RERTR 2022 – 42ND INTERNATIONAL MEETING ON
REDUCED ENRICHMENT FOR RESEARCH AND TEST REACTORS

OCTOBER 3-5, 2022
VIENNA INTERNATIONAL CENTRE
VIENNA, AUSTRIA

Title: A Progress Update on the Highly Enriched Uranium to Low-Enriched Uranium Fuel Conversion at the University of Missouri Research Reactor

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ABSTRACT

The University of Missouri Research Reactor (MURR®) is a 10 MW research reactor on the campus of the University of Missouri in Columbia, Missouri. Safety and performance analyses, fuel fabrication, and fuel qualification efforts have been completed and are continuing in support of converting MURR from highly enriched uranium (HEU) U-Al_x dispersion fuel to low-enriched uranium (LEU) monolithic fuel consisting of uranium-10 wt% molybdenum (U-10Mo). Recent progress includes completion of end fitting structural rigidity analysis of the MURR LEU fuel element and the MURR Design Demonstration Element (DDE), a release of the LEU fuel element specification and drawings for fabrication, and ongoing work on an impact study of the fuel element specification and drawing tolerances on the neutronics and thermal hydraulic performance of the reactor. These three activities may contribute to further refinement of the MURR specification and drawings and fabrication of the LEU fuel element for conversion.

1 Introduction

The University of Missouri Research Reactor (MURR®), located on the campus of the University of Missouri – Columbia in Columbia, Missouri, is a 10 MW_{th} research reactor that provides a broad array of irradiation services, including radiopharmaceutical isotopes, radiochemistry, education, and various other research projects. MURR is one of six United States (U.S.) high performance research and test reactors (USHPRR) (including one critical facility) that plans to convert from highly enriched uranium (HEU) fuel to low-enriched uranium (LEU) fuel under the direction of the U.S. Department of Energy (DOE) National

Nuclear Safety Administration (NNSA) Office of Material Management and Minimization (M^3) Reactor Conversion Program. The MURR core consists of eight fuel elements loaded in an annular configuration around a central flux trap. MURR intends to convert from its current HEU U-Al_x dispersion fuel to an LEU alloy of U-10 wt% Mo (U-10Mo). This fuel system has undergone fuel development, demonstration testing, and commercial fabrication development efforts, and these efforts continue today, with testing, fabrication campaigns, and fuel qualification planned into the future.

In partnership with the NNSA M^3 Conversion Program USHPRR Project Reactor Conversion (RC) Pillar, led by Argonne National Laboratory, MURR has completed safety and performance analyses for both prototypic mixed-burnup equilibrium cores and the sequence of transition cores that moves from the initial all-fresh LEU core to prototypic mixed-burnup operations [1, 2]. These preliminary analyses for the fuel conversion at MURR, along with an increase of its operating power from 10 MW to 12 MW and a change to the reactor Technical Specifications, met all safety acceptance criteria and provides experiment performance that was equivalent to current HEU metrics.

This paper summarizes work that has recently been completed to evaluate the structural rigidity provided by the end fittings of the MURR LEU fuel element and the MURR Design Demonstration Element (DDE). In lieu of a lead test element being directly inserted into the MURR core, the MURR DDE will be irradiated at the Idaho National Laboratory (INL) Advanced Test Reactor (ATR). MURR DDE will be irradiated at conditions as close to the prototypic MURR operating conditions as possible. Because the end fittings for the MURR LEU fuel element and the MURR DDE are different, analysis was done to assess the effect of the end fittings on the stiffness of the two elements, and how the stiffness differs between the elements.

Other work that has recently been completed is the approval and release of a specification and drawings for the fabrication of the MURR LEU fuel element. Work is currently underway to evaluate impacts induced by parameter variations within and beyond the fabrication tolerances of the MURR LEU fuel element. These fabrication parameters affect key design characteristics, specifically shutdown margin, operating cycle length, onset of flow instability (OFI) power, critical heat flux ratio (CHFR), and fuel temperature. The requirements for these design characteristics must be met within the bounds of the fabrication parameter variations. This activity is being completed in collaboration with the Fuel Fabrication (FF) Pillar, led by Pacific Northwest National Laboratory (PNNL). This paper details some of the early results of this activity.

Finally, an overview of recently completed and current activities is summarized. In addition to the fabrication specification impacts analysis discussed previously, a major effort will be undertaken in the next year to verify aspects of the preliminary design for the MURR LEU core under Nuclear Quality Assurance (NQA-1) standards. Work will also continue on a planned revision of the MURR LEU specification and drawings that will incorporate results from the fabrication specification impacts analysis and fuel plate fabrication demonstrations.

2 MURR LEU Fuel Element and DDE End Fitting Structural Rigidity Analysis

As part of the effort to qualify the LEU U-10Mo fuel, mini-plate and large-plate irradiations have been successfully performed by the USHPRR Fuel Qualification (FQ) Pillar, led by INL. As an additional demonstration test, a full element that is prototypic of the MURR LEU fuel element design, identified as the MURR DDE, will be irradiated in the ATR at INL.

MURR DDE is required to have the same geometry of the fuel plates and coolant channel gaps as those in the MURR LEU fuel element. However, design changes relative to the MURR LEU fuel element are allowed to facilitate required inspections and to accommodate the experiment assembly in the ATR flux-trap test position. For this reason, the conceptual design of the MURR DDE end fittings (EF) is substantially different from that of the end fittings in the MURR preliminary LEU fuel element [3]. Isometric views of the MURR LEU fuel element and the MURR DDE (referred to as the LEU fuel element and the DDE throughout the remainder of this paper) are shown in Figure 1. The LEU fuel element has an identical design for the top and bottom end fittings. The DDE top end fitting is simplified to allow for easier access for the channel gap inspections. The DDE bottom end fitting is also different, but similar in shape to the LEU fuel element end fitting. Also, while the end fittings in LEU fuel element are equidistant from the fuel plates on both ends (2.25 inch), the axial location of the top end fitting in the DDE is closer to the fuel plates (0.5 inch) and the bottom end fitting is further from the fuel plates (5.5 inch). Finally, the overall length of the DDE (33.25 inch) is 0.75 inch greater than that of the LEU fuel element (32.5 inch). Because of these design changes, the stiffness of the end fittings and the entire element could be affected.

The design objective of MURR DDE is to be prototypic of the MURR LEU fuel element. In work documented in Reference [3] and summarized here, the structural responses of the MURR LEU fuel element and MURR DDE under hydraulic and thermal loads are analyzed. This has been done to assess the stiffness of MURR DDE relative to the MURR LEU fuel element to confirm the prototypic nature of the demonstration experiment. The relative contribution of the end fittings to the overall stiffness of the two types of elements has also been evaluated.

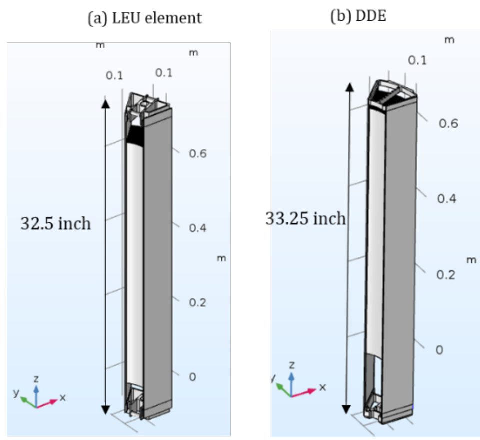

Figure 1: Isometric view of (a) MURR LEU fuel element and (b) MURR DDE

Four finite element (FE) models were developed in the COMSOL Multiphysics 5.3a software [4] for this analysis to represent the LEU fuel element and the DDE with and without the end fittings. The models without end fittings were built to evaluate the contribution of the end fittings to the overall stiffness of the elements under the specified loads. Identical mechanical constraints were used in the models of both the LEU fuel element and the DDE to facilitate the comparison of the relative stiffnesses of the elements. The constraints primarily prevent the rigid body motions in the simulations.

Two loading cases of most interest are considered in this paper: 1) hydraulic load due to the flow-induced pressure differential on a fuel plate and 2) thermal load due to the thermal expansion induced by the non-uniform temperature field within the element. Note that both the hydraulic and thermal loads are simplified, but remain representative, for the comparison between the LEU fuel element and the DDE.

In previous work [5], preliminary fluid-structure interaction (FSI) simulations were performed for the MURR LEU fuel element on a geometry of a single LEU plate and two surrounding channels. The simulated plate represented plate 22 (the second outermost fuel plate) of the LEU fuel element. In the current work, the pressure differential distribution extracted from [5] is applied to plate 22 for the hydraulic load case.

For the thermal load case, because the fluid flow and heat transfer are not considered, the temperature field is needed as a model input to characterize the thermal strain in the components of the fuel element (including all 23 fuel plates). The input temperature field was obtained using the software PLTEMP/ANL v.4.3 [6] for the element with the highest temperature in a prototypic mixed-burnup equilibrium LEU core (beginning-of-life, fresh element). The temperatures of the top and bottom end fittings are assumed to be the inlet and outlet coolant temperatures, respectively, and the average coolant temperature among all channels is used to represent the side plate temperature distribution.

For the fresh element, the increased temperature of the fuel relative to the reference temperature (assumed to be 20 °C) causes thermal strain. Elastic, unirradiated properties govern the behavior of the fuel elements at that stage. The irradiation-induced effects are outside the scope of the present work, which focuses only on the relative rigidity of the fuel elements, encompassing the linear elastic effects only. In this work, the elastic properties of aluminum alloy 6061 (AA6061) are used to represent the whole element.

For both the LEU fuel element and the DDE, supporting combs (made of AA6061) are present on the leading and trailing edges of the fuel plates. The comb is installed in the center of the span of the fuel plates span to reduce the deflection of the plates. The comb is connected to the plates by a pin that goes through all plates. However, the comb slots (where the fuel plates slide in) are 6 mil (1 mil = 0.001 inch) thicker than the plates [7]. Therefore, if it is assumed that the plate is perfectly centered in the comb slot, there will be a gap of 3 mil for the deflection of the plate with limited restrictions provided by the comb and the pin.

As a result, if the plate displacement is very small, the effect of the comb could be negligible, and if the displacement is large, the support from the comb should be considered. In this work, the simulations with and without the combs are performed as two bounding cases. For the simulation cases with the combs, the gaps between the comb and the plates are neglected and a perfect bond between the comb and the plates is assumed.

Table 1 presents the maximum displacements calculated for all models under the hydraulic load. With the combs, the maximum displacement for the LEU fuel element and the DDE occurs at around one-quarter of the plate length downstream from the leading edge. The predicted maximum displacement magnitude is similar for both the LEU fuel element and the DDE including the cases without end fittings. Without the combs, the maximum displacement for the LEU fuel element and the DDE occurs at the leading edge. Note that the maximum displacement (shown in Table 1) in the model of the DDE with the end fitting but without the comb is about 16% smaller than the maximum displacement in the corresponding model of the LEU fuel element. This is because the distance between the top end fitting and the fuel plates in the DDE is smaller than that in the LEU fuel element, so the DDE end fitting can provide more support through the side plates to reduce plate deflection. Therefore, the model of the DDE element without end fittings predicts 24% higher displacement compared to the model of the DDE element with end fittings. For the LEU element without the comb, the case without end fittings predicts a 2% higher maximum displacement compared to the case with end fittings, indicating that for the LEU element the end fittings have a small contribution to the stiffness of the fuel plate under the analyzed hydraulic load.

Table 1: Maximum Displacement Under Hydraulic Load

Fuel element type	Maximum displacement (mil)	
	With comb	**Without comb**
LEU	0.619	1.049
LEU w/o EF	0.619	1.072
DDE	0.620	0.877
DDE w/o EF	0.621	1.087

The maximum displacement for all models under the thermal load is presented in Table 2. No significant difference was observed between the LEU fuel element and the DDE in the structural response under the simulated thermal load. Also, the contribution of the stiffness of the end fittings to the stiffness of the overall element under the thermal load was found to be not substantial. To evaluate the effect of thermal expansion on channel gap thickness reduction, the maximum channel gap reduction due to horizontal displacement is also listed in Table 2. Channel 23 is selected as an example. For the cases with the comb, the minimum channel 23 gap thickness (between fuel plates 22 and 23) occurs at the upper part of the plate, with a value of 0.81 mil less than the nominal thickness of 93 mil. For the cases without the comb, the minimum channel gap thickness occurs at the trailing edge because of the inward displacement of plate 23 at this position. The value is around 2.4 mil smaller than the nominal value (93 mil) for all four cases.

Table 2: Maximum Displacement Results Under Thermal Load

	Fuel Element Type	Max. Disp. (mil)	Max. Horizontal Disp. (mil)	Channel 23 Gap Reduction (mil)
With comb	LEU	35.9	13.7	0.81
	LEU w/o EF	36.4	13.9	0.81
	DDE	37.6	13.7	0.81
	DDE w/o EF	37.6	13.9	0.81
Without comb	LEU	35.9	14.9	2.44
	LEU w/o EF	36.3	15.7	2.42
	DDE	37.5	15.3	2.43
	DDE w/o EF	37.5	15.9	2.41

In summary, simplified structural analyses of both the MURR LEU fuel element and the MURR DDE were performed to evaluate the relative contribution of the end fittings to the overall stiffness of both elements and to determine whether the structural response of the DDE is similar to that of the LEU fuel element under hydraulic and thermal loads that are assumed to be similar for both elements.

For the two types of loads analyzed, no significant difference in rigidity was found between the LEU element and the DDE. The conceptual design of the DDE end fittings was found to be adequate for ensuring that the DDE will have a structural response to these loads that are prototypic for the MURR LEU fuel element.

3 Fabrication Specification and Impacts Analysis

As a part of efforts to convert MURR to LEU fuel, an LEU fuel element design comprised of 23 curved plates with a very high density U-10Mo alloy fuel core was developed during preliminary design work for both prototypic mixed-burnup equilibrium cores and the sequence of transition cores that moves from the initial all-fresh LEU core to prototypic mixed-burnup operations [1, 2]. These preliminary analyses for the fuel conversion at MURR, along with an increase of its operating power from 10 MW to 12 MW and a change to the reactor Technical Specifications, showed margins to safety comparable with current HEU operations. The design also demonstrates equivalent performance for nearly 500 experimental performance metrics, identified by specialists at MURR, which are key to meeting the scientific mission of the facility.

A specification and drawings for fabrication of the MURR LEU fuel element [7] were recently approved and released. The specification and drawings were reviewed by a newly formed LEU Fuel Element Design Authority (DA) Team that has the responsibility to review and approve reactor-specific specifications suitable for licensing and procurement of commercial LEU fuel for conversion and operation of the USHPRR, including MURR. This DA Team is comprised of the reactor operator, subject matter experts across pillar organizations, and representation by the current fuel fabricator. Future revisions of the specification and drawings are planned to improve key product characteristics, incorporate feedback from earlier reviews requiring major revisions, and update aspects of the design based on data documented from fuel plate fabrication demonstrations and fabrication specification impact analysis.

The specification and drawings include critical parameters that impact reactor operations. MURR and Argonne staff have identified seven critical parameters to assess their impact:

- U-235 enrichment
- U-235 element mass loading
- Fuel plate thickness

- Impurities in fuel and cladding
- Fuel homogeneity
- Coolant channel gap thickness
- Boehmite oxide layer thickness from pre-treatment

Each of these parameters has a nominal value called out in the specification or drawings, along with a tolerance range. While the nominal values for each of these critical parameters have been analyzed extensively in a wide range of prior work, the specified tolerance ranges for each of the parameters have not been analyzed for their impact on key design characteristics of the reactor. These key design characteristics for MURR, and their requirements, are detailed in Table 3.

Table 3: MURR Key Design Characteristics and Requirements

Design Characteristic	Requirement
Shutdown Margin	≥ 2% Δk/k
Operating Cycle Length	6.3 Days (Prototypic)
OFI Power	No OFI at Limiting Safety Systems Settings (LSSS) Power
CHFR at LSSS Power	≥ 2
Fuel Temperature	< Fuel Temperature Safety Limit (95% lower prediction bound of preliminary fuel blister threshold temperature)

While most of these analyses are independently evaluated between neutronics and thermal hydraulics, the combined effects on both neutronics and thermal hydraulics have been evaluated for the OFI power and CHFR based on a change to the fuel composition, U-235 mass loading, and the fuel plate thickness. An increase in U-235 mass (or a decrease in fuel impurities) will increase the excess reactivity in the reactor, necessitating the control blades to be more deeply inserted to maintain the critical state of the reactor. Likewise, because MURR has a negative void reactivity coefficient in the core, a decrease in the plate thickness increases the amount of moderation in the core, increasing the excess reactivity. The control blades again have to be more deeply inserted to compensate for this increase in reactivity, which affects the core power distribution. The core power distribution is the foundational input for the OFI power and CHFR calculation, so any change in the power distribution could affect these design characteristics.

Table 4 lists the fabrication parameters that were varied for this analysis. Two cases were analyzed, labeled "off-normal" and "high reactivity." These cases were deviations of the "prototypic" fresh LEU fuel composition. These two cases represent conservative core conditions that will increase core reactivity and affect OFI power and CHFR. The prototypic and standard deviation values for the fuel definition come from the Process Design Standard-1 (PD-STD-1) assay data [8].

Table 4: Cases Analyzed for Combined Neutronics/Thermal Hydraulics Impact

Design Parameter	Case 1 (Off-Normal)	Case 2 (High Reactivity)
U-235 Element Mass Loading	5% Overload (5x Spec Limit)	5% Overload (5x Spec Limit)
Fuel Impurities	Prototypic	+2σ U-235 -2σ U-234, U-236, and Impurities
Plate Thickness	-2 mil (1x Spec Limit)	-2 mil (1x Spec Limit)

The power distribution was calculated using MCNP5 version 1.60 [9]. The fuel core is subdivided into nine azimuthal "stripes": three 5 mm stripes on each edge of the fuel core and three equal arclength stripes in the middle of the fuel core. Each fuel core is further subdivided into 24 axial segments, making a 9x24 mesh on each of the 23 fuel cores. The power generation rate is calculated using the f7 tally in MCNP5, then normalized to a total core power of 12 MW. The resultant tallies are then processed and used as an input to the thermal hydraulics software PLTEMP/ANL [6]. The PLTEMP/ANL model for the MURR core includes all eight fuel elements including 23 fuel plates and 24 coolant channels for each element. To avoid OFI at LSSS power, OFI power, which is defined as the minimum reactor power at which the OFI occurs (OFI ratio of 1.0), needs to be greater than the LSSS power of 15 MW. To obtain the OFI power, PLTEMP/ANL performs power iterations until OFIR of 1.0 for one channel is obtained using the Whittle and Forgan correlation. For the CHFR criterion, a single PLTEMP/ANL calculation is performed to determine the minimum CHFR for a given core case using the extended Groeneveld CHF lookup table (2006).

Table 5 details the results of cases evaluated for the combined neutronics/thermal hydraulics impact from changes in U-235 loading, fuel composition, and plate thickness conditions summarized in Table 4 for all-fresh LEU core. Each case was evaluated for the MURR core loaded with eight fresh LEU fuel elements. For prior thermal hydraulics safety analysis, one of the user-supplied hot channel factors was based on an assumed 10% uncertainty for the predictions of the fuel plate stripe-averaged and local heat flux under nominal conditions. This heat flux uncertainty impacts both the OFI power and CHFR calculated with the PLTEMP/ANL model. The results of the neutronics calculations show that for both the off-normal and high reactivity cases the maximum change in the stripe-average heat flux is well below the 10% uncertainty assumed in the thermal hydraulics analysis. The change in the local heat flux exceeds the 10% uncertainty assumption at certain positions. However, these positions are in areas of relatively little importance with regard to safety margins. In areas of high importance, the heat flux change is less than the 10% uncertainty assumed in the analysis. The PLTEMP/ANL results show that for the combined neutronics/thermal hydraulics analysis there are only very slight reductions in the predicted OFI power and CHFR relative to the base case for the all-fresh LEU core.

Table 5: Cases Analyzed for Combined Neutronics/Thermal Hydraulics Impact on All-Fresh LEU Core

Case	Stripe-averaged heat flux change	Local heat flux change	OFI power, MW	CHFR at LSSS power
Base case	-	-	19.7	2.68
Off-Normal	Max 3.1%	Max. 15% (6.9% at locations of interest)	19.1 (2.8% reduction)	2.65
High Reactivity	Max. 3.3%	Max. 21% (7.2% at locations of interest)	19.2 (2.7% reduction)	2.67

It should be noted that the results shown above were obtained with the 10% local heat flux uncertainty even though the perturbations in the core power distributions were explicitly modeled. This is a conservative approach since the uncertainties in power distribution calculation are overestimated. Therefore, the results indicate that the thermal hydraulics safety margins are not very sensitive to the conditions affecting the core neutronics and that this sensitivity analysis on core power distribution does not need to be performed going forward (since the perturbations are well-bounded by the 10% uncertainty factor already included in the analysis).

The results presented are from the all-fresh LEU core. However, previous thermal hydraulics analysis on the transition cycles and equilibrium LEU operation indicates that the minimum margins for both OFI and CHF occur on more burned cores (transition cycle 28 and equilibrium LEU core). Therefore, more limiting core configurations are planned to be evaluated in future work to evaluate the impact of the fabrication specifications on the cores of interest as determined by prior transition core analysis.

Other preliminary results for a fresh LEU core have also been obtained for the MURR fabrication specification impact analysis and are summarized in Table 6. Each of these impacts is assessed independently as either neutronics or thermal hydraulics impacts, and not in combination. The most significant impacts are seen to be from the impurities in the AA6061 cladding and the fuel plate thickness.

The MURR LEU fuel element specification places limits on the weight fractions of boron, lithium, and cadmium in the AA6061 cladding. In combination, these impurities have an equivalent boron concentration (EBC) of 67 ppm, compared to an EBC of 17.9 ppm for the alloying nuclides and impurities determined through a recent assay of prototypic material. Consequently, when the cladding impurities in all eight fuel elements in the MURR core are modeled at the limits allowed in the specification there is a significant impact on the reactor's operating cycle length, which is typically 6.3 days. It is, therefore, expected that the cladding impurity limits will need to be carefully considered in consultation with the DA Team in a future revision of the MURR LEU fuel element specification. Also, due to the sensitivity of MURR to moderation/voiding in the core, the fuel plate thickness should be controlled to the maximum extent possible to ensure that the minimum reactor shutdown margin (SDM) requirements are met for the initial all fresh LEU core. Plate fabrication demonstration data are expected to provide more information as to the controllability of the fuel plate thickness.

Table 6: Summary of Initial Results for MURR Fabrication Specification Impacts Analysis for Fresh LEU Core

Parameter		**Nominal Value**	**Current Fabrication Tolerance**	**Impact: OFI Power, Min. SDM = 2% (Nom. 2.05%), Typ. Cycle Length = 6.3 days, ~6 days available @ EOC**
U-235 Enrichment		19.75 wt%	±0.2%	SDM = 2.00% @ 19.95 wt% U-235
Fuel Mass Loading (Element)		1507g U-235	±1.0% (15g)	SDM = 2.01% @ 1522 g U-235
Fuel Plate Thickness				
Plates 1 through 22		44 mil	±2 mil	SDM = 1.46% @ 8 fuel elements -2 mil (not credible)
Plate 23		49 mil	±2 mil	SDM = 2.00% @ 1 fuel element -1.5 mil (beyond -2σ, assuming normal distribution for -2 mil tolerance)
Impurities	Fuel	PD-STD-1: 4.0 EBC	< 5 ppm EBC	-0.08 Days @ 5 EBC (8 fuel elements)
	Cladding	2020 Assay: 17.9 EBC (18 nuclides)	< 30 ppm B, 80 ppm Li & Cd (67 EBC)	-3.5 Days @ 80 EBC (8 fuel elements) (18 nuclides)
Coolant Channel Gap	Interior Channels	Chan. 2-5 & 20-23: 93 mil, Rest: 92 mil	±8 mil	OFI power less than LSSS power at 2x lower spec limit
	End Channels	80.5 mil to roller	±13 mil	
Fuel Homogeneity (0.2-inch wide stripe average)		N/A	±4% to ±9%, depending on plate	OFI power above LSSS power for all cases to 3x upper spec

4 Conclusions and Future Work

As a part of the ongoing effort to convert MURR to LEU fuel, several activities have recently been completed, and many activities are either ongoing or planned for future work.

Among the work which has been completed recently is an evaluation of the rigidity of the MURR LEU fuel element and MURR DDE provided by their respective end fitting designs. Predictions from finite element modeling have demonstrated that the differences in the end fitting designs and their position relative to the fuel plates in the MURR DDE have a negligible impact on the element rigidity compared to that in the MURR LEU fuel element for all loads considered, especially if the comb is considered. Both the MURR LEU fuel element and MURR DDE are planned to include a comb.

Additionally, a specification and drawings for the fabrication of the MURR LEU fuel element have been approved by the LEU Fuel Element Design Authority and released.

Work is currently underway to evaluate impacts induced by parameter variations within and beyond the fabrication tolerances for the MURR LEU fuel element. This impact assessment includes combined neutronics/thermal hydraulics analysis for some cases. Where the impact of simultaneous variations to the element fuel mass loading, fuel composition, and fuel plate thickness on the core power distribution in an all-fresh LEU core are considered, it has been found that the predicted OFI power and CHFR are not significantly impacted by more conservative off-normal and higher reactivity cases relative to nominal conditions. Further analyses remain to be done with more limiting core states to ensure that prior safety analyses are still valid for the MURR LEU core design when combined neutronics/thermal hydraulics impacts are considered.

Where neutronics and thermal hydraulics impacts due to fabrication parameter variations are treated independently, the importance of two key parameters has been identified. First, it was found that the MURR weekly operating cycle length is significantly impacted if the fuel plate cladding in all eight elements in the core is at the cladding impurity limits allowed by the current MURR LEU fuel element specification. The cladding of all eight elements at the specification limit is a very conservative assumption. Presently, impurities in the cladding used for HEU operations are considerably less than these high impurity limits. The preliminary recommendation to address this impact is to utilize the lower cladding impurities feedstocks that are available and to set specification limits based on the impurities presently found in the feedstock material. Second, the fuel plate thickness tolerance has been identified as a key parameter impacting the predicted reactor minimum shutdown margin. Analysis is continuing to properly understand the credibility of various scenarios of the fuel plate thicknesses (i.e., number of thin plates in the MURR core and the range of fuel plate thicknesses within the specification) and the impact of these scenarios on the shutdown margin.

Finally, near-term future work is planned to be completed in key areas. Among these key areas are:

- Fabrication specification impact analysis (continuation of work described above), including iterations with the FF Pillar;
- Preliminary design verification (PDV) to be performed per Nuclear Quality Assurance (NQA-1) standards, including alternate calculations for neutronics and radiological consequences (PDV of thermal hydraulics analysis has already been completed);
- Structural & FSI analysis for the MURR LEU fuel element; and
- Planned revisions to the MURR LEU fuel element specification and drawings to incorporate changes to improve key product characteristics, incorporate feedback from earlier reviews requiring major revisions, and update aspects of the design based on data documented from the fabrication specification impact analysis and fuel plate fabrication demonstrations. This work will be completed in consultation with the LEU Fuel Element Design Authority Team.

5 Acknowledgement

This work was sponsored by the U.S. Department of Energy, Office of Material Management and Minimization in the U.S. National Nuclear Security Administration Office of Defense Nuclear Nonproliferation under Contract DE-AC02-06CH11357.

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