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Development of Fuel Cycle Data Packages for Two-stage Fast Reactor Fuel Cycle Options for Optimum Resource Utilization and Waste Management

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ABSTRACT:

In order to develop sustainable nuclear fuel cycles from mining and enrichment to power generation to ultimate disposal of the used nuclear fuel or derived waste products, the Office of Fuel Cycle Technologies (FCT) conducts R&D on nuclear fuel cycle technologies that have the potential of being deployed in the future. For effective allocation of available resources to R&D efforts that have the greatest potential benefits and returns on investment, the Office of FCT is conducting Evaluation and Screening (E&S) for a wide range of nuclear fuel cycle options and developing a catalog of fuel cycle options. The Fuel Cycle Options Campaign of the FCT program is soliciting fuel cycle analysis from universities for the purposes of populating the fuel cycle catalog, developing university expertise in the analysis of advanced fuel cycle systems, and training the next generation of fuel cycle analysts. In response to this solicitation, we propose to evaluate the two-stage fast reactor fuel cycle options below. These options correspond to the second and third groups of the three solicited fuel cycle groups and offer efficient use of uranium resources and the ability to burn actinides and long-live fission products (LLFPs). Evaluation of these fast fuel cycle options will serve as a useful complement to the options currently being considered in the Fuel Cycle Options Campaign. The proposed two-stage fast reactor fuel cycle options are:

1. *Two-stage fuel cycle option of continuous recycle of plutonium (Pu) in a fast reactor (FR) and subsequent burning of minor actinides (MAs) in an accelerator driven system (ADS)*: The first stage is a sodium-cooled fast reactor fuel cycle starting with low-enriched (i.e., less than 20%) uranium fuel; at the equilibrium cycle, the reactor is operated using the recovered plutonium without supporting LEU. Plutonium and uranium are co-extracted from the discharged fuel and recycled in stage 1, and the recovered MAs are sent to stage 2. U-10Zr and U-Pu-10Zr metal alloy fuels will be used to utilize their favorable passive safety characteristics. To maximize resource utilization, the fissile conversion ratio will be maximized without using fertile blanket (to reduce proliferation risk) while maintaining the reactivity swing within a reasonable control requirement. The second stage is a sodium-cooled ADS in which MAs are contained and burned in an inert matrix fuel form. The discharged fuel is reprocessed, and the recovered heavy metals (HMs) are recycled. Since all TRU isotopes are recycled, essentially all fissile and fertile isotopes are utilized, except for small losses in processing.

2. *Two-stage FR/ADS fuel cycle option with MA and long-lived fission product targets*: The first stage is a sodium-cooled fast reactor fuel cycle similar to that of the above FR/ADS fuel cycle option. Plutonium and uranium are co-extracted from the discharged fuel and recycle in stage 1, but the recovered MAs are not sent to stage 2 directly. The recovered MAs are made into moderated targets with zirconium hydride moderator and inserted into the reflector region of the fast reactor. To avoid a power peak at the core and target interface, LLFP target pins are used as the thermal neutron filter. Since the MAs of used fuel are mainly fertile isotopes, the moderated MA targets will breed fissile isotopes. After a certain number of cycles to be determined, the MA targets will be withdrawn and inserted into the second-stage ADS without moderator. Because of bred fissile isotopes, the MA inventory to achieve a fixed multiplication factor will be reduced significantly, compared to the ADS of the above FR/ADS fuel cycle option. The discharged fuel of ADS is reprocessed, and the recovered heavy metals (HMs) are recycled. The recovered LLFP will be recycled in the reflector region in a moderated target form.

For the evaluation of proposed fuel cycle options, point reference core designs will be developed for FR and ADS, including optimized MA and LLFP target designs. The core compositions, geometries/dimensions, and other design parameters will be determined based on three-dimensional neutronics, thermal-fluidic, and fuel cycle analysis. Kinetics parameters and reactivity feedback coefficients will also be evaluated, and design iteration will be performed, if necessary, to obtain favorable passive safety features. Fuel cycle performance will be evaluated against the Fuel Cycle Evaluation Metrics, and fuel cycle data including the information needed and associated analysis assumptions will be prepared in accordance with the Fuel Cycle Data Package template. The FR and ADS core design and fuel cycle evaluation activities will also be utilized in developing expertise in the analysis of advanced fuel cycle systems at Purdue University and training the next generation of fuel cycle analysts.