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Modeling Assumptions for the Advanced Test Reactor Fresh Fuel Shipping Container

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MODELING ASSUMPTIONS FOR THE ADVANCED TEST REACTOR FRESH FUEL SHIPPING CONTAINER

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The Advanced Test Reactor Fresh Fuel Shipping Container (ATR FFSC) is currently licensed per 10 CFR 71 (Ref. 1) to transport a fresh fuel element for either the Advanced Test Reactor, the University of Missouri Research Reactor (MURR), or the Massachusetts Institute of Technology Research Reactor (MITR-II). During the licensing process, the Nuclear Regulatory Commission (NRC) raised a number of issues relating to the criticality analysis, namely (1) lack of a tolerance study on the fuel and packaging, (2) moderation conditions during normal conditions of transport (NCT), (3) treatment of minor hydrogenous packaging materials, and (4) treatment of potential fuel damage under hypothetical accident conditions (HAC). These concerns were adequately addressed by modifying the criticality analysis. A tolerance study was added for both the packaging and fuel elements, full-moderation was included in the NCT models, minor hydrogenous packaging materials were included, and fuel element damage was considered for the MURR and MITR-II fuel types.

I. INTRODUCTION

The ATR FFSC (NRC Docket Number 71-9330, Ref. 2) has been designed to transport fresh research reactor fuels for the ATR, MURR, and MITR-II reactors. All three fuels are high-enriched uranium plate fuels with aluminum cladding and exhibit similar neutronic behavior. Each fuel type is shipped inside a unique fuel handling enclosure (FHE), which is inserted into the circular inner cavity of the ATR FFSC. The ATR FFSC is shown in Figure 1. The ATR, MURR, and MITR-II fuels are shown in Figures 2, 3, and 4, respectively.

During the licensing process with the NRC, a number of questions were raised, leading to extensive rework of the analysis. These additional questions relate to (1) manufacturing tolerances on the fuel elements and packaging, (2) moderation conditions during NCT, (3) treatment of minor hydrogenous packaging materials, and (4) treatment of potential fuel damage during HAC. These concerns and their resolution are discussed in the following sections.

II. MODELING CONSIDERATIONS

II.A. Treatment of Fuel and Packaging Tolerances

The ATR FFSC is comprised of a circular inner tube and a square outer tube made of stainless steel. In the original criticality analysis, the outer tube was not modeled in the HAC analysis. This assumption is highly penalizing, as it significantly reduces the package spacing in the HAC array analysis. It also reduces parasitic neutron absorption in the packaging materials. The conservative effect on the multiplication factor was quite large (Δ=0.220), which was demonstrated in the original analysis.

The ATR FFSC was certified by 9.1 m (30 foot) drop tests. In the drop tests, the outer square tube experienced little damage. Therefore, it was acceptable to take credit for the presence of the outer tube in the criticality analysis, although this was not done. It was stated in the criticality analysis that credit could be taken

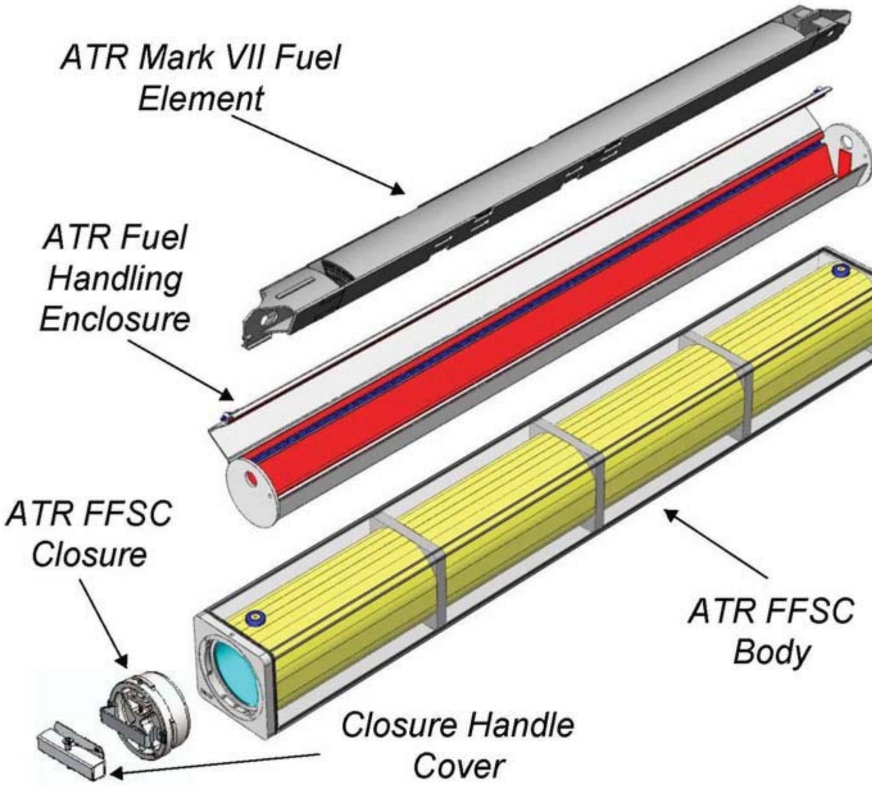

Fig. 1. ATR FFSC and ATR FHE

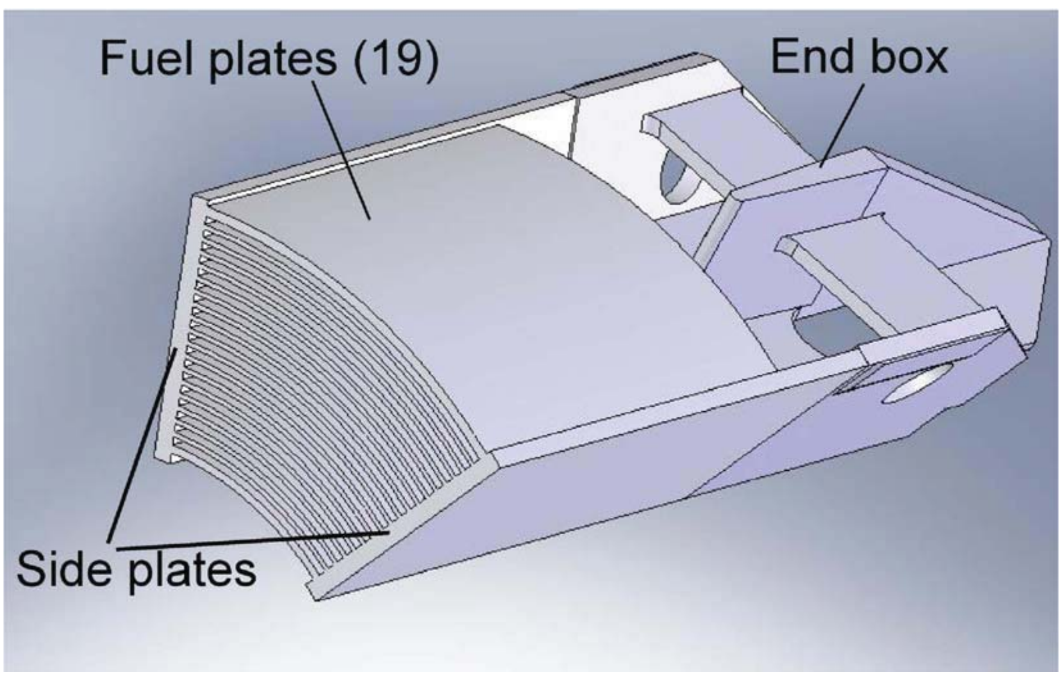

Fig. 2. ATR Fuel Element Section

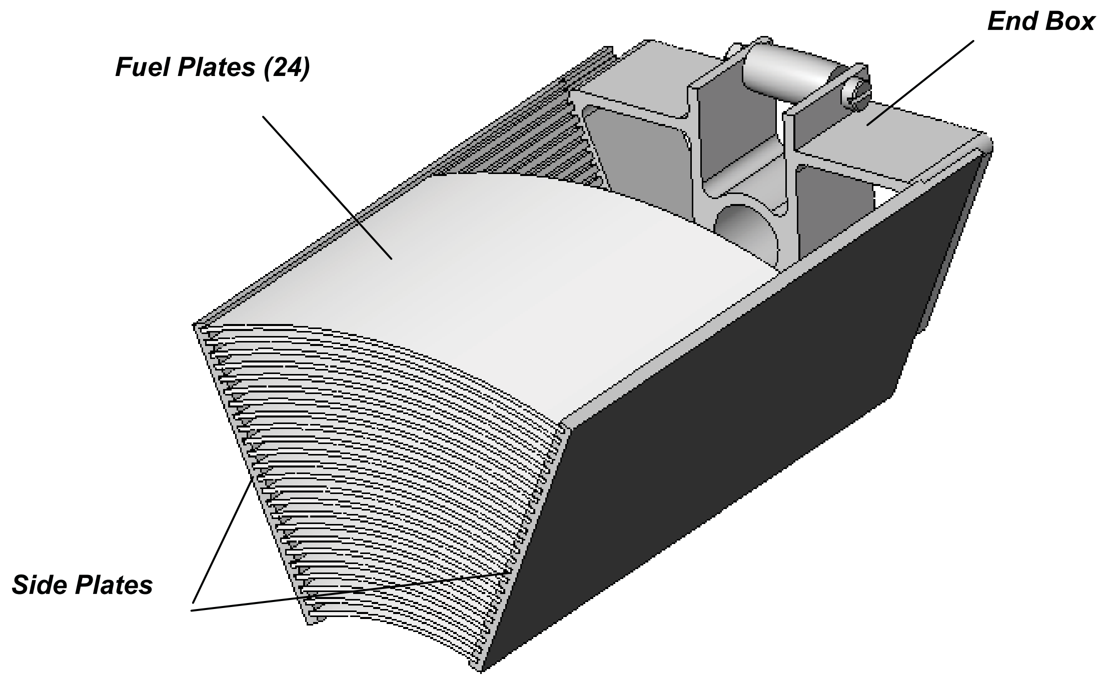

Fig. 3. MURR Fuel Element Section

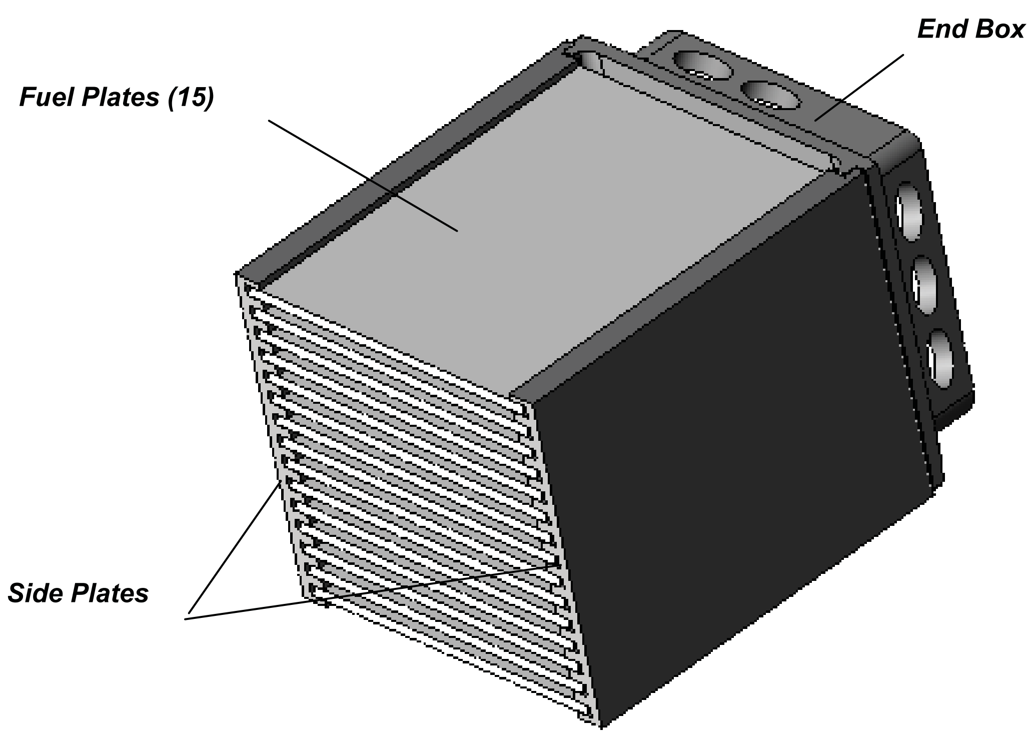

Fig. 4. MITR-II Fuel Element Section

for the outer square tube, if desired. The intent of including such large conservatisms was to demonstrate that the system remained subcritical under extreme, non-realistic conditions. However, because of the many conservative assumptions, the most reactive cases approached the upper subcritical limit (USL).

Because the most reactive cases approached the USL, the NRC requested that the analysis include a full treatment of tolerances in the packaging materials and the fuel elements, as both the packaging and fuel had been modeled at nominal values. Although it was understood that the model contained very large conservatisms as a result of not modeling the outer steel tube under HAC, this tolerance study resulted in the USL being exceeded by a small margin. Consideration of tolerances had the largest effect in regards to the gap between the fuel plates, as increasing the gap increases system moderation and hence reactivity. To reduce the system reactivity, the outer square steel tube was added to the criticality models, which pushed the fuel elements apart significantly. Once the outer steel tube was added, the reactivity dropped significantly, and the positive reactivity effect of the worst-case tolerances was negligible.

The lesson learned is that credit should be taken for structural members that provide significant criticality control if it has been demonstrated that these items retain structural integrity under HAC. Had the original analysis taken credit for this outer steel tube, it is quite possible the NRC would not have required a study of the tolerances, since the final maximum reactivity was significantly below the USL.

II.B. Moderation Conditions during Normal Conditions of Transport

The ATR FFSC is not a leaktight package. Because the ATR FFSC is transported horizontally in an enclosed transport vehicle, there was no credible mechanism by which the ATR FFSC could be flooded under NCT. Therefore, dry conditions were utilized in the NCT analysis.

The NRC challenged the assumption of a dry package under NCT because the package is not leaktight. A water spray test described in 10 CFR 71.71(c)(6) is designed to simulate a 5.1 cm/hour (2 in/hour) rainfall for a 1 hour time period. This test had not been performed on the ATR FFSC because the primary intent of the test is to demonstrate that the package does not disintegrate when subjected to a water environment, which is not a concern for a stainless steel package. However, this test could be used to justify the quantity of water ingress during NCT.

To satisfy the NRC concerns, full-moderation was utilized in the NCT models. Optionally, the water spray test could have been performed and the measured water ingress used in the analysis, although this approach would be expensive. Alternately, the maximum water ingress could have been estimated using conservative assumptions and the known test rainfall rate, although it was decided to use the more conservative full-moderation assumption out of simplicity.

The lesson learned is that dry NCT conditions may be utilized only if a package is leaktight. If a package is not leaktight, the quantity of water ingress during NCT may be determined by test, or estimated using conservative assumptions. Alternately, full-moderation may be conservatively used for NCT analyses.

II.C. Treatment of Hydrogenous Packaging Material

The ATR FFSC utilizes 3.2 mm (1/8 in) thick neoprene padding attached to the FHEs. This padding is used to protect the fuel elements from scratches during transport. Neoprene contains hydrogen (chemical composition C_4H_5Cl), and therefore will moderate neutrons to some degree. In the criticality models, the neoprene was neglected for simplicity, because the effect on the reactivity would be small in the HAC cases, which were fully flooded. In the original NCT models, which were not moderated by water, the neoprene might have more impact.

The NRC requested that the moderating effect of the neoprene be addressed. Therefore, the analysis was modified to address neoprene explicitly. The results showed that including neoprene in the models actually reduced the reactivity due to absorption in chlorine. Because the condition of the neoprene is unknown after a fire event, to avoid potential questions about whether the chlorine remained after an accident, the neoprene was modeled without chlorine in both the NCT and HAC models. The reactivity effect of the chlorine-free neoprene was quite small.

The lesson learned is that hydrogenous packaging materials should be addressed in the analysis for completeness, even if the effect on the reactivity is small.

II.D. Treatment of Potential Fuel Damage during HAC

The ATR FFSC was certified by 9.1 m (30 foot) drop tests. As part of the testing program, an ATR fuel element was included in the drop tests. The tests resulted in only small, localized damage to the fuel element over the active fuel length, although the end boxes of the ATR fuel element shattered. Because the ATR fuel element was modeled only over the active fuel length, the condition of the end boxes did not affect the criticality analysis, and it was concluded that the ATR fuel element could be modeled with undamaged geometry during HAC. The NRC accepted these modeling assumptions.

However, no tests were performed for either the MURR or MITR-II fuel elements to demonstrate their robustness under HAC. Rather, the criticality analysis simply stated that ATR, MURR, and MITR-II fuels were all aluminum plate-type fuels of similar construction (see Figures 2, 3, and 4) and hence the MURR and MITR-II fuels would behave in a similar manner to the tested ATR fuel during HAC. Therefore, the MURR and MITR-II fuels were modeled as undamaged over the active fuel length during HAC.

The NRC challenged the assumption that the MURR and MITR-II fuels would remain essentially undamaged during HAC because the fuels had not been explicitly tested. In particular, the ATR end boxes absorbed some of the impact energy during the drop, and the designs of the MURR and MITR-II end boxes were not the same. Three options were available: (1) perform drop tests with MURR and MITR-II fuel to assess the impact damage to the fuel, (2) determine the impact damage to the fuel by analysis, and (3) postulate conservative damaged fuel conditions.

The first option was ruled out due to cost and time constraints. The second option was ruled out because a reliable drop analysis of fuel impact would be difficult and costly. The third option was therefore selected. In the absence of hard data, bounding assumptions relating to fuel damage were developed.

Both the MURR and MITR-II fuel elements are undermoderated. Therefore, separating the fuel plates results in a more reactive condition due to an increase in the water gap between the plates. It was postulated that the plates could separate due to damage to the side structural members. Even in an accident, based on the ATR test results, it is not credible that all the plates would completely separate from the fuel element. At most, there could be additional separation between a limited number of plates. As a bounding condition, it was assumed that all fuel plates reconfigured with the largest uniform pitch until the plates were constrained by the FHE. It was further assumed that the MURR and MITR-II FHEs, which are comprised of two pieces with the fuel element sandwiched in between, separated due to failure of the connecting mechanisms. When the FHE damage with worst-case tolerances is combined with a uniform pitch expansion, the degree of fuel damage is quite large and exceeds the worst-case configuration expected based on the ATR test data. Cross-section views of the MCNP5 modeling for both MURR and MITR-II are shown in Figure 5. This approach was accepted by the NRC.

The lesson learned is that expected fuel damage during HAC must be quantified in some manner, either by test, structural analysis, or highly bounding assumptions.

III. CONCLUSIONS

The criticality analysis of the ATR FFSC presented several challenges. The NRC commented on a number of aspects of the analysis, including: (1) the treatment of packaging and fuel element tolerances, (2) moderation conditions during NCT, (3) treatment of hydrogenous packaging materials, and (4) treatment of potential fuel damage during HAC. The lessons learned are: (1) Explicitly consider packaging and fuel element tolerances, particularly if the most reactive case is close to the USL. Also, take credit for all structural components that survive HAC and reduce the reactivity; (2) If the package is not leaktight, some water ingress should be utilized in the NCT analysis. The amount of water may be determined by test, analytically, or alternatively, full moderation may be utilized; (3) Explicitly address all hydrogenous packaging materials, even if the effect on the reactivity is small; and (4) Under HAC, fuel damage should be verified by test or analysis for each fuel type, if possible, or conservative fuel damage assumptions utilized.

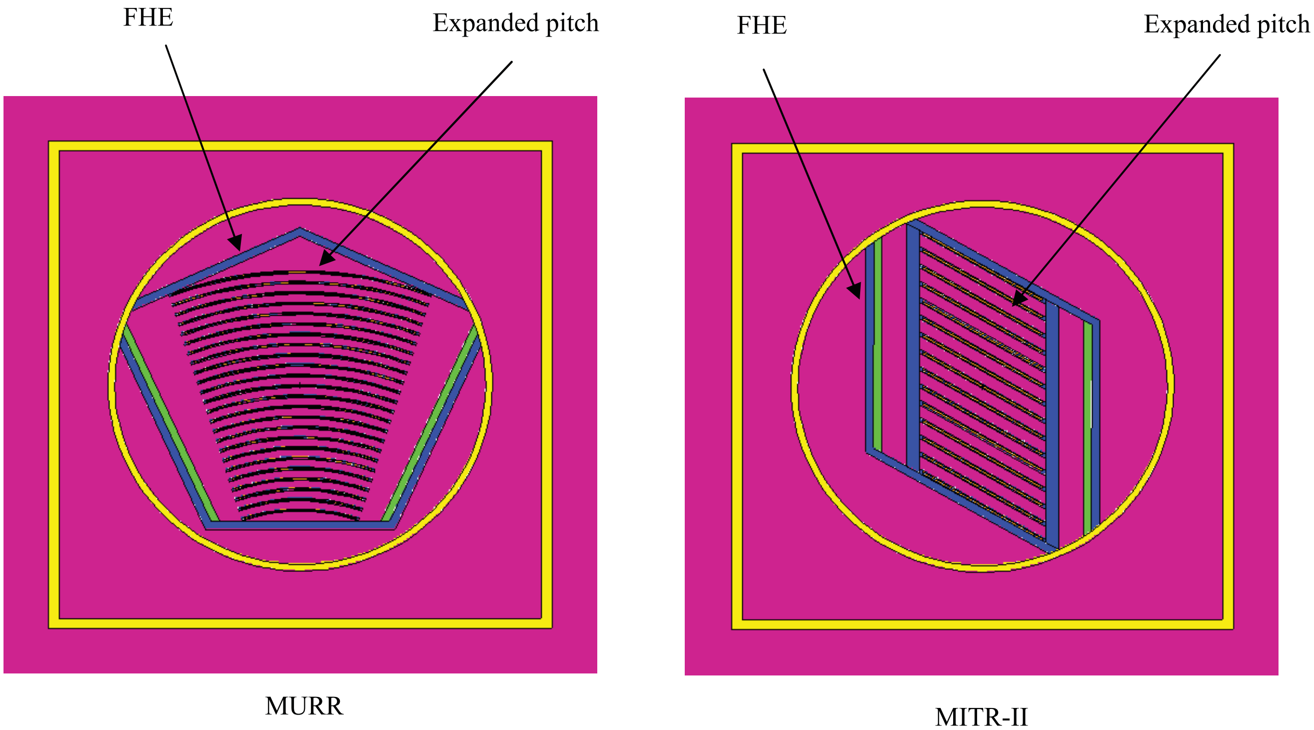

Fig. 5. Damaged MURR and MITR-II Fuel with Expanded Pitch

ACKNOWLEDGMENTS

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REFERENCES

1. Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), *Packaging and Transportation of Radioactive Material* (2006).

2. *Advanced Test Reactor Fresh Fuel Shipping Container*, Revision 4, NRC Docket Number 71-9330, AREVA Federal Services LLC, Tacoma, WA (2009).