worrisome failure modes (e.g. fission gradients, thin-clad structural stability)
- Demonstrate Fabrication by producing the plates/elements as demonstration products [6]
- Give Confidence in the LEU fuel design prior to conversion

This design is intended for irradiation in the Advanced Test Reactor (ATR) and channel gap measurements in the ATR spent fuel storage canal area (hereafter referred to as the canal). The majority of the scientific information gathered is planned to occur in Post Irradiation Examination (PIE) activities at the Hot Fuel Examiniation Facility (HFEF).

2. OVERVIEW

2.1 Ownership of the F&OR

This F&OR is owned by the Irradiation Testing Lead for the Global Threat Reduction Initiative-Convert (GTRI-Convert) Fuel Development (FD) program. The GTRI-Convert program experiment working group is also responsible for identification of the requirements found in this document.

2.2 End-User of Engineered Item or Activity

End users of this design will include:

- Fuel Fabrication Capability (FFC) pillar fabrication group
- FD characterization group
- PIE group and HFEF operations
- ATR experiment design and analysis group
- ATR experiment engineering and canal operations
- In-canal channel gap probe user team
- NBSR stakeholders (who will submit the final data to the Nuclear Regulatory Commission as part of the licensing request to operate with LEU fuel)

3. ENGINEERING INPUTS

3.1 Functional Requirements

3.1.1 The DDE-NBSR experiment shall be designed to irradiate fuel specimens which include prototypic NBSR LEU fuel plate geometry under representative irradiation conditions as defined in the DDE-NBSR experiment critical characteristics in Appendix A.

3.1.2 The DDE-NBSR experiment shall be designed with features which enable irradiation in ATR Center Flux Trap (CFT) for several irradiation cycles, but shall be removable for high power cycles (e.g. PALM).

3.1.3 The DDE-NBSR experiment shall be designed with fuel plate coolant channel gaps which can be characterized via the in-canal channel gap probe.

3.1.4 The DDE-NBSR experiment should be designed to accommodate dosimeters to enable cycle to cycle as-run benchmarking of burn-up analysis.

3.1.5 The DDE-NBSR experiment should be designed so that the power within the experiment is somewhat adjustable to compensate for the CFT's lack of direct adjustability and potential for other flux trap users to vary target power levels. In order to accomplish this, components of nuclear significance, which may be removed or installed during outages, may be used as part of the overall experiment configuration (e.g. H-positions may be considered).

3.1.6 The DDE-NBSR experiment shall be designed to be easily removable and re-installable in CFT during routine outages.

3.1.7 The DDE-NBSR experiment shall fit within existing fresh and spent fuel shipping containers.

3.1.8 The DDE-NBSR experiment shall be designed to be characterized by the ATR in-canal channel gap probe before irradiation, between each cycle (during outage) and after irradiation. The channel probe has two "cradles"; one will be dedicated to ATR fuel element geometry. The remaining cradle must accommodate both the DDE-MITR and DDE-NBSR experiments. Since the channel probe will likely need to be removed from the canal for modification to accommodate the DDE's it is desirable to remove the channel probe from the canal only once for the modifications needed for both DDE's.

3.1.9 The DDE-NBSR experiment shall be designed to fit in the ATR CFT, which will likely require removal of any loop facilities, and shall account for the interfaces and geometries which will result (e.g. chopped in-pile tube, lower CFT support).

3.1.10 The DDE-NBSR experiment shall be designed to mitigate the risk of fuel plate damage (e.g. scratches).

3.1.11 DDE-NBSR buckets, canisters, and other extra-reactor handling equipment shall be designed to allow decay heat removal via low-impedance free-convection pathways.

3.1.12 The DDE-NBSR element side plates of the experiment must enable the fabricator (i.e. Babcock and Wilcox) to "swage" the fuel plates.

3.2 Operational Requirements

3.2.1 The DDE-NBSR experiment shall be designed so that moving part interfaces resist binding, galling, galvanic corrosion, and other phenomena which may cause the assembly to be inoperable.

3.2.2 The DDE-NBSR experiment shall be designed so that features of nuclear significance are axial symmetric about the ATR center plane so that axial perturbations of the ATR flux profile are minimal.

3.2.3 The DDE-NBSR experiment shall be designed so that it may be fixtured within the ATR-Critical facility for low power physics measurements.

3.2.4 The DDE-NBSR experiment shall be designed to be disassembled at the HFEF with minimal redesign of PIE equipment and risk of damaging the fuel plate specimens.

3.2.5 The DDE-NBSR experiment shall be designed so that duplicate components can be identified with unique features (e.g. identification markings) that are present in locations where the risk for damage or obliteration of such features is minimized.

3.2.6 The DDE-NBSR experiment shall be easy to handle remotely and must be very robust to mitigate unintended separation of components in the reactor.

3.2.7 All materials shall meet ATR primary coolant system and canal requirements. [7]

3.2.8 The DDE-NBSR experiment shall be designed so that the coolant flow through the whole experiment, including that through the fuel section, annular bypass, and any other cooling paths (e.g. hafnium), combined with quadrant preferential discharge path, do not violate the quadrant-to-quadrant DP requirements (especially those for emergency flow conditions) [8] or "starve" the rest of the reactor (i.e. >77 psi DP through core in 2-pump flow).

3.2.9 The DDE-NBSR experiment shall be designed to retain captivity of and provide adequate cooling (via PCS) to non-fueled components which may include items of significance with regard to nuclear heating (e.g. hafnium).

3.2.10 The DDE-NBSR irradiation test assemblies shall enable adequate cooling of the specimens with "design environment" cooling conditions (i.e. ATR primary coolant system 2 pump flow) with those uncertainties assumed for safety analysis.

3.2.11 The DDE-NBSR experiment shall be designed for an ATR in-core service lifetime of at least ## ATR cycles (~50 days each).

3.2.12 The DDE-NBSR experiment shall be designed to allow decay removal adequate to prevent melting of the aluminum cladding in the event that the irradiated assembly is dropped horizontal in water during handling.

3.2.13 The DDE-NBSR experiment shall minimize the use of difficult or high risk welds, especially thin-to-thick section or small throat aluminum welds.

3.2.14 The DDE-NBSR experiment shall be designed to provide structural integrity through use of simple and robust components which remain intact during irradiation/handling and alleviate the risk of damaging the fuel plate specimens.

3.2.15 The DDE-NBSR experiment shall be designed so that the position of the fuel plate specimens/element and all other components remains fixed during reactor operation.

3.2.16 The DDE-NBSR experiment shall be designed so that functional mock-up(s) may be produced during or just following the conceptual design phase in order to perform a “dry run” of all anticipated assembly and handling evolutions. As applicable, lessons learned from these activities shall be incorporated into revised and/or subsequent design documents. These shall include, but are not limited to:

3.2.16.1 Fabrication of mock-up assemblies (e.g. assembly, welding, inspection) using those facilities, tools, and personnel which are expected to produce the actual assemblies

3.2.16.2 Mock-up handling in the ATR canal (e.g. specimen extraction, channel gap probe characterization, assembly reconfiguration) using those tools and personnel which are expected to handle the actual assemblies

3.2.17 The DDE-NBSR experiment shall be designed to contain less than 365g U-235. [9]

3.2.18 The DDE-NBSR experiment shall be designed for storage in existing ATR storage racks.

3.2.19 The DDE-NBSR experiment shall be designed for transport in and out of the ATR vessel through the drop chute with handling tools evolutions through the reactor head ports. For the CFT in particular, which must include insertion/extraction through the neck-shim housing, the design shall enable handling tools to “pivot” about lifting interfaces to alleviate bending caused by extreme tool angles.

3.2.20 The DDE-NBSR irradiation test assemblies shall allow for test element fabrication/assembly at the commercial facilities within the fabrication process to be established by the FFC pillar.

3.2.21 The DDE-NBSR irradiation test assemblies shall allow for non-fueled hardware fabrication/assembly at the commercial facilities within the existing capabilities of facilities at the INL complex.

3.2.22 The DDE-NBSR irradiation test assemblies shall be designed so that every item, which may be handled as a single unit, has a handling interface (e.g. handle) which enables expected handling evolution as well as off-normal handling events (e.g. item retrievable after being dropped).

3.2.23 The DDE-NBSR irradiation test assemblies shall be designed so that simple, yet robust, components are used which provide reasonable structure and protection to the fuel plates.

3.2.24 The DDE-NBSR irradiation test assemblies shall be designed so that no more than three canal operators and three canal tools are required concurrently for a given handling evolution (e.g. vessel to canal transport, in-canal examination, reconfiguration, etc.).

3.2.25 The DDE-NBSR irradiation test assemblies shall be designed to facilitate timely accomplishment of outage work so that the specimen extraction, in-canal characterizations, and experiment reconfiguration, for one irradiation assembly, can be accomplishment in one normal working day.

3.2.26 The DDE-NBSR irradiation test assemblies shall be designed with intuitive mechanisms and handling interfaces which are compatible with existing canal tool concepts.

3.3 Owner Specified Technical Requirements

3.3.1 The DDE-NBSR experiment should be designed to minimize the acquisition of additional PIE equipment by accommodating with the existing fabrication and PIE infrastructure at the INL (e.g. machine tools, PIE measurement bench, etc.).

3.3.2 The DDE-NBSR irradiation test assemblies shall be designed to satisfy all nuclear safety requirements and to prohibit operational failure modes. The specific requirements relating to this shall be recorded in a Technical and Functional Requirements (TFR) document.

3.3.3 The DDE-NBSR experiment shall be designed to achieve the desired fission density targets assuming 85% operational efficiency of the ATR (i.e. each cycle is actually 85% of it published length).

3.3.4 The fuel specimen of the DDE-XXXX experiment shall be fabricated as a demonstration process by the commercial fuel fabrication facilities and process.

3.4 Supporting Information

3.4.1 Quality Level of Engineered Item or Activity

Those activities needed to perform this engineering task for which graded application is applicable include:

- Calculations and Analysis – QL# per QLD#######
- Design Control – QL# per QLD#######
- Configuration Management – QL# per QLD#######
- Material Acquisitions – QL# per QLD#######
- Fabrication – QL# per QLD#######

3.4.2 Need for Configuration Management

Configuration management shall be needed for this engineering activity.

3.4.3 Sensitive Information

This engineering activity is not expected to include or produce information of a sensitive nature.

3.4.4 Need for Engineering Change Control

Engineering change control shall be needed for this engineering activity.

3.4.5 Level of Verification Needed

The engineering deliverables associated with this design shall be verified by way of design review per the applicable INL procedure. Additionally, the GTRI-Convert program experiment working group will review the design and ensure that it is adequately engineered to meet the programmatic experiment objectives. These design reviews shall each take place upon completion of the conceptual, preliminary, and final design phases of the DDE-NBSR experimental campaign.

3.4.6 Technical Integrator

The technical integrator is the Experiment Manager for the DDE-NBSR irradiation campaign.

4. REFERENCES

[1] M.K. Meyer and R.B. Nielsen, "Utilization of the Center Flux Trap for Irradiation During Cycles 157A – 160B", draft white paper 11/17/11.

[2] "Applying Quality Assurance Requirements to Research and Development Activities", rev 3, 8/12/2010, INL Document LWP-13016.

[3] N.E. Woolstenhulme, D.M. Wachs, and M.K. Meyer, "Design and Testing of Prototypic Elements Containing Monolithic Fuel", Proceedings of the RERTR-2011 International Conference, Santiago Chile, October 23-27, 2011.

[4] D.M. Wachs, "RERTR Fuel Development and Qualification Plan", rev 5, 07/05/2011, INL external report INL/EXT-05-01017.

[5] A.B. Robinson et al., "Irradiation Performance of U-Mo Alloy Based 'Monolithic' Plate-Type Fuel – Design Selection", INL external report INL/EXT-09-16807, Aug. 2009.

[6] D.E. Burkes, "Overview of the GTRI Fuel Fabrication Capability (FFC) Project", presentation given at High Power Research Reactor Working Group Meeting, Cambridge Massachusetts, July 26-27, 2011.

[7] "Material Practices and Restrictions for ATR PCS and Experiment Loops", SP-10.3.1.13, rev 8, 03/16/2010.

[8] "Emergency Coolant Pumps and CK-A-1-17 and CK-A-1-20 Functional Test", DOP-7.7.13, rev 24, 2/22/12.

[9] INL Document TSR-186, "ATR Complex-ATR Nuclear Safety Basis - Technical Safety Requirements".

APPENDIX A

Critical Characteristics Submittal for DDE-NBSR

____________________________________ ____________________
J. Stevens Date
RC National Technical Lead

____________________________________ ____________________
S. O'Kelly Date
NBSR Director

____________________________________ ____________________
E. Wilson Date
RC Analysis Lead

Introduction

The National Bureau of Standards Reactor (NBSR) is slated for conversion to Low Enriched Uranium (LEU) using a monolithic Uranium Molybdenum (U-Mo) alloy base fuel design which is currently under development by the Fuel Development (FD) pillar of the Agency Global Threat Reduction Initiative Convert (GTRI-Convert) program. The NBSR licensing basis restricts them from testing their own LEU lead test elements. Consequently, a Design Demonstration Experiment campaign (DDE-NBSR) will be performed with irradiation of NBSR prototypic LEU fuel plates/assemblies in the Advanced Test Reactor (ATR) located at the Idaho National Laboratory (INL) in the Center Flux Trap.

As set forth in INL document PLN-4061, the DDE-NBSR campaign will be executed primarily by the FD pillar. Scoping design and feasibility studies have shown that this irradiation campaign can likely achieve the experiment objectives. The FD pillar is ready to enter a formalized engineering process, beginning with conceptual design, and requires further explication of experiment objectives from the Reactor Conversion (RC) pillar of the GTRI-Convert program. This submittal is referred to as the Critical Characteristics of the experiment. The sections below constitute submittal of the requested Critical Characteristics.

APPENDIX A

Nominal Fuel Element Design

Table 1: Nominal Element Characteristics

Plates Per Element	Interior Channel Spacing

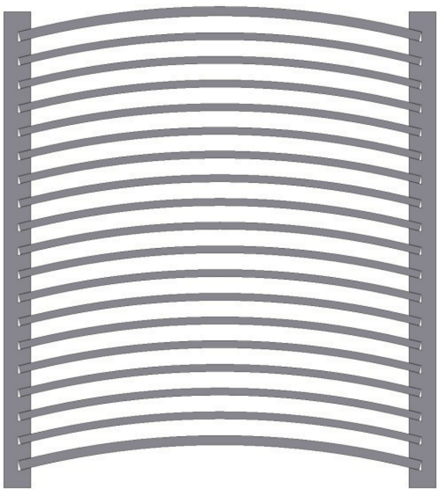


Table 2: Nominal Plate Dimensions

Plate Length	Plate Width	Plate Total Thickness	Plate Radius	Fuel Length	Fuel Width	Fuel Thickness (U-Mo)

Table 3: Plate Constituents

U-Mo Mass	U-235 Mass	Zr Mass	Al-6061 Mass

Appendix A (Draft F&OR)

APPENDIX A

<u>Target Irradiation Conditions</u>

Table 4: Key Irradiation Parameters

Parameter	Value
Coolant Velocity	
Peak Local Heat Flux	
Peak Plate Surface Temp	
Peak Fuel Meat Centerline Temp	
Target Fission Density (total fissions from all isotopes)	

Fuel plate 2D heat flux maps for the peak case were obtained. For the hottest plate, results can be seen in
Table 5. In order to give refined results each fuel meat was analyzed with ## and ## cells in the transverse and axial directions, respectively.

Table 5: Fuel Plate Heat Flux (W/cm2)

Plate Number ##

		Cell Transverse Location (from edge of fuel meat)									
		##	**##**	**##**	**##**	**##**	**##**	**##**	**##**	**##**	**##**
Cell Axial Location (from top of fuel meat)	**##**	##	##	##	##	##	##	##	##	##	##
	##	##	##	##	##	##	##	##	##	##	##
	##	##	##	##	##	##	##	##	##	##	##
	##	##	##	##	##	##	##	##	##	##	##
	##	##	##	##	##	##	##	##	##	##	##
	##	##	##	##	##	##	##	##	##	##	##
	##	##	##	##	##	##	##	##	##	##	##
	##	##	##	##	##	##	##	##	##	##	##
	##	##	##	##	##	##	##	##	##	##	##
	##	##	##	##	##	##	##	##	##	##	##
	##	##	##	##	##	##	##	##	##	##	##
	##	##	##	##	##	##	##	##	##	##	##
	##	##	##	##	##	##	##	##	##	##	##
	##	##	##	##	##	##	##	##	##	##	##
	##	##	##	##	##	##	##	##	##	##	##
	##	##	##	##	##	##	##	##	##	##	##

APPENDIX A

The normal NBSR LEU fuel cycle is expected to consist of ## cycles of approximately ## full power days each. The peak conditions noted above are expected to occur at ##. Beginning and end of life heat fluxes are expected to be ## and ##, respectively. More detailed 2D heat flux maps for time steps of interest can be seen

<u>Discussion</u>

It is acknowledged that the above Critical Characteristics were produced as part of a suite of ongoing analyses, design, and development activities lead by the RC pillar. While these Critical Characteristics may be subject to change, they represent the best known data at this time and are the most appropriate design inputs for proceeding with the conceptual design of DDE-NBSR. Any future changes to the Critical Characteristics will be communicated in follow-on submittals.

Appendix B (Draft Coupon Specification)

Document ID: SPC-1569
Revision ID: 0 (Draft)
Effective Date: TBD

Specification

Specification for U-Mo Coupons for DDE-NBSR

Idaho National Laboratory

The INL is a U.S. Department of Energy National Laboratory operated by Battelle Energy Alliance.

Appendix B (Draft Coupon Specification)

REVISION LOG

Rev.	Date	Affected Pages	Revision Description
0	TBD	All	New Issue.

Appendix B (Draft Coupon Specification)

CONTENTS

1. SUMMARY

This specification defines the requirements for *U-Mo* (see def.) Coupons for use in production of fuel plates for the Design Demonstration Experiment (DDE) for the National Bureau of Standards Reactor (NBSR).

2. APPLICABLE CODES, PROCEDURES, AND REFERENCES

Applicable portions of the following documents as defined herein, form a part of this specification. Where there is a conflict between the document cited and its latest revision, the supplier shall notify the Purchaser of the conflict and use the latest revision in effect unless otherwise directed by the Purchaser.

2.1 Standards and Specifications

ASTM C1233-03	Standard Practice for Determining Equivalent Boron Content of Nuclear Materials
SPC-1315	Specification for DDE-NBSR Fuel Elements

3. TECHNICAL REQUIREMENTS

3.1 Isotopic Composition

The uranium isotopic composition shall be within the limits shown in Table 1.

Table 1: Isotopic Composition

Element	Symbol	Units	Limit
U-232	U-232	µg/gU	≤ 0.002
U-234	U-234	wt%U	≤ 0.330%
U-235	U-235	wt%U	25.00% ±0.50%
U-236	U-236	µg/gU	≤ 4600
Trans-U (Alpha)[1]	TRU	Bq/gU-Mo	≤ 250.0
Fission Products[2]	Gamma	Bq/gU-Mo	≤ 600.0

[1] The “Alpha activity” reflects measured *transuranium* elements to include: Americium 241, Curium 243/244, Neptunium 237, Plutonium 238, and Plutonium 239/240.

[2] Only those isotopes with a mass number less than 200 shall be considered fission products. Fission product activity levels which are false positive due to gamma photopeak interference may be excluded.

3.2 Chemical Composition

The composition of the LEU-Mo material shall be uranium alloyed with molybdenum (nominally 10 wt% Mo). Molybdenum content shall be no less than 9.00% and no greater than 11.00% by weight. Total weight percent uranium shall be reported. Chemical composition and impurities shall be determined on each Lot of material and shall be within the limits in Table 2.

Table 2: Chemical composition and impurities of the alloyed material

Element	Symbol	Units	Limit	EBC Factor
Aluminum	Al	μg/gU-Mo	≤ 150	0.0000
Beryllium	Be	μg/gU-Mo	≤ 10.0	0.0000
Boron	B	μg/gU-Mo	≤ 3.0	1.0000
Cadmium	Cd	μg/gU-Mo	≤ 5.0	0.3172
Calcium	Ca	μg/gU-Mo	≤ 100.0	0.0002
Carbon	C	μg/gU-Mo	≤ 725.0	0.0000
Chromium	Cr	μg/gU-Mo	≤ 50.0	0.0008
Cobalt	Co	μg/gU-Mo	≤ 10.0	0.0089
Copper	Cu	μg/gU-Mo	≤ 50.0	0.0008
Dysprosium	Dy	μg/gU-Mo	≤ 5.0	0.0818
Erbium	Er	μg/gU-Mo	≤ 100.0	0.0135
Europium	Eu	μg/gU-Mo	≤ 2.0	0.4250
Gadolinium	Gd	μg/gU-Mo	≤ 1.0	4.3991
Iron	Fe	μg/gU-Mo	≤ 250.0	0.0006
Lead	Pb	μg/gU-Mo	≤ 10.0	0.0000
Lithium	Li	μg/gU-Mo	≤ 10.0	0.1439
Magnesium	Mg	μg/gU-Mo	≤ 50.0	0.0000
Manganese	Mn	μg/gU-Mo	≤ 50.0	0.0034
Nickel	Ni	μg/gU-Mo	≤ 100.0	0.0011
Phosphorus	P	μg/gU-Mo	≤ 100.0	0.0000
Samarium	Sm	μg/gU-Mo	≤ 3.0	0.5336
Silicon	Si	μg/gU-Mo	≤ 250.0	0.0000
Sodium	Na	μg/gU-Mo	≤ 25.0	0.0003
Tin	Sn	μg/gU-Mo	≤ 100.0	0.0000
Tungsten	W	μg/gU-Mo	≤ 100.0	0.0014
Vanadium	V	μg/gU-Mo	≤ 30.0	0.0014
Zirconium	Zr	μg/gU-Mo	≤ 250.0	0.0000
Total Impurities [1]		μg/gU-Mo	≤ 1500	
Equivalent Boron Content [2, 3]		μg/gU-Mo	≤ 10.0	

[1] Total Impurities includes all unlisted elements; remainder shall be U-Mo.

[2] EBC Factors are taken from ASTM C1233-03, "Standard Practice for Determining Equivalent Boron Contents of Nuclear Materials." EBC calculation will include: Boron, Cadmium, Dysprosium, Europium, Gadolinium, Lithium, and Samarium. Other EBC factors are provided for information purposes only.

[3] The limit on EBC may restrict some elements to lower values than shown in the table above.

3.3 Equivalent Boron Content

The EBC shall be calculated in accordance with ASTM C1233, “Standard Practice for Determining Equivalent Boron Contents of Nuclear Materials”. The individual μg/gU-Mo impurity limits shall not be exceeded except as allowed in Section 3.4. The total impurities (μg/gU-Mo) and EBC shall not exceed the limits shown in Table 2.

3.4 Out-of-Limits Condition

An out-of-limits condition for Table 2 elements is acceptable for a maximum of two elements not to exceed 10% of the limit established in Table 2 provided the EBC and total impurities limits are not exceeded.

3.5 Product Form

U-Mo shall be provided in the form of a Coupon meeting the dimensional requirements of Figure 1. The dimensions L, W, and T as well as quantity of Coupons will be specified by the Purchaser in a purchase order or similar contractual document.

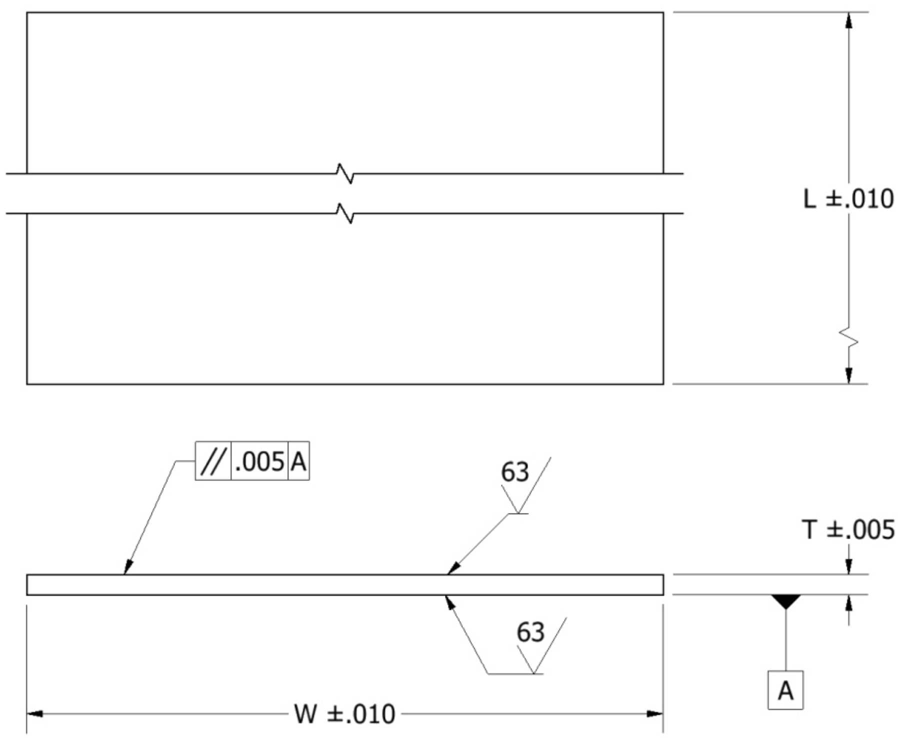


Figure 1: Coupon Dimensional Tolerances

3.6 Defects

Every Coupon shall be visually examined for surface defects. Each coupon surface shall be found free the following:

- Visible inclusions greater than 0.063 in any dimension
- Surface scratches and cracks greater than 0.003 in. in depth or 0.25 in. in length
- Surface pores greater than 0.063 in. in any dimension, except depth, which shall not exceed 0.031 in.

One randomly selected Coupon per Lot shall be examined by radiography and evaluated against the above criteria. Radiography parameters shall produce images of sufficient quality to identify the types of defects and rejection criteria as above.

3.7 Cleanliness

There shall be no volatiles, oil, grease, particulate, or other foreign materials on the surfaces of finished Coupons.

4. QUALITY ASSURANCE

The supplier shall document, implement, and maintain a quality program in compliance with Title 10, Code of Federal Regulations, Part 830.120, “Quality Assurance”.

4.1 Supplier Responsibility

The supplier shall be responsible for performing all tests and inspections required for the product form provided prior to shipment of the material. The results of all tests shall be recorded as quantitative data and furnished to the Fabricator as stipulated by Section 6.1.1.

4.2 Sampling

Each Lot of U-Mo shall be sampled and tested in accordance with the requirements of this specification and a purchaser approved sampling plan.

4.3 Acceptance Tests

The following tests shall be conducted on all Lots of U-Mo.

4.3.1 Isotopic Composition

The isotopic composition of each Lot of uranium alloy shall be determined by mass spectrographic analysis or equivalent method. The isotopic concentration shall be in conformance with Section 3.1. Isotopic composition of total uranium content shall be calculated by difference or equivalent method.

4.3.2 Chemical Composition

The chemical composition and impurities shall be determined on each Lot of material. The results shall be in conformance with Section 0.

4.4 Source Inspection

The supplier shall facilitate access to Purchaser-assigned quality assurance and/or technical representative(s) sufficient to provide the information necessary to verify and accept the product per the requirements of this specification.

5. PACKAGING AND SHIPPING

5.1 Packaging

Packaging and shipping containers shall comply with DOE and NRC Regulations in effect at the time of delivery.

6. NOTES

6.1 Definitions

6.1.1 *Certification Package*. A written and signed document from the supplier which certifies that the material described thereon complies with this specification and provides results of tests performed

6.1.2 *Coupon*. A thick rectangular product form intended to be reduced to final foil thickness by rolling

6.1.3 *Fabricator*. The primary entity selected by the Purchaser to use the U-Mo coupons to fabricate fuel plates

6.1.4 *Lot*. A group of pieces handled as a unit or material traceable to a common processing step

6.1.5 *Purchaser*. Idaho National Laboratory

6.1.6 *Supplier*. The primary entity selected by the Purchaser to supply the U-Mo coupons

6.1.7 *U-Mo*. A binary alloy comprised of uranium and molybdenum

6.2 Quality Verification Test Results

A Certification Package shall be provided for each shipment or group of shipments. Certifications shall be signed by project quality engineer or equivalent. Three (3) copies of the Certified Test Results (see Section 4.1) and certification as required above shall be provided to the fuel plate fabricator and one (1) copy to the Purchaser at time of shipment. Also one (1) copy should accompany the shipment or be provided to the receiver at time of shipment. The Certification Package shall include the following:

6.2.1 A statement that the material meets the requirements contained in this specification

6.2.2 A list of Coupon identification numbers and total Coupon, U-Mo alloy, uranium, and isotope masses

Appendix C (Draft Element Specification)

Document ID: SPC-1315
Revision ID: 0
Effective Date: TBD

Specification

Specification for DDE-NBSR Fuel Elements

Idaho National Laboratory

The INL is a U.S. Department of Energy National Laboratory operated by Battelle Energy Alliance.

REVISION LOG

Rev.	Date	Affected Pages	Revision Description
0	TBD	All	New Issue

CONTENTS

1. SCOPE

1.1 Introduction

This Specification details the materials, components, testing, inspection, and Quality Control requirements for the fabrication of Fuel Elements for the Design Demonstration Experiment (DDE) representing the National Bureau of Standards Reactor (NBSR) low enriched uranium fuel design. DDE-NBSR Fuel Elements are designed for irradiation in the Advanced Test Reactor (ATR) at the Idaho National Laboratory (INL). If there appears to be any conflict between parts of this Specification, such as its referenced drawings and standards, the Purchaser and Stakeholder shall be notified for resolution.

1.2 Definitions

For the purpose of this Specification, the following terms are identified:

1.2.1 *Cladding*. The aluminum bonded to the Fuel Meat

1.2.2 *Controlled Work Area*. A work area to which access of personnel, tools, and materials is limited and physically controlled. Temporary enclosures may be used where adjacent activities produce contamination which is detrimental to the job

1.2.3 *Coupon.* A thick rectangular product form intended to be reduced to final foil thickness by rolling

1.2.4 *Development*. A determination of processes, equipment, and parameters required to produce a product in compliance with this Specification

1.2.5 *Failure*. A condition where the Manufacturing Process appears to be out of control or damage to Fuel Plates or Fuel Elements or breakdown of equipment causes delays and/or excessive cost

1.2.6 *Fuel Meat*. The uranium bearing region of each Fuel Plate

1.2.7 *Fuel Element*. An assembly of Fuel Plates and hardware components

1.2.8 *Fuel Plate*. The Fuel Meat complete with aluminum Cladding

1.2.9 *Hot Isostatic Press (HIP)*. Fabrication process which bonds Cladding to Monolithic foils by subjecting un-bonded Fuel Plate materials to a high pressure and temperature

1.2.10 *In-Process Controls*. Inspection and tests made during Production to ensure that the Manufacturing processes, equipment, and personnel are producing a product meeting specified requirements

1.2.11 *Interlayer.* Thin zirconium layer applied to the surface of Monolithic foils

1.2.12 *Lot*. A group of pieces handled as a unit or material traceable to a common processing step

1.2.13 *Manufacturing*. All fabrication, assembly, test, inspection, and Quality Control processes

1.2.14 *Monolithic.* Fuel type composed of a metallic alloy in the form of a foil.

1.2.15 *Production*. That phase of the program, following Qualification, during which the product is in Manufacture

1.2.16 *Purchaser*. Idaho National Laboratory

1.2.17 *Qualification*. A documented demonstration approved by the Purchaser that the Manufacturing processes, equipment, and personnel can produce a product in compliance with this Specification

1.2.18 *Quality Control*. The sampling plans, inspections, and tests required during Production to assure that the product is in compliance with this Specification

1.2.19 *Rejection*. Refusal of acceptance of materials, parts, components, or assembly products as part of the contract requirements of this program because of noncompliance with this Specification

1.2.20 *Requalification*. A demonstration that a single, or group of Manufacturing processes, equipment, and personnel can produce a product in compliance with this Specification after the original Qualification has been completed and becomes invalid

1.2.21 *Specification*. All parts and attachments of this document, its references, drawings, and standards, as may be modified from time to time by contractual document

1.2.22 *Stakeholder*. National Bureau of Standards Reactor

1.2.23 *Subtier Supplier*. Any vendor selected by the Supplier to furnish materials, services, or manufactured parts to the Supplier

1.2.24 *Supplier*. The primary vendor selected by INL to Manufacture the product

1.2.25 *U-Mo.* A binary alloy comprised of uranium and molybdenum

2. APPLICABLE DOCUMENTS

2.1 Applicable Standards

The applicable portions of the following documents, as defined herein, form a part of this Specification. Where there is a conflict between the documents cited and the latest revision, thereof, the Supplier shall notify the Purchaser of the conflict and use the latest revision unless otherwise directed by the Purchaser.

2.1.1 National Codes and Standards

MIL-C-45662	Calibration System Requirements
RDT F6-2T	Welding of Reactor Core Components and Test Assemblies (Section 1, 2, 3, and 6)

2.1.2 American Society for Testing and Materials (ASTM)

ASTM E 1742	Standard Practice for Radiograph Examination
ASTM E 8	Methods of Tension Testing of Metallic Materials
ASTM E 29-93a	Recommended Practice for Indicating Which Places of Figures are to be Considered Significant in Specified Limiting Values

2.1.3 American Welding Society

AWS D1.6	Structural Welding Code-Stainless Steel

2.1.4 American National Standards Institute (ANSI)

ANSI B46.1	Surface Texture
ANSI Y14.5	Dimensioning and Tolerancing for Engineering Drawings

2.1.5 American Society of Mechanical Engineers (ASME)

ASME	Boiler and Pressure Vessel Code Section V
ASME NQA-1	Quality Assurance Requirements for Nuclear Facility Applications

2.1.6 Idaho National Laboratory

STD-7022A	Cleanliness Acceptance Levels for Nuclear or Non-Nuclear Service Components
SPC-1569	Specification for U-Mo Coupons for DDE-NBSR

2.1.7 American Society for Nondestructive Test (ASNT)

SNT-TC-1A	American Society For Nondestructive Testing (ASNT) Recommended Practice

2.1.1 Drawings (INL)

603876	DDE-NBSR Fuel Element Assembly
603877	DDE-NBSR Fuel Element Details
603878	DDE-NBSR Fuel Plate

3. REQUIREMENTS

3.1 Records and Reports

3.1.1 Two (2) copies of the following data and records shall be supplied to the Purchaser for review and approval prior to fabrication of Fuel Elements.

One (1) information copy shall be supplied to the Stakeholder by the Supplier.

3.1.1.1 All shop drawings of Fuel Element components and assemblies to be used in the fabrication of Fuel Elements

3.1.1.2 Integrated Manufacturing and Inspection Test Plan, submittal of Supplier route cards, operation procedures, drawings, and flow sheets may fulfill this requirement

3.1.1.3 A detailed description as to the manner by which the Supplier proposes to assign Fuel Plate U-235 content, included in the description shall be sampling, analytical, and Quality Control procedures; a statement as to the estimated absolute accuracy of the assigned Fuel Plate and Fuel Element U-235 content

3.1.1.4 Qualification Package for Fuel Plate fabrication

3.1.2 Concurrent with or prior to the shipment of each Fuel Element the Supplier shall provide the Purchaser with the items in Section 6 of this Specification.

3.1.3 Two (2) copies of the following reports are required by this Specification:

3.1.3.1 <u>Monthly Reports</u>: A monthly report using Line of Balance, Program Evaluation and Review Technique (PERT), or similar reporting techniques which details program progress against a previously submitted schedule shall be provided by the Supplier to the Purchaser and Stakeholder by the fifteenth (15^{th}) working day of each month.

3.1.3.2 <u>Failure Notification</u>: During Production, complete records shall be kept by the Supplier. In the event of a Failure, the time, nature, description, corrective action taken, and proposed further corrective action shall be reported to the Purchaser within five (5) working days after such Failure. An information copy shall be sent to the Stakeholder when process Failures are involved.

3.2 Manufacturing Procedures

All changes and modifications to programs, processes, procedures to be used to Manufacture the product shall be submitted to the Purchaser for review and approval prior to use. Information copies shall be provided to the Stakeholder. These shall include:

3.2.1 Supplier's Specifications for all materials used

3.2.2 Identification of Subtier Suppliers

3.2.3 Complete Development program, including material, process, equipment, and test procedures, Supplier submittal of the Qualification data package may fulfill this requirement

3.2.4 All fabrication, assembly, cleaning, surface treating, handling, and demonstration procedures

3.2.5 All test, inspection, Production, and Quality Control procedures, including all nondestructive tests and standards

3.2.6 In-Process Controls, sampling programs, and procedures

3.2.7 Quality Control sampling program and procedures

3.2.8 All rework or repair programs and procedures

3.2.9 All final inspection, washing, packaging, storage, and shipping procedures

3.2.10 Manufacturing plan and inspection procedure for Fuel Plate and Fuel Element fabrication

3.2.11 The Supplier shall prepare and maintain written procedures also for radiograph test, ultrasonic test, visual examination, and personnel certification

3.3 Quality Assurance

The Supplier shall document, implement, and maintain a quality system in compliance with ASME NQA-1. Measurement equipment used for tests and inspection required in this section and in Section 5 shall be calibrated in conformance with Mil-C-45652. A description of the Quality Assurance Program and the procedures to maintain adequate control and quality shall be furnished to the Purchaser.

The Supplier shall permit the Purchaser to conduct pre-award and continuing evaluation of the Supplier's quality system. The Supplier shall be subject to Source Inspection by the Purchaser at the Supplier's facility and also at the

Subtier Supplier's facility if deemed necessary. The Purchaser will identify hold points to the Supplier to be witnessed by the Purchaser's representative. The Purchaser's source inspection does not constitute final acceptance of the items. A Quality Supplier Release, which is approved by the source inspector, shall be required before shipment to the facility designated by the Purchaser.

Personnel performing NDE examinations, specifically radiographic, ultrasonic, and visual shall be certified to American Society for Nondestructive Testing (ASNT) Number SNT-TC-1A and certification documentation shall be made available to the purchaser.

The Supplier is required to qualify the processes or portions of the process, or be exempt from same by written approval of the Purchaser. Only materials which comply with this Specification shall be used. Fuel Plate Qualification shall be satisfied by the fabrication of a minimum of two (2) Lots of consecutively produced Fuel Plates having a yield of at least 65% acceptable Fuel Plates which meet the requirements of this Specification. The Lot size shall be determined by an agreement between the Purchaser and Supplier.

Fuel plates made prior to and during qualification runs that fail to meet the 65% yield requirements shall not be used in fabricating Fuel Elements without prior approval of the purchaser.

3.3.1 Operator Qualification: Operator Qualification shall be accomplished via an approved Supplier Internal Qualification program for the following operations:

3.3.1.1 Swaging

3.3.1.2 Welding

3.3.1.3 Final machining

In addition to the operations specified above, the Supplier shall also show evidence of the training and competency of those individuals who perform any of the following Fuel Element fabrication and inspection activities:

3.3.1.4 HIP pack assembly and preparation

3.3.1.5 Fuel Plate, Fuel Element, and component cleaning

3.3.1.6 Dimensional inspection of Fuel Plates, Fuel Elements, and subcomponents

3.3.1.7 Visual inspection of the Fuel Plates, Fuel Elements, subcomponents, and bend test specimens

3.3.1.8 Coolant channel gap dimensioning or probing

3.3.1.9 Radiography and inspection of Fuel Plate radiographs

3.3.1.10 Ultrasonic testing

3.3.1.11 Eddy current testing

The individuals performing these operations shall have specific requirements imposed on them that will demonstrate their knowledge and ability to perform their respective assignments. Documented evidence of the training of those individuals shall be maintained and shall be made available to the Purchaser upon request.

3.3.2 In-Process Controls: The Supplier shall establish a process control program whereby checks are made on the Fuel Plate Manufacturing processes, operational procedures, intermediate product characteristics, and equipment to demonstrate process stability during Production is at least equal to that demonstrated during Qualification. These In-Process Controls shall monitor, as a minimum, the following fuel plate characteristics:

3.3.2.1 Fuel Homogeneity

3.3.2.2 Fuel Configuration

3.3.2.3 Cladding Thickness

3.3.2.4 Internal defects and bond integrity

3.3.2.5 Surface finish and defects

3.3.2.6 Cleanliness

3.3.2.7 Dimensional

3.3.2.8 Swage joint pull tests

3.3.3 Requalification: The Supplier shall notify the Purchaser of any proposed process change. A changed process may not be used in Production until the Supplier has submitted the results and data of the Requalification effort to the Purchaser and received written approval to use the changed process in Production. The Supplier may be exempt from Requalification if the Supplier can demonstrate to the Purchaser by proof test or engineering explanation, and receives written approval from the Purchaser, that the proposed process change will not degrade the quality of the product.

3.4 Product Requirements

3.4.1 Fuel Meat: Fuel Meats shall be U-Mo Monolithic foils fabricated from U-Mo Coupons furnished per SPC-1569. U-Mo Monolithic foils shall have zirconium Interlayers bonded to the largest surfaces for which the nominal thickness is 0.001 inch each. Zirconium materials shall be at least 99.5% pure (metals basis excluding hafnium) with no greater than 100ppm hafnium impurities. Zirconium materials shall be purchased with vendor certifications and shall be verified by independent laboratory analysis. During Qualification a minimum of two (2) randomly selected Monolithic foils shall be examined for Interlayer thickness per section 3.4.1.1. During Production a minimum of one (1) randomly selected Monolithic foil per 100 shall be examined for Interlayer thickness per section 3.4.1.1.

3.4.1.1 Interlayer Thickness: At least four (4) microscopic examinations per foil shall be evaluated for Interlayer thickness. Each side of the foil shall be represented by at least one (1) sample as in Figure 1. Samples shall be taken from those portions of the foil that are removed during final sizing. Each sample shall be sectioned, polished, and dimensional measurements shall be obtained at 50X minimum magnification. At least ten (10) thickness measurements shall be obtained for each of the two (2) Interlayers on each of the four (4) samples. The average of each set of ten (10) readings shall not be less than 0.0005 inch.

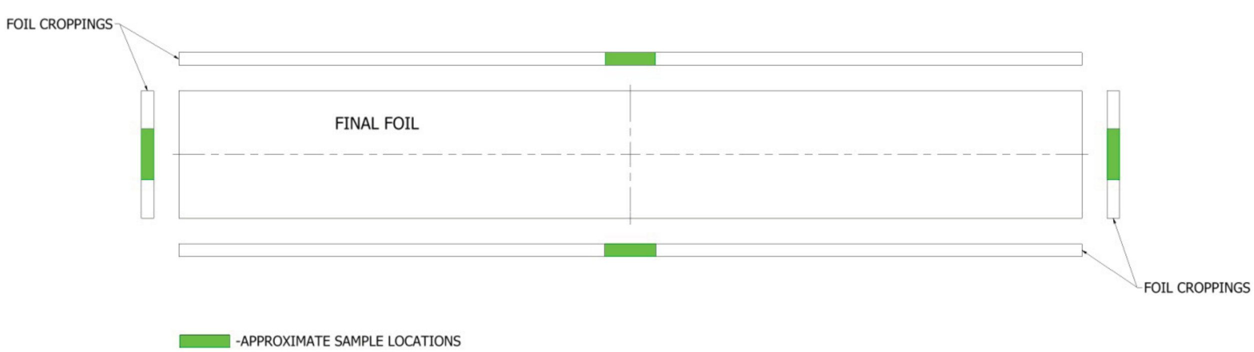


Figure 1: Foil Sample Locations

3.4.2 Fuel Plates

Fuel Loading: Each Fuel Plate shall contain 14.25 ± 0.28 gram U-235. Requirements for fuel loading shall be established in accordance with Section 3.1.1.3 by the Supplier subject to the approval of the Purchaser.

3.4.2.1 Requirements for Radiography of Fuel Plates: A procedure shall be written by the Supplier to specify the details for achieving acceptable Fuel Plate radiographs. The procedure shall include the requirements given in this Specification and shall be approved by the Purchaser.

The voltage shall be at least 100 k.v.p with focal spot size of 5mm maximum. The distance between the focal point and the Fuel Plate shall be at least twice the length of the Fuel Plate. The focal point shall be centered laterally and longitudinally over the Fuel Plate or group of Fuel Plates. Any method(s) used to mitigate and/or correct for undercutting effects at Fuel Meat edges shall be documented in the procedure.

The image outline shall be clear and sharp; the film shall be free of runs, streaks, scratches, blurs, and cassette defects that will affect the area covered by the Fuel Plates.

Film density for fuel homogeneity radiographs, as read over the Fuel Meat region, shall provide densitometer readings of between 1.0 and 4.0.

Density standard(s) shall be exposed simultaneously with each Fuel Plate.

The film shall be an extreme sensitivity, extra fine grain, high contrast, double emulsion, industrial X-ray type, (Kodak type M or equal) which is acceptable to the Purchaser. Development of the film shall be in accordance with the manufacturer's recommendation.

A system of identification of the film shall be provided by the Supplier which shall show as a minimum:

3.4.2.1.1 Fuel Plate Lot number

3.4.2.1.2 Fuel Plate serial number

3.4.2.1.3 Orientation of density standard

3.4.2.1.4 Density standard identification

3.4.2.1.5 Date of radiography

3.4.2.2 Fuel Homogeneity: Density of the Fuel Meat per an 0.080 inch diameter Fuel Meat area shall not exceed the limit of +27% as compared to a density standard at any location in the Fuel Meat.

Average density within a 0.080 inch x 1.0 inch band along the plate shall not exceed the limit of +12% as compared to a density standard at any location in the Fuel Meat.

3.4.2.3 Fuel Configuration: The outline of the Fuel Meat shall be within the largest and smallest areas as defined by dwg 603878 dimensions and their respective tolerances.

Compliance with Fuel Meat configuration requirements shall be by visual inspection of Fuel Plate radiographs of all Fuel Plates. Visual radiograph inspections shall be performed on a light table having a light range of 450-600 footcandles at the table surface and the area darkened to give a light range of 5-15 footcandles 18 inches above the light table with radiographic film in place on the table.

3.4.2.4 Cladding Thicknesses: All Fuel Plates shall be evaluated for Cladding thickness by UT and shall have a minimum Cladding thickness of 0.0105 inches.

3.4.2.5 Internal Defects and Bond Integrity: During Qualification all Fuel Plates shall be evaluated for bond integrity by UT and bend testing. During Production all Fuel Plates shall be evaluated for bond integrity by UT and one (1) Fuel Plate per Lot shall be evaluated by bend testing.

Any UT indications of debond, voids, blisters, or delaminations larger than 0.060 inches over the Fuel Meat or 0.120 inches outside the Fuel Meat area shall be cause for Rejection. A maximum of two (2) indications less than 0.060 inches in diameter are allowed in the Fuel Meat area provided they are more than 0.250 inches apart. A maximum of two (2) indications less than 0.120 inches in diameter are allowed in any edge or end clad area, outside the Fuel Meat area, provided they are not any closer than 0.050 inches to the edge or end of the Fuel Plate and no closer together than the major dimension of the largest indication.

Bend test samples shall be the portions of the Fuel Plate assembly adjacent to the final Fuel Plate which are removed from the assembly during final sizing of the Fuel Plate. Each sample shall be bent around a mandrel 90 degrees in one direction, returned to 0 degrees, then bent 90 degrees in the other direction, and returned to 0 degrees. The edges of the bend test specimen adjacent to the Fuel Plate shall then be visually examined, without magnification, for delamination. Any edge adjacent to the Fuel Plate showing visual delamination of the Cladding layers shall be cause for Rejection of the associated Fuel Plate. At least six (6) bend samples per Fuel Plate, including two (2) along each long side and one (1) along each short side, shall be tested and visually inspected to verify bonding.

3.4.2.6 Surface Finish and Defects: Prior to assembly, the surfaces of the aluminum cladding on the Fuel Meat region shall be examined for pits, scratches, and dents. Pits and scratches greater than 0.005 inch deep over fuel or 0.006 inch deep on any other surface shall result in rejection of the fuel plate. Dents greater than 1/4 inch in diameter and/or greater than 0.006 inch deep shall also result in rejection of the plate.

Compliance with surface finish and defect requirements shall be established by 100% visual inspection without magnification of all Fuel Plates. An optical depth gage shall be used to evaluate questionable defects.

3.4.2.7 Dimensional: Fuel Plate outer dimensions shall be verified by inspection of three (3) Fuel Plates per Lot. If any of these three (3) is discrepant, the entire Lot shall be dimensionally inspected. All Dimensions shall apply at a temperature of 75° F ± 5°F.

3.4.2.8 Identification: Each finished Fuel Plate shall be identified by a marking method approved by the Purchaser over the non-fueled region per dwg 603878 and shall not be in excess of 0.0105 inch deep. Positive identification shall be maintained relative to the complete fabrication history including the Fuel

Plate Lot, Monolithic foils, basic material Lots, U-Mo coupons, Manufacturing cycle, and Quality Control phases.

3.4.2.9 Storage: All Fuel Plates that have received final cleaning shall be contained in clean polyethylene containers or other containers approved by the Purchaser while awaiting final assembly, being transferred into storage, and being maintained in storage. Any material exposed to contamination shall be re-inspected to the requirements of Section 3.4.3.7.

3.4.3 Fuel Elements

3.4.3.1 Fuel Loading: Each Fuel Element shall contain 128.25 ±2.57 grams U-235.

3.4.3.2 Mechanical Integrity: The Supplier shall assemble fuel plates to side plates by swaging. Mechanical integrity of swage joints shall be established by performing pull tests with care equivalent to performing tension tests as prescribed in ASTM E 8. Swaged joints between the Fuel Plates and side plates shall be able to withstand a load of not less than 150 pounds per linear inch of swage joint.

Pull test samples shall have matching geometry compared to the Fuel Elements except that they shall be 3.0±0.1 inch long and that the plate portions may be made from “blank” aluminum stock in lieu of fueled plates. Swaging of test specimens shall be interspersed in the normal Fuel Element swaging process without adjustment of the swaging parameters. The swage test specimen quantity, placement, type, and sequencing shall be sufficient to comprehensively represent each Fuel Element’s swaging operation in all of the following parameters:

3.4.3.2.1 Each fuel plate column or side plate slot (one through three)

3.4.3.2.2 Each side plate (left and right)

3.4.3.2.3 Each fuel plate row in direction of swage bed travel (fore, middle, and aft or rows A, B, and C)

3.4.3.2.4 Swaging sequence (both prior to and following swaging of the Fuel Element)

3.4.3.3 Identification: Each Fuel Element assembly shall be identified as shown in drawing 603876.

3.4.3.4 Dimensional: Compliance with all external dimensions of all the Fuel Elements and all coolant flow channels as measured in accordance with dwg 604017 shall be verified by inspection of all Fuel Elements. All dimensions of this Specification shall apply at a temperature of 75°F±5°F.

Dimensional Inspection Acceptance Criteria:

3.4.3.4.1 External dimensions of each Fuel Element assembly shall be in compliance with drawing 603876.

3.4.3.4.2 Inspection data for Fuel Plates and Fuel Elements and shall identify item part, drawing, Specification number, item serial number, Lot number, each characteristic, inspection results, examination method, inspector, signature of audit person, and NDE reports.

3.4.3.4.3 Each coolant gap dimension shall be inspected by a system that provides dimensions of channel gap in two (2) places equally spaced from each side plate for the full length of channel. Results of the inspection shall be submitted to the Purchaser and the Stakeholder.

3.4.3.5 Welding: Welding and inspection shall be performed in accordance dwg 603876.

3.4.3.6 Surface Finish and Defects: Fuel Elements surfaces, which are not Fuel Plate surfaces, shall be free from pits, dents, scratches, and other removal of metal in excess of 0.015 inches deep and 0.180 inches in diameter.

3.4.3.7 Cleanliness and Surface Contamination: The Supplier's fabrication, assembly, and storage areas used for the Production of Fuel Elements and/or components shall conform to the requirements of a "Controlled Work Area" as defined in Paragraph 1.3.6 of STD-7022A. Cleanliness shall be in compliance with STD-7022A, paragraphs 1.1, 1.2.3, 3.1, 3.2-b,

-d, -1, 3.3-d, -e, 4.1.3, 4.2, and 4.3. Freon shall not be used to clean Fuel Elements or components.

There shall be no foreign materials on the surfaces of the finished Fuel Plates or Fuel Elements. Use of graphite or organics for marking purposes is prohibited. The use of abrasives for cleaning the Fuel Plates or for any other purpose is prohibited, as is any procedure which removes aluminum from the surface of the finished Fuel Plates. Any corrosion products, dirt, scale, graphite, oil products, metal chips, finger prints, etc., shall be removed without violating minimum Cladding thickness. Degreasing agents shall be approved by the Purchaser. After degreasing, all surfaces, including all crevices shall be thoroughly rinsed with distilled water. Water marks that do not affect the mechanical integrity of the swage joints are allowed.

Fuel Plate and Fuel Element cleanliness requirements of shall be verified by visual inspection of 100% of the Fuel Plates and Fuel Elements and by In-Process Controls. The surfaces of each Fuel Plate and the completed Fuel Element shall be smeared and the smear counted for radioactive contamination. The alpha count shall be less than five (5) dpm per 100 cm^2 and the beta-gamma count shall be less than two hundred (200) dpm per 100 cm^2.

3.4.3.8 Fuel Element Surface Treatment: After Fuel Elements are final machined and inspected they shall be subjected to an environment that will cause an evenly distributed boehmite layer to form on all surfaces of the entire assembly. The treatment process shall be performed under controlled conditions, which shall require the Supplier to maintain a record of the thermal history of the autoclave. The records shall include heat charts of recorded time and temperature. The Supplier shall maintain documented evidence of the controls placed on the autoclave.

Each Fuel Element shall have a corresponding aluminum plate cropping, made from Fuel Plate end crops, placed near the Fuel Element during the boehmite formation process. The aluminum plate croppings shall be subjected to the same environment as the Fuel Elements and each aluminum plate cropping measured for boehmite thickness via Eddy current instrumentation. The average of these measurements shall not be less than less than 0.00006 inch or more than 0.0003 inch thickness.

Fuel Elements and aluminum plate croppings subjected to the boehmite formation process shall be carefully handled to preclude scratches, dents, and gouges that would cause removal of boehmite.

3.4.3.9 Storage: All Fuel Elements that have received boehmite treatment shall be sealed in clean polyethylene containers or other containers approved by the Purchaser while being transferred into storage, maintained in storage, and prepared for packaging and shipment. Any material exposed to contamination shall be re-inspected according to the requirements of Section 3.4.3.7.

4. MATERIALS OF CONSTRUCTION

4.1 All items prepared for Fuel Element assembly shall be traceable to the raw material from which they were fabricated.

4.2 Prior to fabrication of Fuel Plates and Fuel Elements, the Supplier or an independent laboratory shall perform chemical analysis, and mechanical tests where applicable, on U-Mo alloys, zirconium Interlayer, side plates, and Fuel Plate Cladding materials.

5. TEST AND INSPECTION REQUIREMENTS

5.1 Responsibility

Unless otherwise specified, the Supplier shall be responsible for the performance of all tests and inspections required prior to submission to the Purchaser of any Fuel Element for acceptance. The following tests and inspections, in addition to the ones listed in the various sections of the Specification, shall be performed by the Supplier to assure that the product quality is in accordance with the requirements of this Specification.

5.1.1 Materials: Compliance with material requirements shall be established by Supplier certification. A certification of chemical analysis or a certified Mill Test Report shall be supplied to the Purchaser for each Lot of material used in the fabrication of Fuel Elements. All materials shall be traceable to the Fuel Elements fabricated from these materials.

6. DELIVERY SUBMITTALS

6.1 Two (2) copies (except as noted) of the following data and records shall be sent previous to or concurrent with shipments to the Purchaser and one (1) copy shall be sent to the Stakeholder.

6.1.1 Certification of product compliance to the requirements of this Specification to include any test data pertaining thereto

6.1.2 Certification of material compliance to the requirement of this Specification to include any chemical and physical test results pertaining thereto

6.1.3 Dimensional Data as required by Section 3.4.2.7 and Section 3.4.3.4

6.1.4 Individual Fuel Plate uranium data including:

6.1.4.1 Serial number with foil identification

6.1.4.2 Foil weight

6.1.4.3 Uranium content

6.1.4.4 Total U-235 content

6.1.4.5 Alpha contamination results

6.1.5 Individual Fuel Element Composition data including:

6.1.5.1 Serial number of the Fuel Element

6.1.5.2 Uranium content

6.1.5.3 U-235 content

6.1.5.4 Serial number of each Fuel Plate in the Fuel Element and the stacking order

6.1.6 Radiation smear count from Fuel Plate and Fuel Element exterior, as required by Section 3.4.3.7

6.1.7 Results of swage joint pull tests specified in Section 3.4.3.2

6.1.8 List of all applicable waivers and deviations and related Fuel Plates or Fuel Elements

6.1.9 Radiographs as specified in Section 3.4.2.2 and UT data as specified in Section 3.4.2.5 to be sent to the Purchaser

7. PACKAGING AND SHIPPING

7.1 Purchaser shall provide shipping containers which will protect the Fuel Elements from damage during shipment and which conform in all respects to the applicable regulations of the U.S. Department of Energy, of the U.S. Department of Transportation, and of any other agencies having jurisdiction over the shipment of radioactive materials.

7.2 The Supplier shall load the Fuel Elements into the shipping containers in a sealed polyethylene bag in a clean and dry condition free of extraneous materials.

7.3 The Supplier shall take all necessary precautions during packing to prevent damage to the Fuel Elements during shipment. Each container shall be provided with a tamper-proof seal. The container's loading and shipping documents shall be prepared in accordance with all applicable regulations.

7.4 The Supplier shall make arrangements for shipment to the facility designated by the Purchaser. Approval of shipping date shall be obtained from Purchaser prior to any shipment. The Supplier shall make the shipment per a prepared and maintained handling, packaging, and shipping procedure.

8. ACCEPTANCE INSPECTION

8.1 Acceptance Inspection

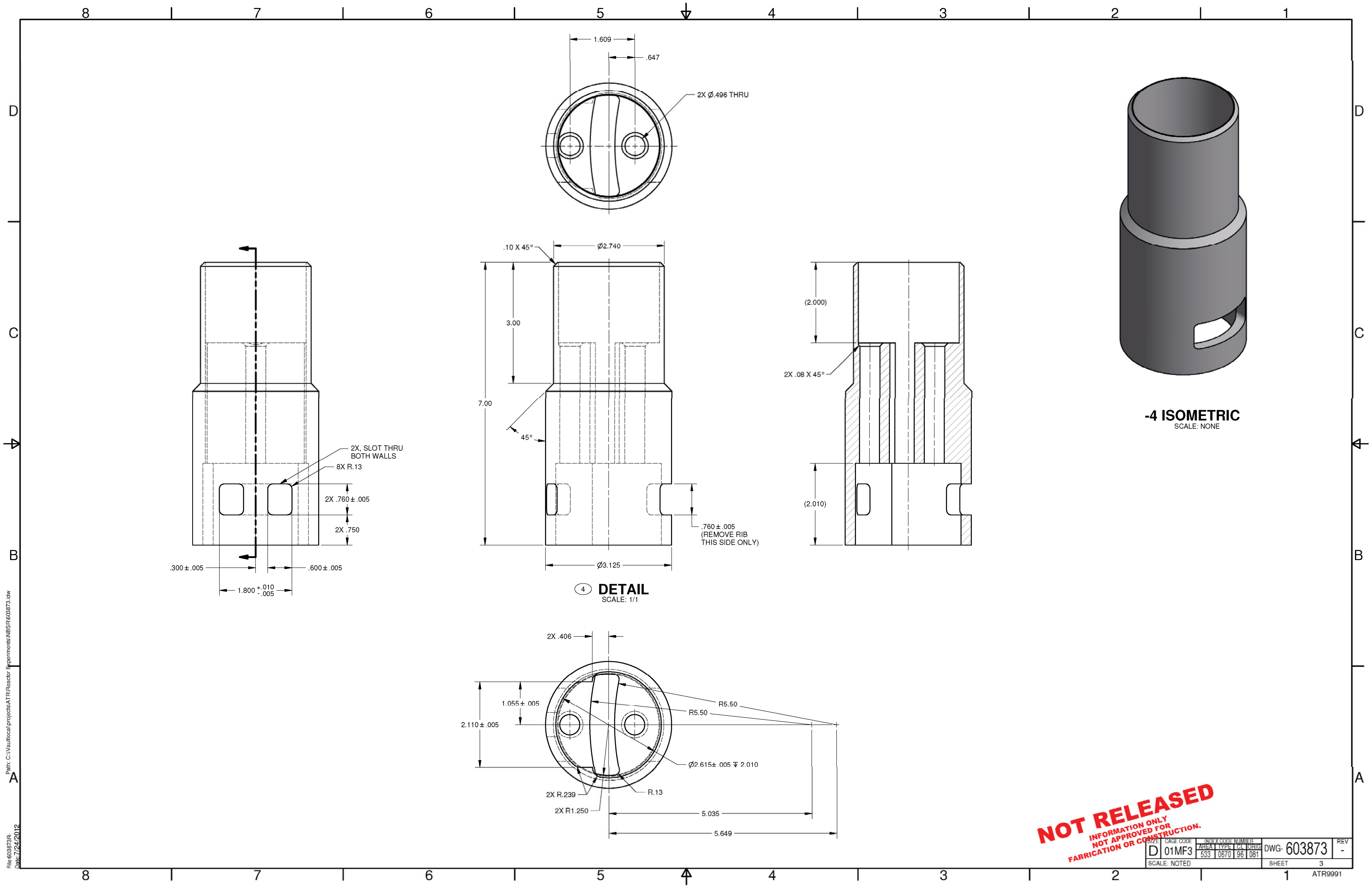
All materials, workmanship, and procedures shall be subject to inspection, examination, test, and Rejection by the Purchaser for noncompliance with the Specifications at any and all times during Manufacture, and at any and all places where such Manufacture is carried on. Final inspection and acceptance or Rejection will be made by the Purchaser at the Supplier's plant. The Purchaser shall have the right to reject any finished products for defects in workmanship, or defects in any of the materials comprising the finished product which otherwise fail to meet the Specification.

8.2 Deviation from Specifications

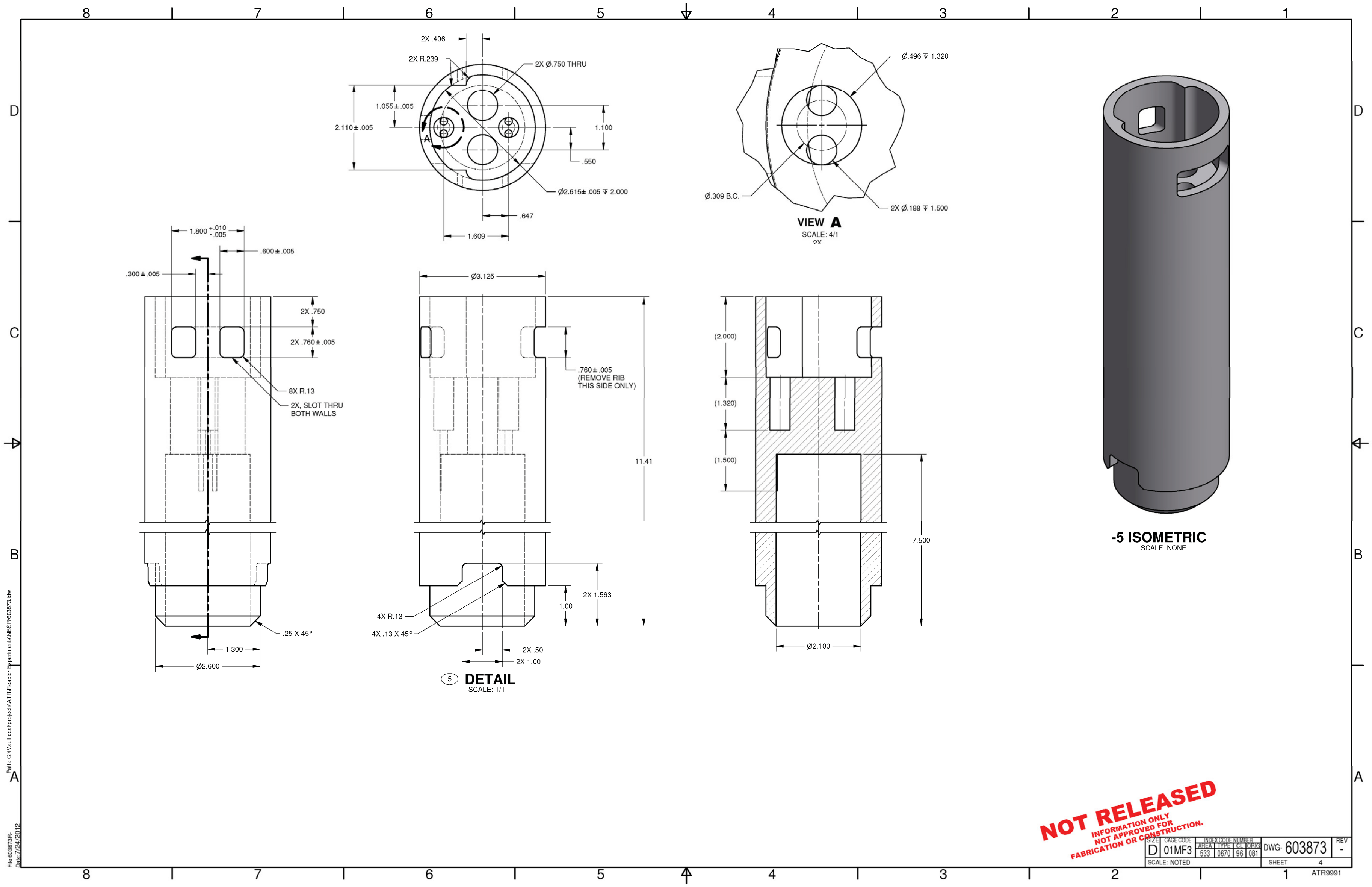
Notwithstanding other provisions of these Specifications, the Purchaser may, when requested in writing, waive certain minor deviations from requirements of the Specifications and drawings where the Failure to meet any specific requirement either alone or in combination with other Failures will not significantly reduce the efficiency or performance of the assembly. Acceptance of a Fuel Element by the Purchaser with deviations from the Specifications shall not be construed to mean the Purchaser approves or will approve similar deviations in Fuel Elements not yet delivered under the contract.

Deviations from design documents shall be documented on a change request form One (1) copy is to be sent to the Stakeholder concurrent to transmittal to the Purchaser.

Appendix D (Drawings)



Appendix D (Drawings)



Appendix D (Drawings)

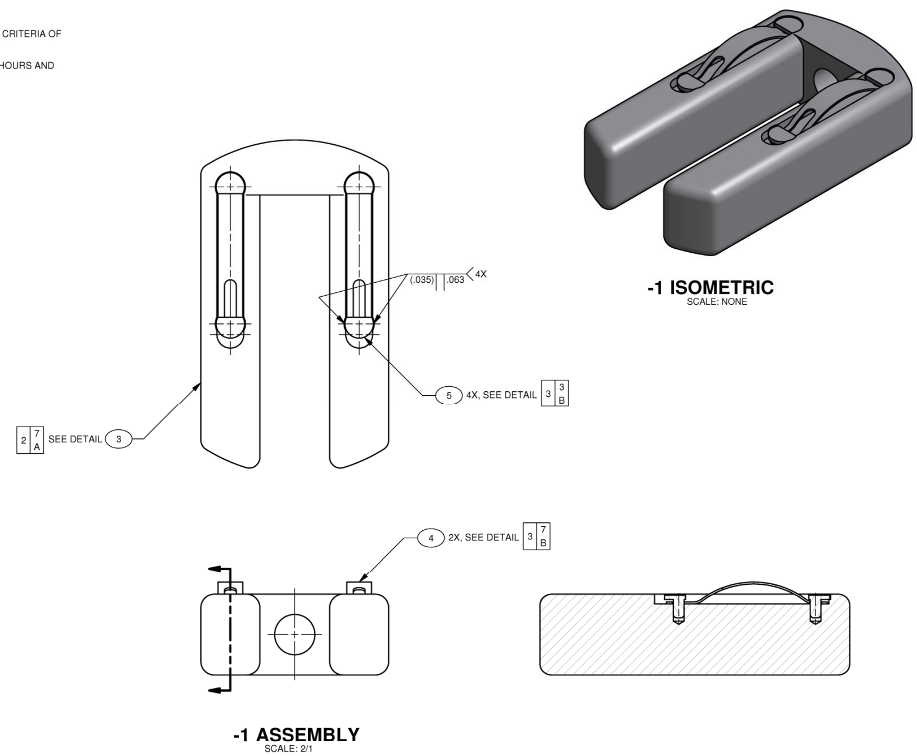
INL.idw Rev 9

NOTES:

1. REMOVE ALL BURRS AND SHARP EDGES.
2. CLEANLINESS PER STD-7022, LEVEL C.
3. QUALITY LEVEL DETERMINATION PER RTC-000073.
4. WELD AUTOGENOUSLY PER AWS 1.6, WITH INSPECTION CRITERIA OF NO VISIBLE CRACKS.
5. HEAT TREAT ITEM 4 (CLIP SPRING) TO 925°F FOR FOUR HOURS AND AIR QUENCH.

SHEET	3	2	1	REV STATUS OF SHEETS
REV	-	-	-	

REVISIONS		
REV	DESCRIPTION	EFFECTIVE DATE:



QTY REQD	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL/SPECIFICATION OR VENDOR NAME	ITEM NO.
4	-5	CLIP PIN	BAR OR PLATE, ASTM A276 OR SS21800SST (NITRONIC 60) A240	5
2	-4	CLIP SPRING	BAR OR PLATE, ASTM A564 17-4 PH SST OR A693	4
1	-3	CLIP BODY	BAR OR PLATE, ASTM A276 OR SS21800SST (NITRONIC 60) A240	3
				2
	-1	CLIP ASSEMBLY		1
-1				

PARTS LIST

NOT RELEASED
INFORMATION ONLY
NOT APPROVED FOR
FABRICATION OR CONSTRUCTION.

DASH NO.	NEXT ASSY
-1	603871

APPLICATION

DIMENSIONING AND SYMBOLOGY PER ASME Y14.5M AND STD-10011
UNLESS OTHERWISE SPECIFIED SURFACE ROUGHNESS 125
DIMENSIONS AND TOLERANCES ARE IN INCHES
TOLERANCES: X = ± .1
DECIMALS: .XX = ± .03 .XXX = ± .010
FRACTIONS ± 1/8
ANGULAR ± 2°
DO NOT SCALE DRAWING

REQUESTER: B. NIELSON
RESP ENGR: B. DURTSCHI
DESIGN: B. DURTSCHI
DRAWN: J. TONKS
PROJECT NO.
SPCL CODE NBSR
FOR REVIEW/APPROVAL SIGNATURES SEE ECR NO. 602817
EFFECTIVE DATE:

Idaho National Laboratory

ATR
NATIONAL BUREAU OF STANDARDS REACTOR (NBSR)
FUEL ELEMENT EXPERIMENT
CLIP
ASSEMBLY AND DETAILS

SIZE	CAGE CODE	INDEX CODE NUMBER AREA	TYPE	CL	ORIG	DWG-	REV
D	01MF3	533	0670	96	081	603875	-

SCALE: NOTED SHEET 1 OF 3

ATR9991

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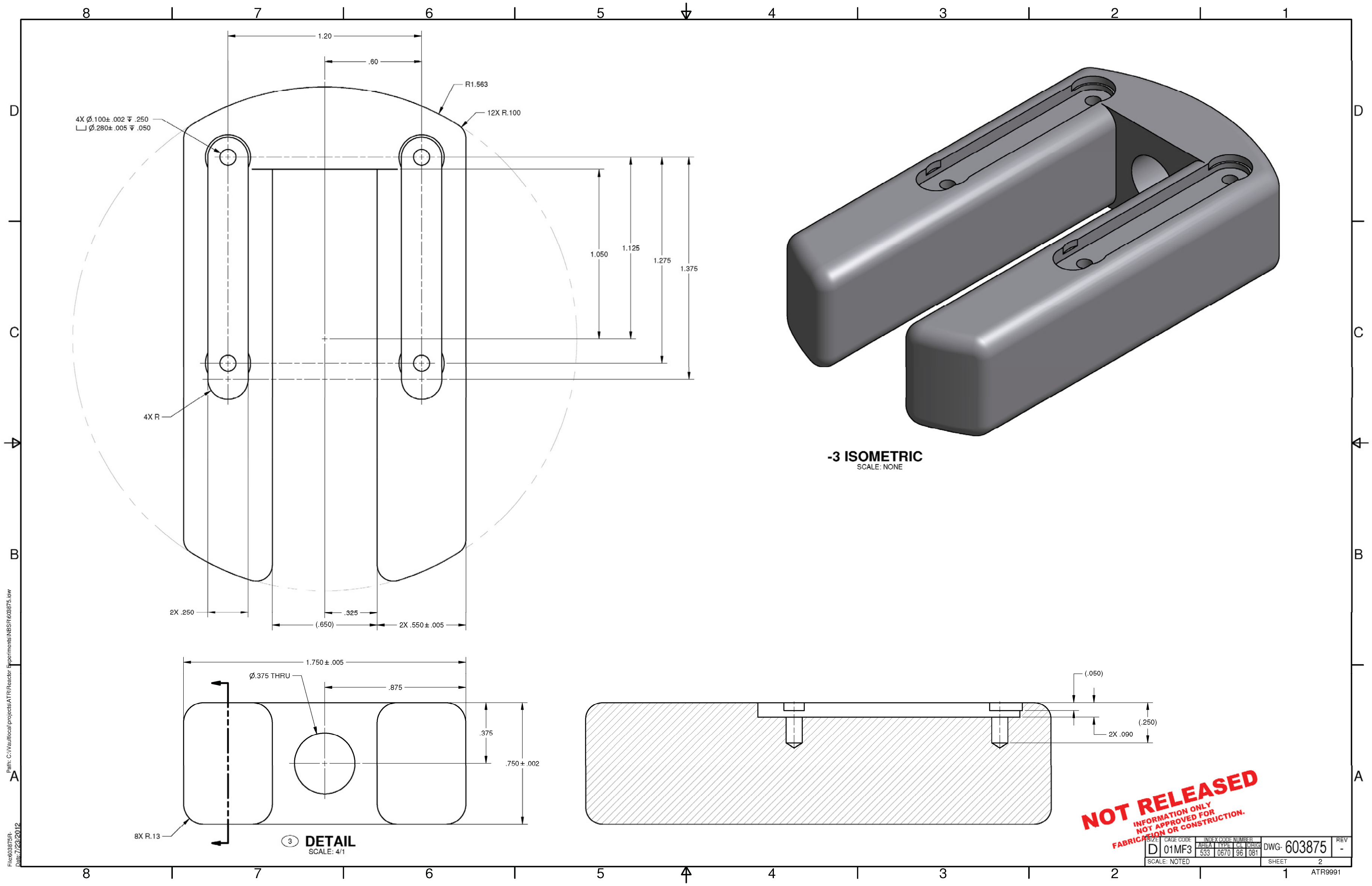
Date:7/23/2012

Appendix D (Drawings)



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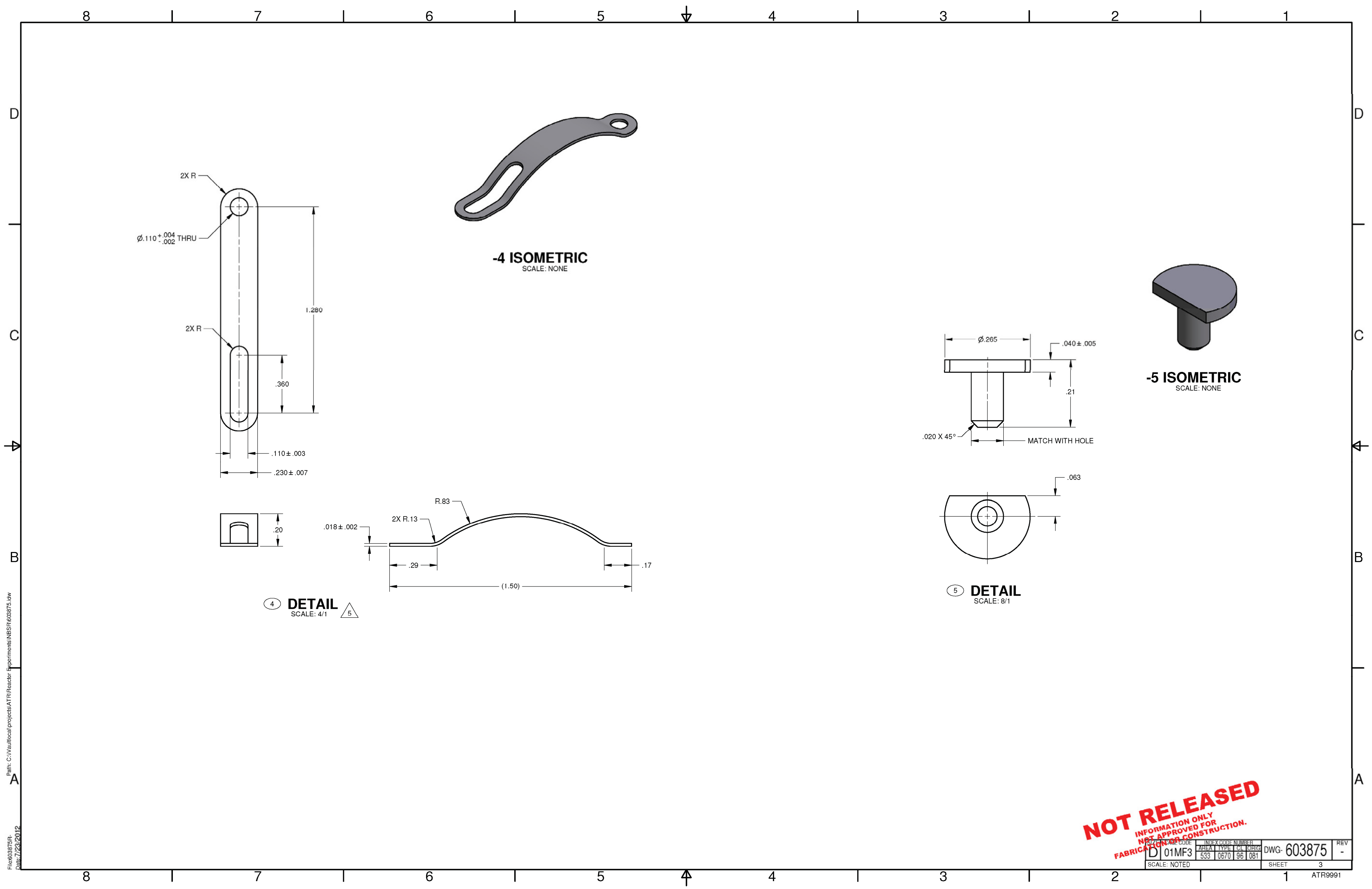
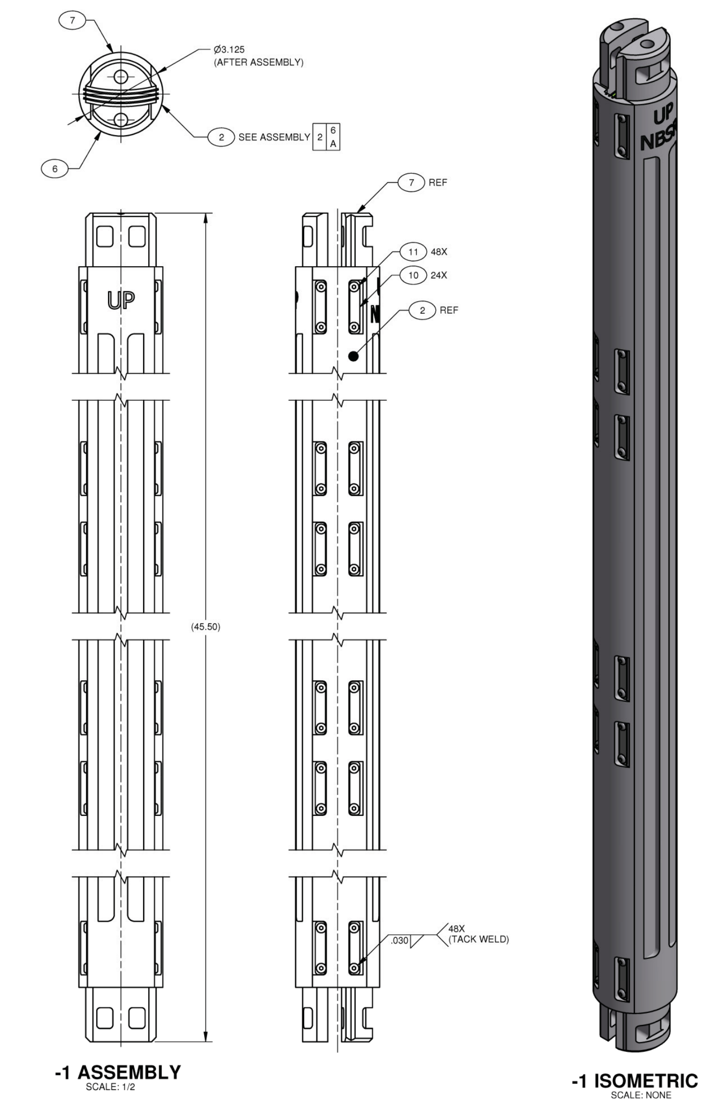


Appendix D (Drawings)

INL.idw Rev 9

NOTES:

1. REMOVE ALL BURRS AND SHARP EDGES.
2. CLEANLINESS PER STD-7022, LEVEL C.
3. QUALITY LEVEL DETERMINATION PER ??????.
4. WELD PER SPECIFICATION AWS D1.6 USING ITEM 13 (WELD FILLER METAL). VISUALLY INSPECT WITH ACCEPTANCE CRITERIA OF NO VISUAL CRACKS.
5. PLATES TO BE SWAGED IN PER FUEL SPECIFICATION 1315.



-1 ASSEMBLY
SCALE: 1/2

-1 ISOMETRIC
SCALE: NONE

SHEET	2	1
REV	-	-

REV STATUS OF SHEETS

REVISIONS		
REV	DESCRIPTION	EFFECTIVE DATE:

NOT RELEASED
INFORMATION ONLY
NOT APPROVED FOR
FABRICATION OR CONSTRUCTION.

QTY REQD -2	QTY REQD -1	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL/SPECIFICATION OR VENDOR NAME		ITEM NO.
	AR		WELD FILLER METAL	ER308L	AWS A5.9	13
						12
	48		CAP SCREW, SOCKET HD #10-24 UNC-2A X .5 LG	304 OR 316 SST	ASTM A193 OR F837	11
	24	603877-5	LONG WASHER			10
						9
9		603878-1	FUEL PLATE			8
	1	603877-4	FUEL ELEMENT HOLDER BACK			7
	1	603877-3	FUEL ELEMENT HOLDER FRONT			6
1		603877-2	FUEL ELEMENT HOLDER SIDE B			5
1		603877-1	FUEL ELEMENT HOLDER SIDE A			4
						3
		-2	FUEL ELEMENT ASSEMBLY			2
		-1	ELEMENT ASSEMBLY			1

PARTS LIST

DASH NO.	NEXT ASSY
-1	603871

APPLICATION

DIMENSIONING AND SYMBOLOGY PER ASME Y14.5M AND STD-10011
UNLESS OTHERWISE SPECIFIED
SURFACE ROUGHNESS
DIMENSIONS AND TOLERANCES ARE IN INCHES
TOLERANCES: .X = ± .1
DECIMALS: .XX = ± .03
.XXX = ± .010
FRACTIONS ± 1/8
ANGULAR ± 2°
DO NOT SCALE DRAWING

REQUESTER: B. NIELSON
RESP ENGR: B. DURTSCHI
DESIGN: B. DURTSCHI
DRAWN: J. TONKS
PROJECT NO.
SPCL CODE NBSR
FOR REVIEW/APPROVAL SIGNATURES SEE ECR NO. 602817
EFFECTIVE DATE:

Idaho National Laboratory

ATR
NATIONAL BUREAU OF STANDARDS REACTOR (NBSR)
FUEL ELEMENT EXPERIMENT
ELEMENT
ASSEMBLY

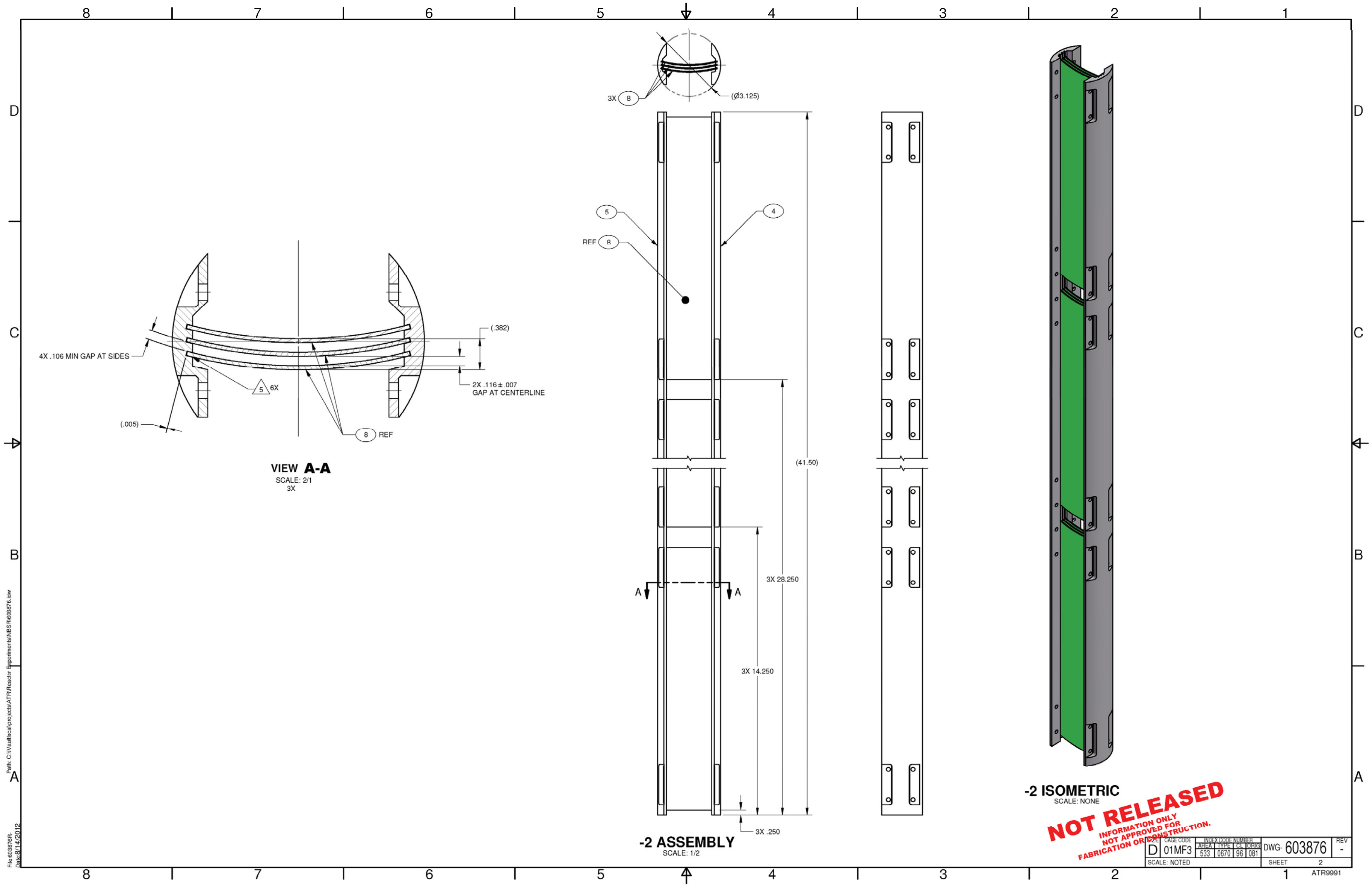
SIZE	CAGE CODE	INDEX CODE NUMBER AREA	TYPE	CL	ORIG	DWG-	REV
D	01MF3	533	0670	96	081	603876	-

SCALE: NOTED SHEET 1 OF 2

ATR9991

Path C:\Vault\local\projects\ATR\Reactor Experiments\NBSR\603876.idw
File 603876R-
Date 8/14/2012

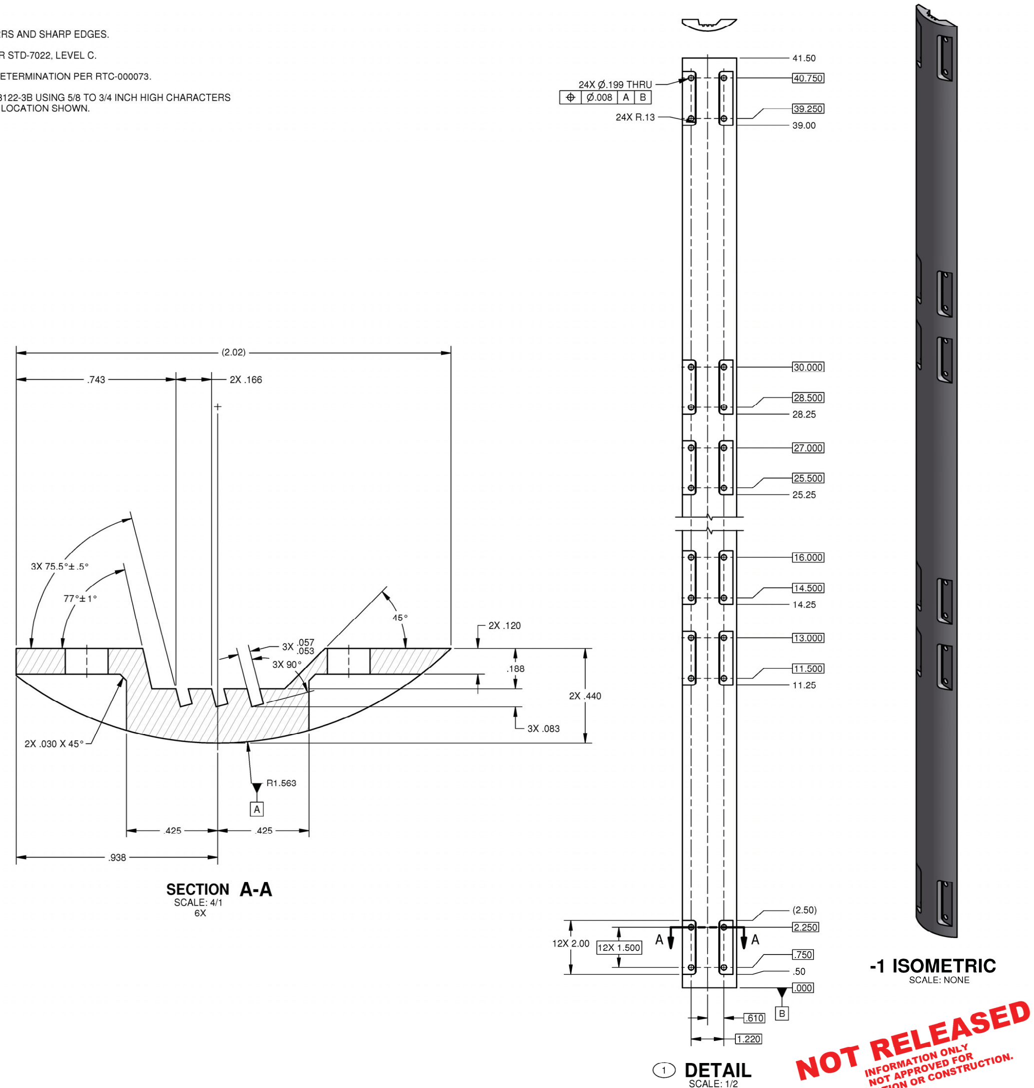
Appendix D (Drawings)



Appendix D (Drawings)

NOTES:

1. REMOVE ALL BURRS AND SHARP EDGES.
2. CLEANLINESS PER STD-7022, LEVEL C.
3. QUALITY LEVEL DETERMINATION PER RTC-000073.
4. MARK PER STD-13122-3B USING 5/8 TO 3/4 INCH HIGH CHARACTERS IN APPROXIMATE LOCATION SHOWN.



NOT RELEASED
INFORMATION ONLY
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FABRICATION OR CONSTRUCTION.

SHEET	4	3	2	1
REV	-	-	-	-

REV STATUS OF SHEETS

REVISIONS		
REV	DESCRIPTION	EFFECTIVE DATE:

QTY REQD		PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL/SPECIFICATION OR VENDOR NAME	ITEM NO.
		-5	LONG WASHER	SHEET, 22 GA (.0299 THK) 316 SST ASTM A240	5
		-4	FUEL ELEMENT HOLDER BACK	BAR OR PLATE, AL 6061-T6 SERIES ASTM B211 OR B209	4
		-3	FUEL ELEMENT HOLDER FRONT	BAR OR PLATE, AL 6061-T6 SERIES ASTM B211 OR B209	3
		-2	FUEL ELEMENT HOLDER SIDE B	BAR OR PLATE, AL 6061-T6 SERIES ASTM B211 OR B209	2
		-1	FUEL ELEMENT HOLDER SIDE A	BAR OR PLATE, AL 6061-T6 SERIES ASTM B211 OR B209	1

PARTS LIST

DASH NO	NEXT ASSY
-5	603876
-4	603876
-3	603876
-2	603876
-1	603876

APPLICATION

DIMENSIONING AND SYMBOLOGY PER ASME Y14.5M AND STD-10011
UNLESS OTHERWISE SPECIFIED
SURFACE ROUGHNESS 125
DIMENSIONS AND TOLERANCES ARE IN INCHES
TOLERANCES: X = ± .1
DECIMALS: XX = ± .03, XXX = ± .010
FRACTIONS ± 1/8
ANGULAR ± 2°
DO NOT SCALE DRAWING

REQUESTER: B. NIELSON
RESP ENGR: B. DURTSCHI
DESIGN: B. DURTSCHI
DRAWN: J. TONKS
PROJECT NO.
SPCL CODE NBSR
FOR REVIEW/APPROVAL SIGNATURES SEE ECR NO. 602817
EFFECTIVE DATE:

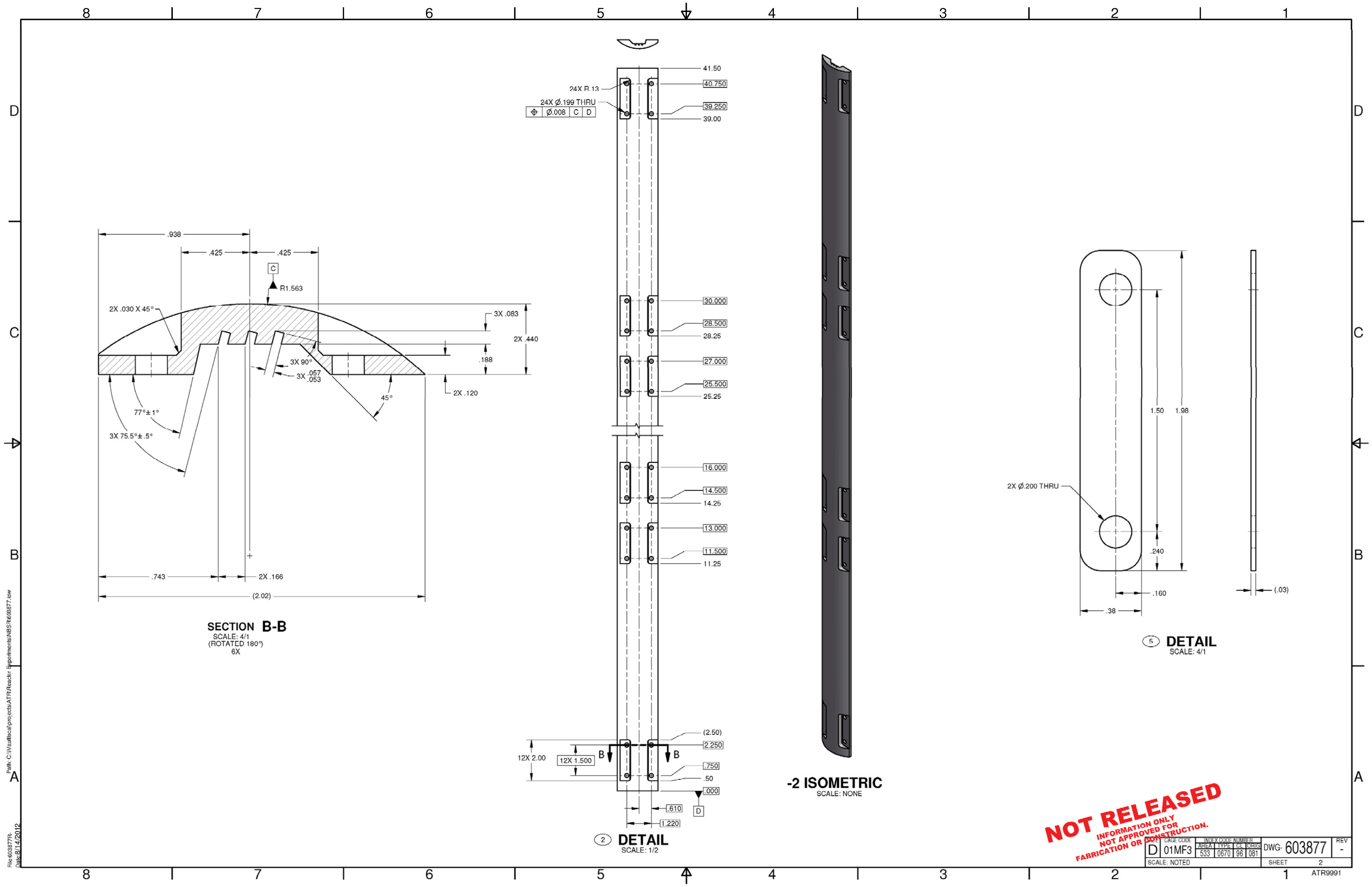
Idaho National Laboratory

ATR
NATIONAL BUREAU OF STANDARDS REACTOR (NBSR)
FUEL ELEMENT EXPERIMENT
ELEMENT
DETAILS

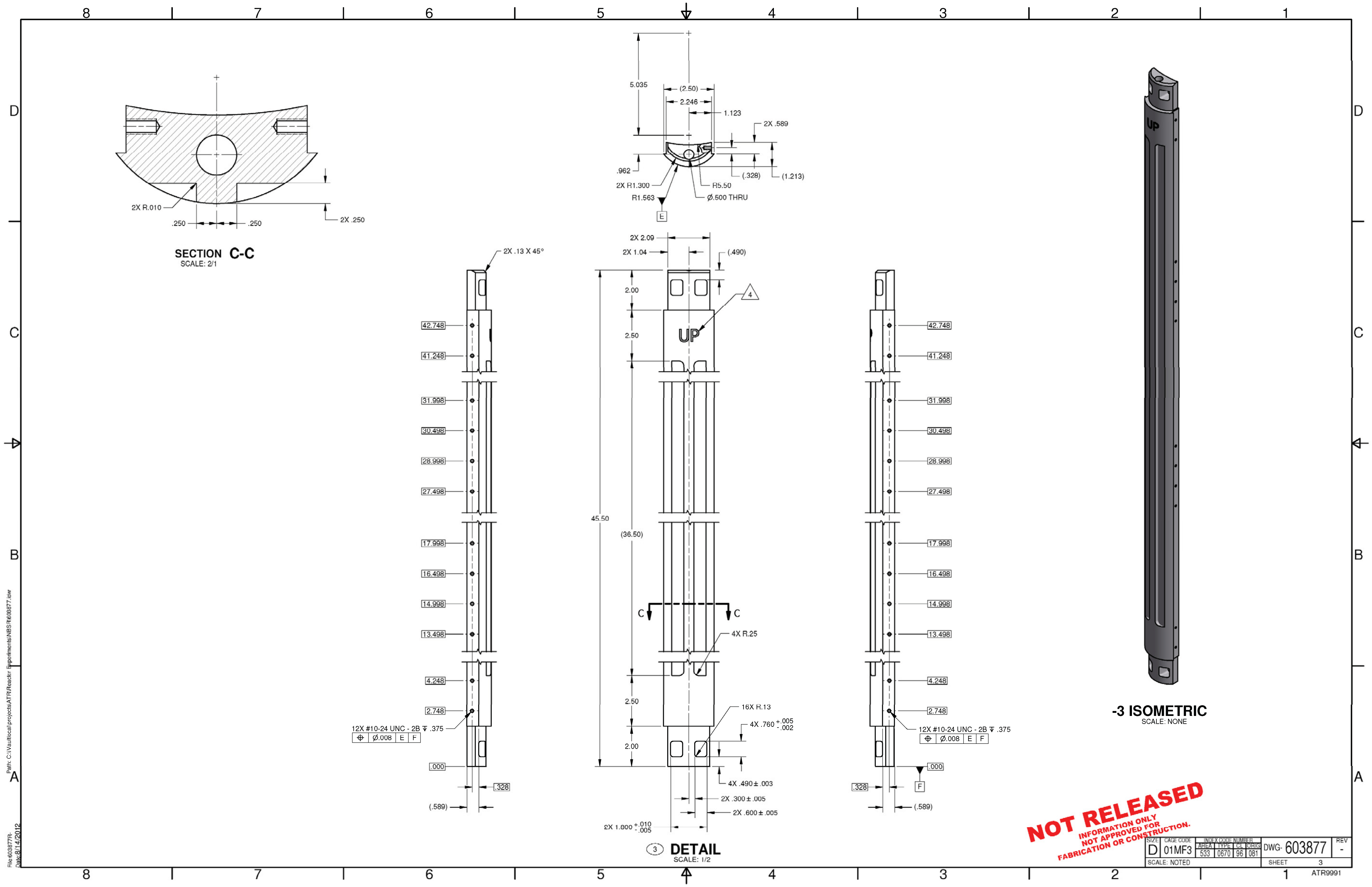
SIZE D CAGE CODE 01MF3 INDEX CODE NUMBER AREA 533 TYPE 0670 CL 96 DISC 081 DWG- 603877 REV -
SCALE: NOTED SHEET 1 OF 4
ATR9991

INL.idw Rev 9
Path: C:\Vaultlocal\projects\ATR\Reactor Experiments\NBSR\603877.idw
File:603877R-
Date:8/14/2012

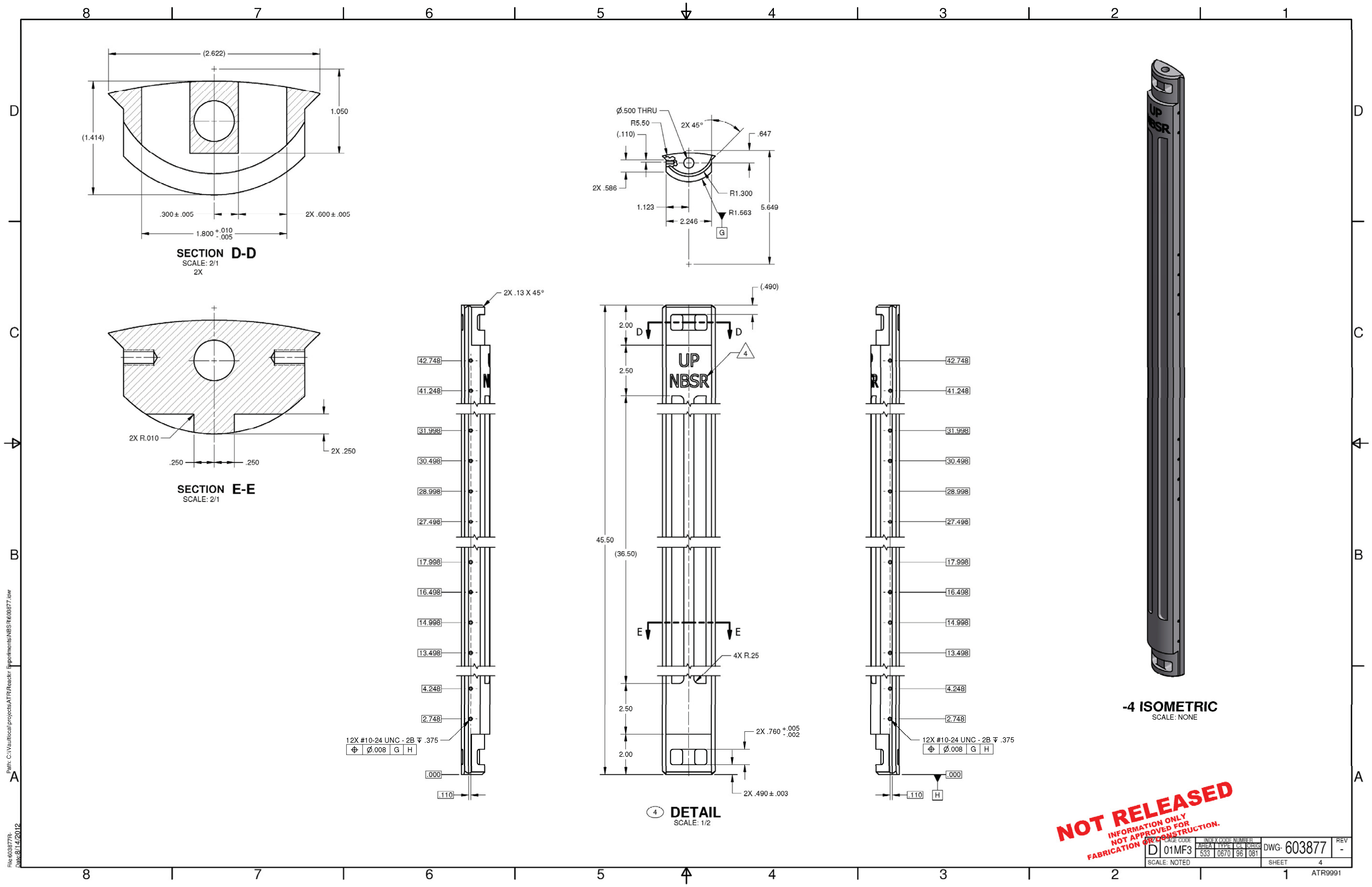
Appendix D (Drawings)



Appendix D (Drawings)



Appendix D (Drawings)

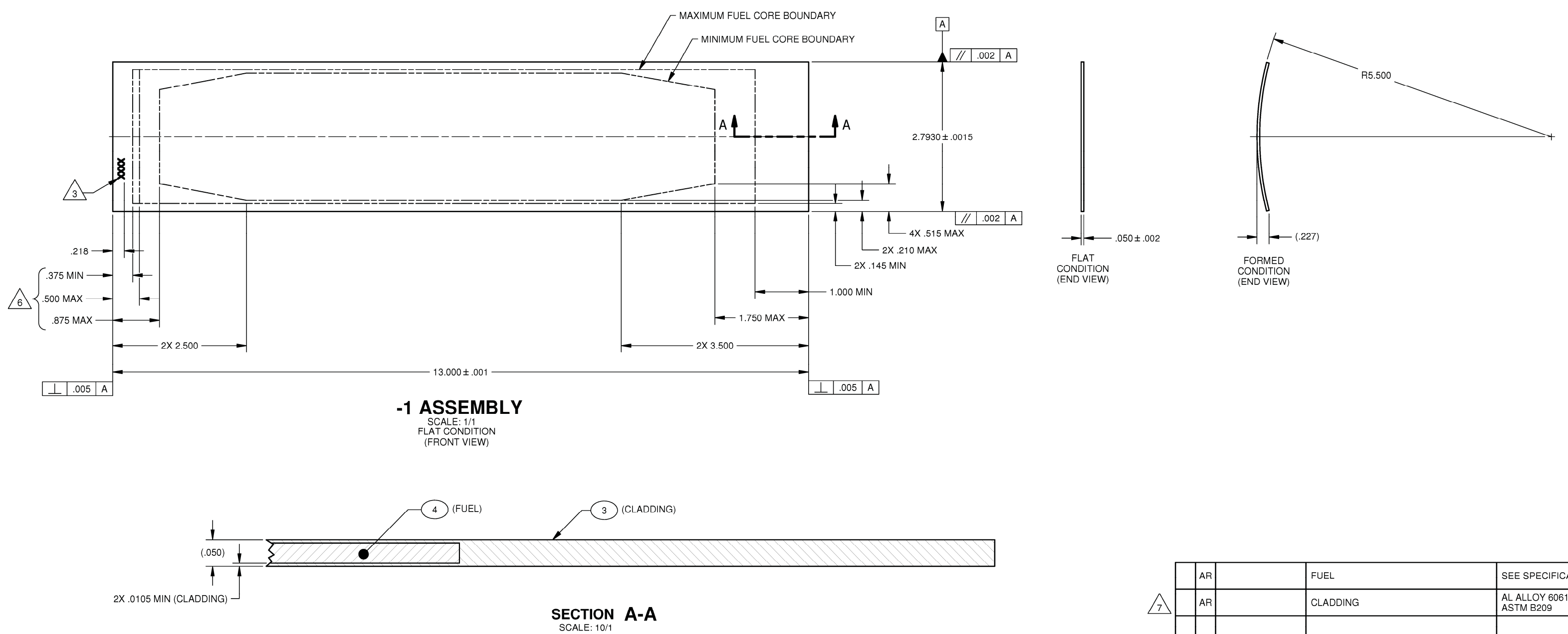


Appendix D (Drawings)

INL.idw Rev 9

NOTES:

1. REMOVE ALL BURRS AND SHARP EDGES.
2. PROCURE, FABRICATE, AND INSPECT PER SPECIFICATION SPECIFICATION-1315.
3. MARK PER INL STD-13122-2A, 2D, OR 3D USING 1/8" HIGH CHARACTERS WITH NUMBER SERIALIZATION PER THE RESPONSIBLE ENGINEER IN APPROXIMATE LOCATION SHOWN. ENSURE MARKING IS NOT DIRECTLY OVER FUEL OR FUEL PARTICLES.
4. SURFACE ROUGHNESS 63.
5. QUALITY LEVEL DETERMINATION PER QLD-???.
6. THE FURTHEST MOST POINT OF FUEL MUST BE WITHIN THE .375 INCH MINIMUM AND .500 INCH MAXIMUM DIMENSIONS. THE REMAINDER OF FUEL MUST FALL WITHIN THE .375 INCH MINIMUM AND .875 INCH MAXIMUM DIMENSIONS.
7. BORON LESS THAN 30 PPM.
   CADMIUM LESS THAN 30 PPM.
   LITHIUM LESS THAN 80 PPM.



QTY REQD		PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL/SPECIFICATION OR VENDOR NAME	ITEM NO.
	AR		FUEL	SEE SPECIFICATION-1315	4
	AR		CLADDING	AL ALLOY 6061 ASTM B209	3
					2
		-1	FUEL PLATE ASSEMBLY		1
	-1				

PARTS LIST

REVISIONS: REV | DESCRIPTION | EFFECTIVE DATE:

NOT RELEASED
INFORMATION ONLY
NOT APPROVED FOR FABRICATION OR CONSTRUCTION.

DASH NO.	NEXT ASSY
-1	603876

APPLICATION

DIMENSIONING AND SYMBOLOGY PER ASME Y14.5M AND STD-10011
UNLESS OTHERWISE SPECIFIED
~~SURFACE ROUGHNESS 125~~
DIMENSIONS AND TOLERANCES ARE IN INCHES
TOLERANCES: X = ± .1
DECIMALS: XX = ± .03
XXX = ± .010
FRACTIONS ± 1/8
ANGULAR ± 2°
DO NOT SCALE DRAWING

REQUESTER: B. NIELSON
RESP ENGR: B. DURTSCHI
DESIGN: B. DURTSCHI
DRAWN: J. TONKS
PROJECT NO.
SPCL CODE: NBSR
FOR REVIEW/APPROVAL SIGNATURES SEE ECR NO. 602817
EFFECTIVE DATE:

Idaho National Laboratory

ATR
NATIONAL BUREAU OF STANDARDS REACTOR (NBSR)
FUEL ELEMENT EXPERIMENT
FUEL PLATE
ASSEMBLY

SIZE: D | CAGE CODE: 01MF3 | INDEX CODE NUMBER: AREA 533, TYPE 0670, CL 96, ORIG 081 | DWG- 603878 | REV -

SCALE: 1/1 | SHEET 1 OF 1

ATR9991

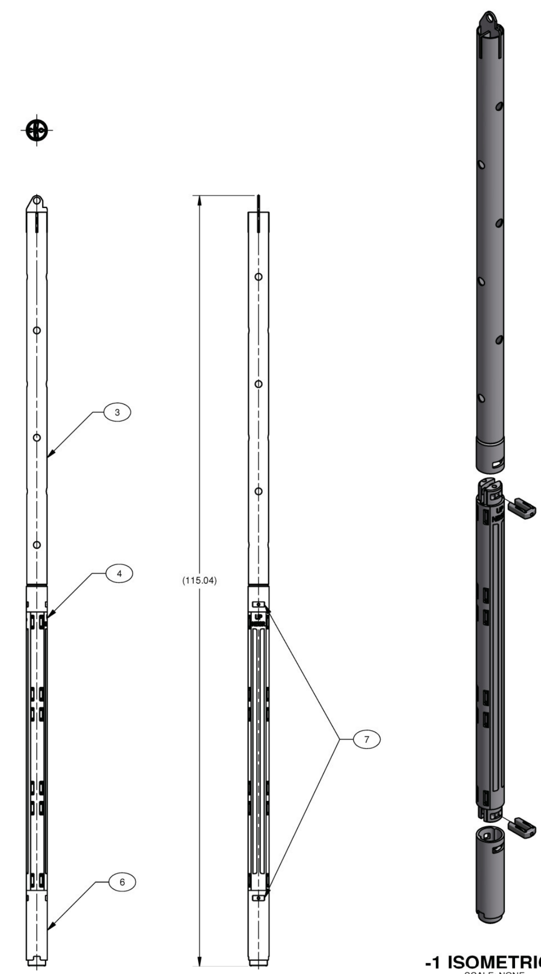
Path: C:\Vaultlocal\projects\ATR\Reactor Experiments\NBSR\603878.idw
File:603878R-
Date:8/28/2012

Appendix D (Drawings)

INL.idw Rev 9

NOTES:

1. REMOVE ALL BURRS AND SHARP EDGES.
2. CLEANLINESS PER STD-7022, LEVEL C.
3. QUALITY LEVEL DETERMINATION PER RTC-000073.



-1 ASSEMBLY
SCALE: 1/8

-1 ISOMETRIC
SCALE: NONE

NOT RELEASED
INFORMATION ONLY
NOT APPROVED FOR
FABRICATION OR CONSTRUCTION.

	2	603875-1	CLIP ASSEMBLY		7
	1	603873-7	EXPERIMENT BOTTOM		6
					5
	1	603876-1	ELEMENT ASSEMBLY		4
	1	603872-1	RECEIVER ASSEMBLY		3
					2
		-1	FINAL ASSEMBLY		1
QTY REQD	-1	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL/SPECIFICATION OR VENDOR NAME	ITEM NO.

PARTS LIST

REV	DESCRIPTION	EFFECTIVE DATE:
REVISIONS		

DASH NO.	NEXT ASSY
-1	FINAL

APPLICATION

DIMENSIONING AND SYMBOLOGY PER ASME Y14.5M AND STD-10011
UNLESS OTHERWISE SPECIFIED
SURFACE ROUGHNESS
DIMENSIONS AND TOLERANCES ARE IN INCHES
TOLERANCES: X = ± .1
DECIMALS: .XX = ± .03
.XXX = ± .010
FRACTIONS ± 1/8
ANGULAR ± 2°
DO NOT SCALE DRAWING

REQUESTER: B. NIELSON
RESP ENGR: B. DURTSCHI
DESIGN: B. DURTSCHI
DRAWN: J. TONKS
PROJECT NO.
SPCL CODE NBSR
FOR REVIEW/APPROVAL SIGNATURES SEE ECR NO. 602817
EFFECTIVE DATE:

INL Idaho National Laboratory

ATR
NATIONAL BUREAU OF STANDARDS REACTOR (NBSR)
FUEL ELEMENT EXPERIMENT
FINAL
ASSEMBLY

SIZE	CAGE CODE	AREA	TYPE	CL	ORIG	DWG-	REV
D	01MF3	533	0670	96	081	603871	-

SCALE: NOTED SHEET 1 OF 1

ATR9991

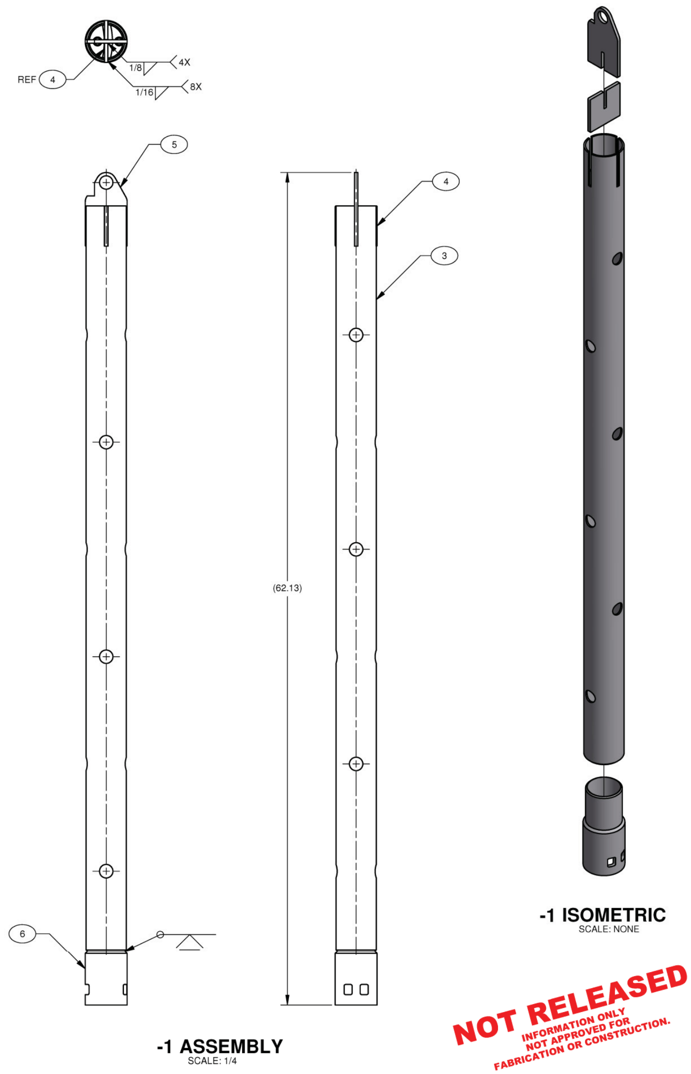
Path C:\Vault\local\projects\ATR\Reactor Experiments\NBSR\603871.idw
File:603871R-
Date:7/25/2012

Appendix D (Drawings)

INL.idw Rev 9

NOTES:

1. REMOVE ALL BURRS AND SHARP EDGES.
2. CLEANLINESS PER STD-7022, LEVEL C.
3. QUALITY LEVEL DETERMINATION PER RTC-000073.
4. WELD PER INL WELD PROCEDURE SPECIFICATION A2.0 USING ITEM 8 (WELD FILLER METAL). VISUALLY INSPECT WELDS PER TPR-13442 WITH ACCEPTANCE CRITERIA PER APPENDIX G, SECTIONS 1 AND 2.



NOT RELEASED
INFORMATION ONLY
NOT APPROVED FOR
FABRICATION OR CONSTRUCTION.

REV	DESCRIPTION	EFFECTIVE DATE:

REVISIONS

QTY REQD	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL/SPECIFICATION OR VENDOR NAME		ITEM NO.
AR		WELD FILLER METAL	ER 4043	AWS A5.10	8
					7
1	603873-4	RECEIVER BOTTOM			6
1	603873-3	RECEIVER LIFTING PLATE			5
1	603873-2	SCREEN MOUNTING PLATE			4
1	603873-1	RECEIVER BODY			3
					2
	-1	RECEIVER ASSEMBLY			1
-1					

PARTS LIST

DASH NO.	NEXT ASSY
-1	603871

APPLICATION

DIMENSIONING AND SYMBOLOGY PER ASME Y14.5M AND STD-10011
UNLESS OTHERWISE SPECIFIED
SURFACE ROUGHNESS
DIMENSIONS AND TOLERANCES ARE IN INCHES
TOLERANCES: X = ± .1
DECIMALS: XX = ± .03
XXX = ± .010
FRACTIONS ± 1/8
ANGULAR ± 2°
DO NOT SCALE DRAWING

REQUESTER: B. NIELSON
RESP ENGR: B. DURTSCHI
DESIGN: B. DURTSCHI
DRAWN: J. TONKS
PROJECT NO.
SPCL CODE NBSR
FOR REVIEW/APPROVAL SIGNATURES SEE ECR NO. 602817
EFFECTIVE DATE:

Idaho National Laboratory

ATR
NATIONAL BUREAU OF STANDARDS REACTOR (NBSR)
FUEL ELEMENT EXPERIMENT
RECEIVER
ASSEMBLY

SIZE D | CAGE CODE 01MF3 | INDEX CODE NUMBER: AREA 533, TYPE 0670, CL 96, ORIG 081 | DWG- 603872 | REV -

SCALE: NOTED | SHEET 1 OF 1

ATR9991

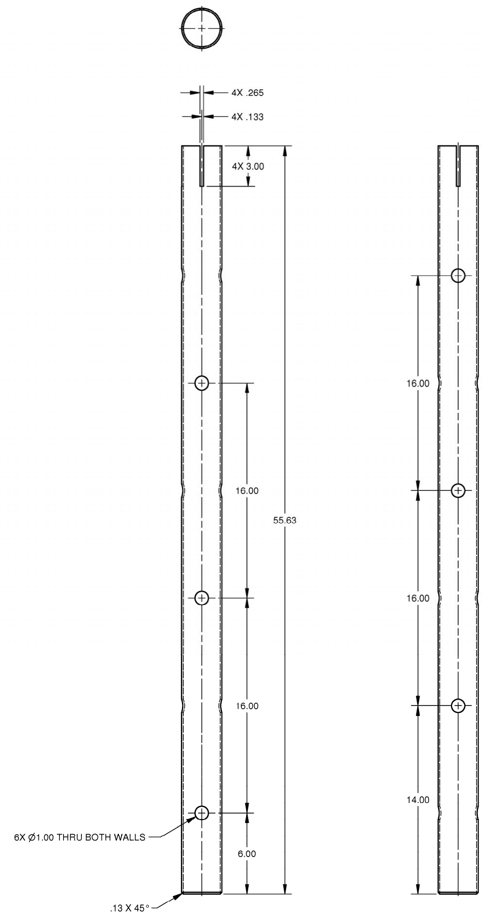
Path: C:\Vault\local\projects\ATR\Reactor Experiments\NBSR\603872.idw
File:603872R-
Date:7/24/2012

Appendix D (Drawings)

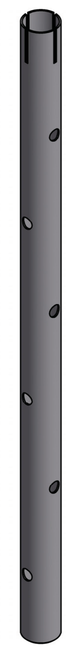
INL.idw Rev 9

NOTES:

1. REMOVE ALL BURRS AND SHARP EDGES.
2. CLEANLINESS PER STD-7022, LEVEL C.
3. QUALITY LEVEL DETERMINATION PER RTC-000073.



① DETAIL
SCALE: 1/4



-1 ISOMETRIC
SCALE: NONE

SHEET	4	3	2	1	REV STATUS OF SHEETS
REV	-	-	-	-	

REVISIONS

REV	DESCRIPTION	EFFECTIVE DATE:

QTY REQD		PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL/SPECIFICATION OR VENDOR NAME	ITEM NO.
		-5	EXPERIMENT BOTTOM	BAR, AL 6061-T651 OR 6061-T6511 ASTM B211 OR B221	5
		-4	RECEIVER BOTTOM	BAR, AL 6061-T651 OR 6061-T6511 ASTM B211 OR B221	4
		-3	RECEIVER LIFTING PLATE	PLATE, 1/4 THK AL 6061-T651 ASTM B209	3
		-2	SCREEN MOUNTING PLATE	PLATE, 1/4 THK AL 6061-T651 ASTM B209	2
		-1	RECEIVER BODY	TUBING, 3 OD X .125 WALL AL 6061-T6 ASTM B210 OR B241	1

PARTS LIST

DASH NO.	NEXT ASSY
-5	603871
-4	603872
-3	603872
-2	603872
-1	603872

APPLICATION

DIMENSIONING AND SYMBOLOGY PER ASME Y14.5M AND STD-10011
UNLESS OTHERWISE SPECIFIED SURFACE ROUGHNESS 125
DIMENSIONS AND TOLERANCES ARE IN INCHES
TOLERANCES: X = ± .1
DECIMALS: XX = ± .03
XXX = ± .010
FRACTIONS ± 1/8
ANGULAR ± 2°
DO NOT SCALE DRAWING

REQUESTER: B. NIELSON
RESP ENGR: B. DURTSCHI
DESIGN: B. DURTSCHI
DRAWN: J. TONKS
PROJECT NO.
SPCL CODE NBSR
FOR REVIEW/APPROVAL SIGNATURES SEE ECR NO. 602817
EFFECTIVE DATE:

Idaho National Laboratory

ATR
NATIONAL BUREAU OF STANDARDS REACTOR (NBSR)
FUEL ELEMENT EXPERIMENT
RECEIVER
DETAILS

SIZE	CAGE CODE	INDEX CODE NUMBER AREA	TYPE	CL	ORIG	DWG-	REV
D	01MF3	533	0670	96	081	603873	-

SCALE: NOTED SHEET 1 OF 4

ATR9991

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Path: C:\Vaultlocal\projects\ATR\Reactor Experiments\NBSR\603873.idw
File:603873R-
Date:7/24/2012

Appendix D (Drawings)