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Comparison of fast neutron spectra in graphite and FLINA salt inserted in well-defined core assembled in LR-0 reactor

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ABSTRACT

The present paper aims to compare the calculated and measured spectra after insertion of candidate materials for the Molten salt reactor/Fluoride cooled high temperature reactor system concept into the LR-0 reactor. The calculation is realized with MCNP6 code using ENDF/B-VII.0, JEFF-3.1, JENDL-3.3, JENDL-4, ROSFOND-2010 and CENDL-3.1 nuclear data libraries. Additionally, comparisons between the slowing down power of each media were performed. The slowing down properties are important parameters affecting the thickness of moderator media in a reactor.

1. Introduction

Graphite and fluorine salts like LiF–NaF or LiF–BeF_2 salts (hereinafter FLINA and FLIBE respectively) with highly enriched ^{7}Li isotope are strong candidates for generation IV reactor designs such as the HTGR (High temperature Graphite Reactor) and FHR (Fluoride cooled high temperature reactor) or MSR (Molten salt reactor). Consequently, there is strong interest in experiments which study reactors composed of graphite and fluoride salts which are important for correct calculation of slowing down properties and also for description of neutron spectra on the structural components of FHR/MSR systems.

The intent of this paper is to present neutron spectra measurements in various configurations in the center of the driver core and compare these measurements to Monte Carlo simulations using various nuclear data libraries. The configurations tested include FLINA salt, graphite insertions and a void center channel. In this paper, FLINA salt with natural Li enrichment was used due to limited availability of high enriched ^{7}Li salt. The fluorine content in FLINA is comparable to that of FLIBE, the primary candidate for FHR systems, thus any discrepancies in ^{19}F, as observed by Kato et al. (2014), should be observed in either salt. The experiments were performed in the LR-0 reactor which is a light water reactor that achieves criticality by increasing moderator level. These experiments are performed in the frame of The Memorandum of Understanding on nuclear power between the Czech Ministry of Trade and Industry and the U.S. DOE (DOE, 2013).

2. Reactor arrangement

The measurements were performed in a special core assembled in the experimental zero-power reactor LR-0 (Research Centre Řež ltd.). Reactor LR-0 located in Řež near Prague (Czech Republic) is an experimental, light-water-moderated zero-power reactor originally designed for research of VVER-1000 and VVER-440 type reactor cores, spent-fuel storage lattices, and for benchmark experiments.

Power control in this core arrangement is achieved by changing the moderator level. Power control can also be realized by adjusting insertion of control rods in certain core configurations. The LR-0 fuel elements are radially identical, but axially shorter than a VVER-1000 fuel assembly. Continuous maximal operating power is 1 kW with thermal neutron flux density $\approx 10^9$ n cm^{-2} s^{-1}.

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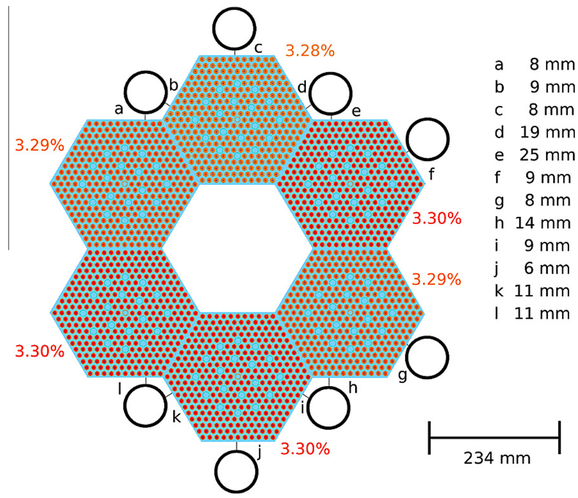

Fig. 1. Radial cross-section of the core with specified enrichment, the distances are upright from pin.

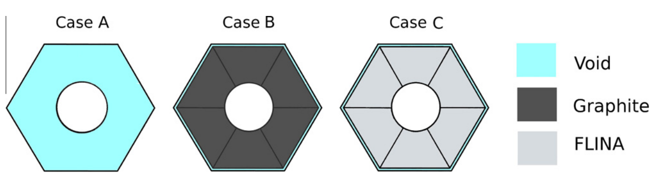

Fig. 2. Various configurations of core insertion.

The main feature of the LR-0 is the flexibility of the supporting structures allowing arbitrary composition of core. In the experiment six fuel assemblies surrounds the experimental dry assembly where the studied media (graphite, void or FLINA) is inserted. The spacing grids and also experimental dry assembly have hexagon key dimension 23.4 cm, the lattice pitch is 23.6 cm. It means between adjoining assemblies there are 2 mm gap (Kyncl et al., 2008). Around the core there are aluminum dry channels with inner diameters of 7 cm and thickness of 5 mm that contain detectors. The detail layout of the core can be found in Fig. 1, with the detailed center channel configurations in Fig. 2. Slight enrichment variations of the as-fabricated assemblies are observed and were modeled using precise uranium inventory data.

3. Experimental and calculation methods

3.1. Measuring arrangement

Neutron spectra in the 0.8–10 MeV energy range were measured via the proton-recoil method using a Stilbene scintillator (10 × 10 mm) with neutron and gamma pulse shape discrimination (hereinafter Stilbene).

The two-parameter spectrometric system FD-11 Sohaj (Veskrna et al., 2014) is fully digitized and it is able to process up to 100 000 impulses per second in energy range from 0.8 to 15 MeV. The input analog signal from photomultiplier is divided in the amplifier into two branches. Each branch is differently amplified and digitized by separate analog to digital converters. This different amplification increases the dynamic range of particle energies so that the spectrometer is capable of processing and increase the signal to noise ratio. Two fast analog to digital converters working on sampling frequency 1 GHz are used and the digital signal processing is implemented in field-programmable gate array. Therefore it is able to process all data flow from both analog to digital converters without any dead time. Pulse shape discrimination is realized by integration method which principle lies in comparison of area limited by a trailing edge of the measured response with area limited by the whole response. Deconvolution of recoiled proton spectra was performed using Maximum Likelihood Estimation (Cvachovec et al., 2008).

Neutron spectra below 1.3 MeV were measured using a hydrogen chamber (hereinafter HPC), operated at 400 kPa in the 0.111–0.368 MeV energy range and at 1000 kPa in the higher range (Jansky et al., 2014).

3.2. Experimental arrangement

The tested material geometry (Fig. 2) composes of 6 blocks. Both graphite (Case B) and salt blocks (Case C) have the same dimensions. Graphite blocks are uncladded, as they are milled from bigger blocks, while the FLINA salt is contained in aluminum canisters with 5 mm wall thickness. The length of both salt cask and graphite block is 60 cm. Thus the salt length is 59 cm because of Al container. The void hexagonal tube (Case A) is also studied. In this case the special experimental dry assembly is filled by air. The axial plot for graphite geometry (Case B) is in Fig. 3.

The graphite used in this experiment has a density of 1.72 g/cm^3 and impurities concentration below 0.2 ppm of boron equivalent. The FLINA salt, one of the possible materials planned for the reactor system, has a composition of 60% LiF + 40% NaF and density of, 1.72 g/cm^3.

In this experiment only the fast neutron flux distribution was studied. This slowing down between 0.1 and 10 MeV can be understood as first part of thermalization. The thermal fluxes were not measured due to occurrence of ^{6}Li in the FLINA (Fig. 4) which significantly changes the thermal neutron distribution (Fig. 5). The thermal neutron distribution will be measured in ^{7}Li enriched FLIBE in frame of common measurement with ORNL (DOE, 2013). These FLINA experiments are preliminary ones to those with FLIBE.

3.3. Calculation methods

The simulations were performed using the MCNP6 Monte Carlo code Pellowitz, 2013 at the experimentally determined moderator height with selected nuclear data libraries: ENDF/B-VII, JEFF-3.1, JENDL-4, JENDL-3.3, ROSFOND-2010 and CENDL 3.1 (ENDF/B-VII, 2006; JEFF-3.1, 2006; JENDL-3.3, 2002; JENDL-4, 2011; ROSFOND-2010, 2007; CENDL 3.1, 2010). Nuclear data libraries were processed using the NJOY code (Mac Farlane, 1994). Good agreement of calculated k_{eff} with critical value (1.000) was

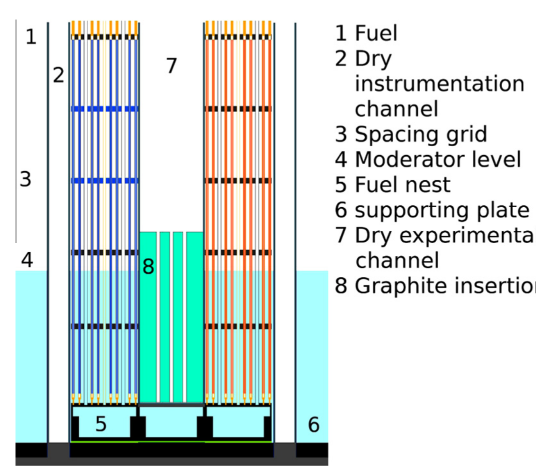

Fig. 3. Axial section of core with graphite insertion (Kostal et al., 2014).