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Reactor physics phenomena in additively manufactured control elements for the High Flux Isotope Reactor ☆

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ABSTRACT

Additive manufacturing is under investigation as a novel method of fabricating the control elements (CEs) of the High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory with greater simplicity, eliminating numerous highly complex fabrication steps and thereby offering potential for significant savings in cost, time, and effort. This process yields a unique CE design with lumped absorbers, a departure from traditionally manufactured CEs with uniformly distributed absorbing material. This study undertakes a neutronics analysis of the impact of additively manufactured CEs on the HFIR core physics, seeking preliminary assessment of the feasibility of their practical use. The results of the MCNP transport simulations reveal changes in the HFIR reactor physics arising from geometric and nuclear effects. Absorber lumping in the discrete CEs yields a large volume of unpoisoned material that is not present in the homogeneous design, in turn yielding increases in free thermal flux in the CE absorbing regions and their immediate vicinity. The availability of additional free thermal neutrons in the core yields an increase in fission rate density in the fuel closest to the CEs and a corresponding increase in neutron multiplication on the order of 100 pcm. The absorption behavior exhibited by the discrete CEs is markedly different from the homogeneous CEs due to several competing effects. Self-shielding arising from absorber lumping acts to reduce the effective absorption cross section of the discrete CEs, but this effect is offset by geometric and spectral effects. The operational performance of the discrete CEs is found to be comparable to the homogeneous CEs, with only limited deficiencies in reactivity worth that are expected to be operationally recoverable via limited adjustment of the CE positions and withdrawal rate. On the whole, these results indicate that the discrete CEs perform reasonably similarly to the homogeneous CEs and appear feasible for application in HFIR. The physical phenomena identified in this study provide valuable background for follow-up design studies.

1. Introduction

The High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory is a flux trap type research reactor which provides one of the highest steady-state neutron sources in the world (Ilas et al., 2015). HFIR neutrons are used for a variety of experiments including scattering, isotope production, and materials irradiation. The two control elements (CEs) in HFIR are key operational and safety components that maintain core criticality and redundant shutdown capability over dozens (~50) of reactor cycles (Betzler et al., 2015). The current fabrication method of the HFIR CEs has been in use since the 1960's (Sease, 1998) and is tedious, expensive, and outdated. In an effort to improve the operational economics of HFIR and demonstrate application of advanced manufacturing techniques to the production of nuclear reactor components, the ultrasonic additive manufacturing (UAM) process is being investigated for production of HFIR CEs (Dehoff and Babu, 2010). The UAM process yields a unique CE design with discretized regions of neutron absorbing material, in contrast to a traditional CE design with uniformly distributed absorbers. This novel design

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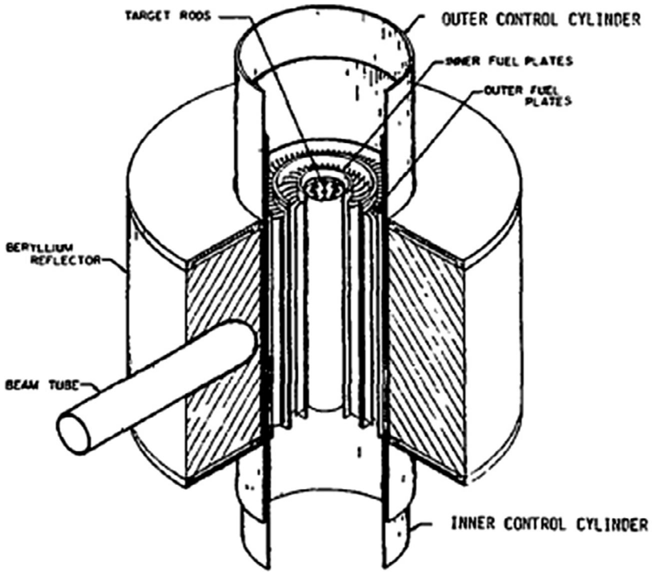

Fig. 1. HFIR schematic (Sease, 1998).

necessitates an investigation of the neutronic impact of additively manufactured CEs on the core physics of HFIR.

Complementary to recent work investigating the material and mechanical characteristics of additively manufactured components (Dehoff and Babu, 2010; Friel and Harris, 2013; Fuji et al., 2017; Schick et al., 2010; Wolcott et al., 2016; Gussev et al., 2017; Hehr et al., 2016; Terrani et al., 2015), this work focuses specifically on the reactor physics phenomena introduced by employing additively manufactured CEs in HFIR and their implications for the safety and operation of HFIR. It is envisioned that identifying the physical phenomena responsible for the behavior of the HFIR core with additively manufactured CEs will provide a preliminary judgment regarding their practical feasibility, in addition to laying groundwork for subsequent design analyses.

1.1. HFIR description

The HFIR core operates nominally at 85 MWt and is light water-cooled and moderated. The core comprises several distinct concentric cylindrical regions, as depicted in Fig. 1 (Sease, 1998). At the center of the core is the flux trap, where the thermal flux reaches a peak of the order of 10^{15} neutrons/cm^2-s. The inner radius of

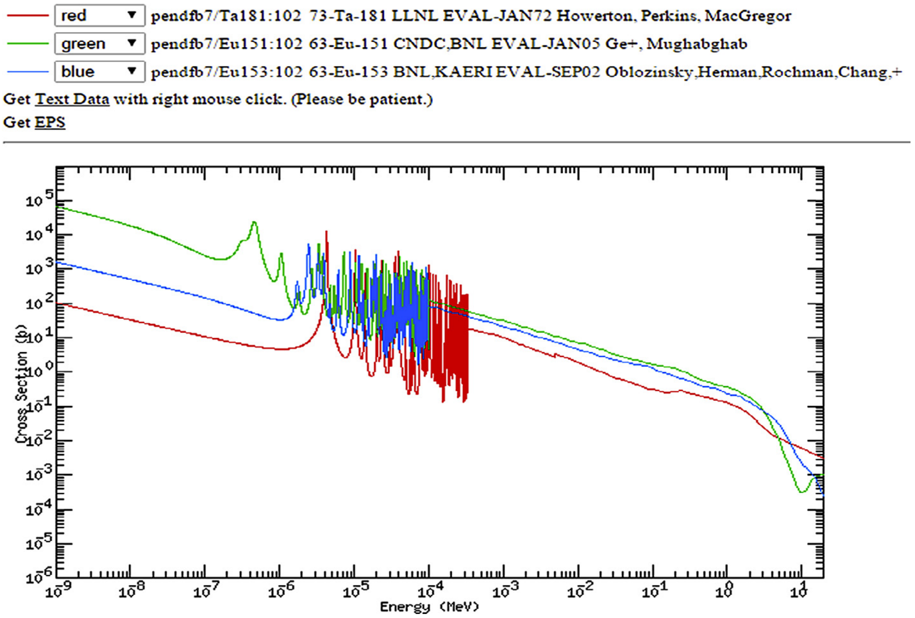

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Fig. 2. Ta and Eu microscopic absorption cross sections (Korea Atomic Energy Research Institute, 2016).

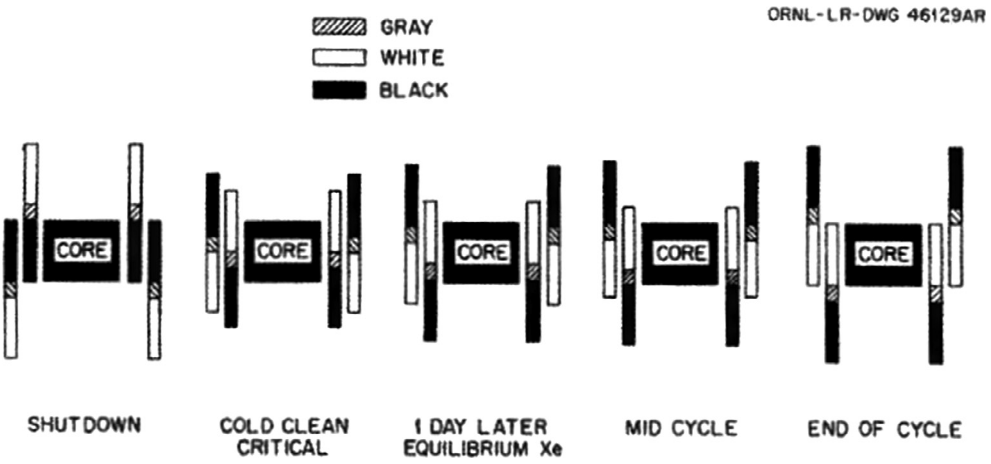

Fig. 3. CE position during HFIR core depletion (Betzler et al., 2015).