The Effects of Impurities in Down-Blending Highly Enriched Uranium on the Reactor Neutronics and Cycle Length

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INTRODUCTION

The NIST Center for Neutron Research (NCNR) National Bureau of Standards Reactor (NBSR) is a 20 MW, heavy water (D_2O) moderated and reflected tank-type research reactor operational since 1967. NBSR has been a vital neutron source for the scientific community since then.

NCNR is collaborating with Brookhaven National Laboratory (BNL) in designing a Replacement Reactor Concept (RRC). RRC is being designed to continue serve the scientific community and to accommodate the increasing demand for the neutron experiments, replacing the aging NBSR.

When conducting a reactor neutronic modeling analysis, many uncertainty sources must be considered, including but not limited to fuel density, stoichiometry, fuel material composition, etc. arising from the fuel production process. One of the most important topics is to provide a proper fuel composition input for the neutronic codes during the modeling of a reactor system. Providing a proper fuel composition will result in high fidelity calculations and also enable correct determination of the Limiting Safety System Settings (LSSS).

The RRC conceptual design uses low-enriched U10-Mo (alloy with 10 % mass fraction Mo) monolithic plate type fuel elements with an enrichment of 19.75 %. The US civilian research and test reactors are planning to use low-enriched uranium (LEU) fuels produced from high-enriched uranium (HEU) by down-blending to 19.75% high assay LEU. Hence, the RRC fuel enrichment is set to 19.75% to be in line with ongoing Nuclear Non-Proliferation efforts. The production of LEU fuel from the HEU for the Research Reactor Uranium Supply Program is governed by the Y-12 National Security Complex [1]. The HEU contains a considerable amount of parasitic uranium isotopes, such as U-232, U-234, and U-236. These parasitic isotopes affect neutronic parameters such as criticality, reactivity, burnup, cycle length, etc. This work aims to determine the effect of parasitic uranium isotopes in fuel composition to the reactor cycle length. As an example, results for the RRC loaded with the downgraded fuel from the HEU, is discussed in detail.

FUEL COMPOSITIONS

Nominal enriched fuel is defined as enriched fuel from the natural composition of uranium to the desired value and contains only U-235 and U-238. The Y-12 LEU fuel is produced by down blending HEU that has been declared surplus to the U.S. national defense needs [1]. Nominal enriched fuel and the Y-12 provided the fuel composition information are given in TABLE. I. TABLE. I shows the limit values of the uranium isotopes and their content in the fuel composition. As shown in TABLE. I, U-232, U-234, and U-236 isotopes maximum limit values are given in the Y-12 fuel composition. The rest of the fuel composition, complement of the total weight percentage, is U-238. Total uranium composition value is less than 100% for Y-12 fuel and given as 99.88%. The difference arises from the transuranics, other fission products and impurities in the fuel content. To simplify the calculations and to observe only the effects of uranium isotopes, the transuranics were replaced with U-238 in the Y-12 fuel composition.

TABLE. I Y-12 Fuel Composition and Nominal Fuel Composition

			Y-12 Fuel	**Nominal Enriched Fuel**
Isotope	**Symbol**	**Units**	**Limit**	**Limit**
Uranium	U-total	wt%U	99.88	100
Uranium-232	U-232	µg/gU	0.002	-
Uranium-234	U-234	wt%U	0.26	-
Uranium-235	U-235	wt%U	19.75	19.75
Uranium-236	U-236	µg/gU	4600	-

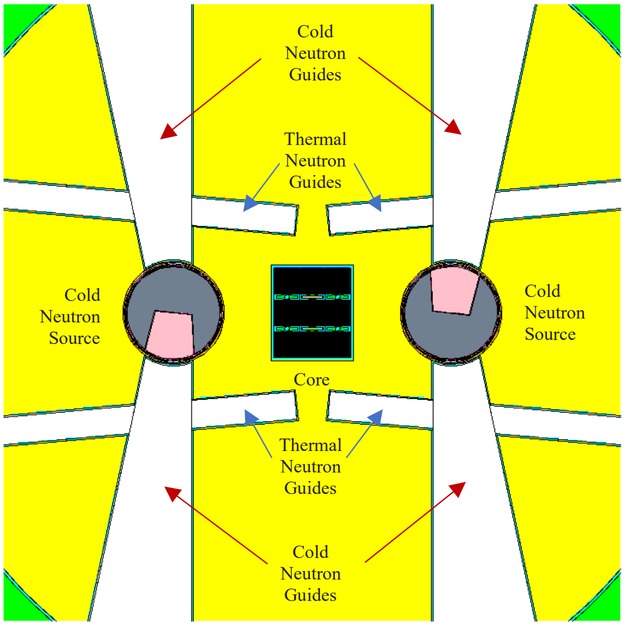

Fig. 1 The RRC central XY view

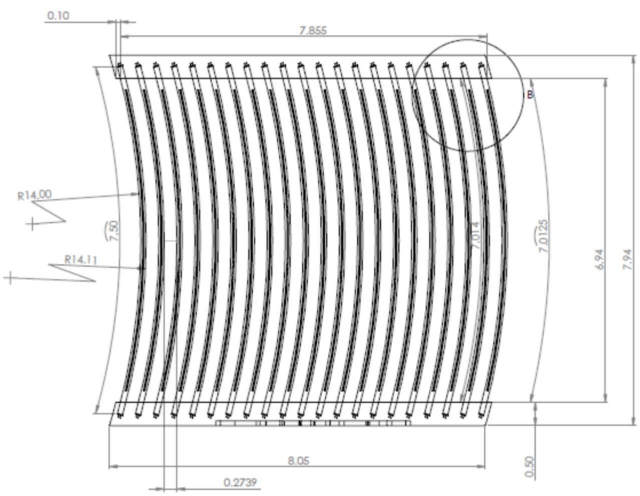

Fig. 2 The RRC assembly XY view

METHODOLOGY

The RRC design is an open-pool type reactor containing 9 fuel assemblies surrounded by beam tubes and cold sources as seen in **Fig. 1**. Each fuel assembly has 21 curved fuel plates as shown in **Fig. 2** and each fuel plate contains 19.75% enriched U-10Mo monolithic type fuel. The previous design composition of the RRC fuel has only U-235 and U-238 isotopes of uranium used in the models **[2]**.

The initial loading composition of the fuel assemblies of the RRC core is created by blending with depleted uranium and Y-12 fuel composition. After initial composition loading is completed, burnup dependent MCNP runs performed in six different cycle states, startup (SU), beginning of cycle (BOC), quarter 2 (Q2), middle of cycle (MOC), quarter 4 (Q4) and end of cycle (EOC) in an operating cycle.

Critical control rod positions are determined for each cycle state before performing the burnup steps. An automated Python **[3]** script directly obtains the criticality values in each cycle state via eigenvalue calculations by changing control rod positions. The script then fits a 5^{th} degree polynomial to determine the critical control rod position. After determination of the critical control rod positions, individual cycle state burnup dependent calculations are performed. As burnup dependent analysis is completed for an individual cycle state, the cycle states' final composition is extracted from the output files and transferred as fuel composition for the next cycle state. After fresh Y-12 fuel composition is loaded to the 3 fresh fuel assemblies, MCNP calculations are performed to determine the cycle length changes for the RRC.

RESULTS AND DISCUSSION

The startup core fuel loading configuration, the first cycle of the RRC, is used for the comparison of Y-12 fuel effects on the RRC's cycle length. The 1^{st} cycle results show a considerable amount of reactivity drop (0.43% reactivity drop) can be observed in **Fig. 3**. This reactivity reduction is due to the parasitic uranium isotope composition in Y-12 fuel. As it can be seen in the **Fig. 3**, when the Y-12 fuel is used in the system, the RRC reactivity reaches about 4 days before to the EOC reactivity result of the nominal fuel.

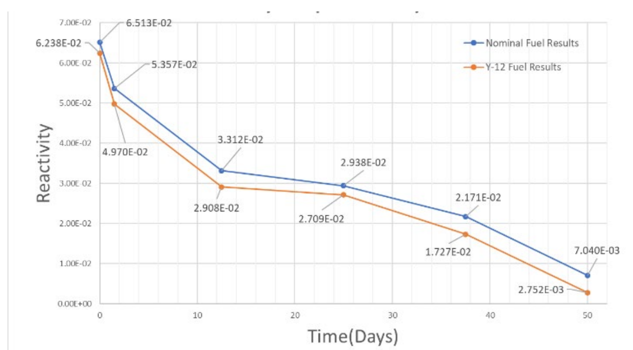

Fig. 3 Reactivity comparison at 1^{st} cycle

This means that Y-12 fuel creates a considerable amount, about 8%, reduction in the cycle length of the RRC. Therefore, potential Y-12 fuel compositions must be considered for research and test reactors to be converted to the LEU fuel from the HEU fuel in the near future to ensure predictable reactor operations.

ACKNOWLEDGEMENTS

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DISCLAIMER

Certain commercial equipment, instruments, or materials are identified in this study in order to specify the experimental procedure adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the materials or equipment identified are necessarily the best available for the purpose.

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