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Extended set of activation monitors for NCT beam characterization and spectral conditions of the beam after reactor fuel conversion

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HIGHLIGHTS

- Conversion from HEU to LEU has only no impact on the spectral characteristics of BNCT beam.
- Neutron flux after conversion is comparable with the flux before the conversion.
- ZN64G, GA71G, AS75G, PD110M, AG109M, SB121G, SB123G reaction are promising for beam monitoring.

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ABSTRACT

Since 2010 the LVR-15 reactor has been gradually converted from highly enriched fuel (36 wt% ^{235}U) to low enriched fuel with the enrichment of 19.75 wt% ^{235}U. Paper presents influence of the core pattern changes on the neutron characteristics of the epithermal beam. The determination of neutron spectrum free in the beam was done with a set of neutron activation monitors. After the reactor conversion the change in neutron spectrum is not provable as differences are in the range of measurement errors.

1. Introduction

The BNCT facility installed at the LVR-15 reactor at Research Centre Rez has been operated since middle of the nineties. The beam filter and core patterns underwent several changes from the original design. The main reason was new type of the reactor fuel accompanied by modifications influencing the beam parameters due to the installation of an additional 5 cm Pb layer to the end of the beam filter for the gamma background in the irradiation room (Fig. 1) to be decreased. Since 2010 the LVR-15 reactor has been gradually converted from highly enriched fuel (HEU) (enrichment of 36 wt% ^{235}U) to low enriched fuel (LEU) with the enrichment of 19.75 wt% ^{235}U. The conversion has been realized via mixed cores with HEU and LEU fuel in a way of replacing each burned HEU fuel assembly (FA) by a fresh LEU FA. From the point of view of reactor operation it was the optimal process which did not have significant influence on the experimental facilities during the conversion.

However, in 2011 the reactor had enough partially burned LEU FAs that the rest of HEU FAs could be replaced all at once. The core changes could have influence on the neutron characteristics of the epithermal beam because of the change of the neutron spectrum in the reactor core. Therefore, the beam was continuously monitored and characterized using the standard set of activation monitors after each significant core pattern change.

A typical arrangement of the core optimized for the BNCT purposes is shown in Fig. 2. Because of the 2.6 m distance from the edge of the core to the beam aperture the last row of the core lattice is filled with FAs (positions from C10 to F10) that function as a neutron booster. The same core pattern is used with the LEU fuel as well.

2. Materials and methods

2.1. Fuel conversion

The determination of neutron spectrum and epithermal neutron flux in the free beam with a set of neutron activation monitors is recommended in Voorbraak and Järvinen (2003) as the reference method. Knowledge of the thermal, epithermal and fast neutron part of spectra is important so the set has to consist of thermal, resonance and threshold monitors. The standard set that is routinely used for the LVR-15 characterization consists of the following monitors.

For the thermal and resonance energy range:

- Bare-$^{197}Au(n,\gamma)^{198}Au$;
- in Cd-$^{186}W(n,\gamma)$ ^{187}W, ^{197}Au (n,γ) ^{198}Au, ^{139}La (n,γ) ^{140}La, ^{55}Mn (n,γ) ^{56}Mn, ^{63}Cu (n,γ) ^{64}Cu, and

For the fast energy range:

- ^{115}In (n,n') ^{115m}In, ^{58}Ni (n,p) ^{58}Co.

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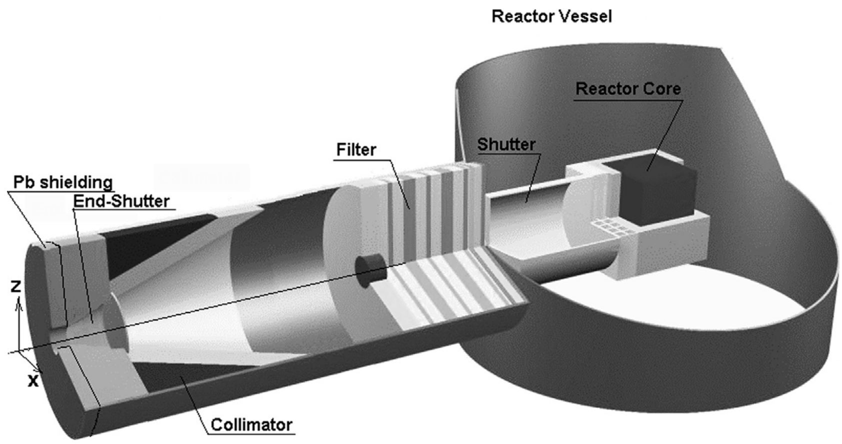

Fig. 1. The filter of the LVR-15 beam with the additional lead shielding.

Energy response of the activation monitors in the epithermal beam is presented in Fig. 3.

The evaluation of the neutron spectrum is based on a calculated neutron spectrum, relevant to the beam, an adjustment is based on the measured reaction rates of the activation monitors. Thus the result is the best estimate of the neutron spectrum with uncertainties. To compare the influence of the core enrichment the following figure of merit were evaluated:

- $R_{Mn/Au}$-the reaction rate ratio of Mn to Au in cadmium describing the stability of measurement
- $R_{Ni/Au}$-the reaction rate ratio of Ni to Au in cadmium showing the ratio of the fast to the epithermal neutrons in the beam
- R_{Cd}-the cadmium ratio for the determination of the thermal neutrons contamination of the beam
- Φ_{epi}-the epithermal neutron fluence rate[$m^{-2}\,s^{-1}$].

Uncertainties of the R_{Cd} and $R_{Mn/Au}$ are usually better then 4% and that of $R_{Ni/Au}$ varies from 5% to 7%.

2.2. Extended set of activation monitors

The IRDF-2002, SNLRML and JENDL dosimetry libraries comprise several other appropriate reactions that can be used for the experimental determination of the neutron spectrum and fluence rates. Also ENDF/B-VII.0 file can be used for generation of group cross sections for other reactions. As for the reactions the data of which cannot be found in the existing dosimetry files, the cross sections were generated with NJOY 99.304 code from the ENDF/B-VII.0 library.

During the project the applicability of the following activation reactions were studied as listed in Table 1. Table 1 comprises also saturated activities calculated in the epithermal neutron beam of the LVR-15 reactor and energy limits representing 90% of the response of the activation monitors.

In Table 2 there are listed the basic parameters of the selected reactions and the material compositions of the monitors which were used for testing.

The monitors were irradiated in free air of the LVR-15 reactor epithermal neutron beam. The activities were measured with an HPGe detector system and evaluated with GENIE-CANBERRA software. The neutron spectrum that was previously evaluated for the LVR-15 beam (Marek et al., 2006) was used as the a-priori neutron spectrum for the adjustment procedure using the SAND-II code.

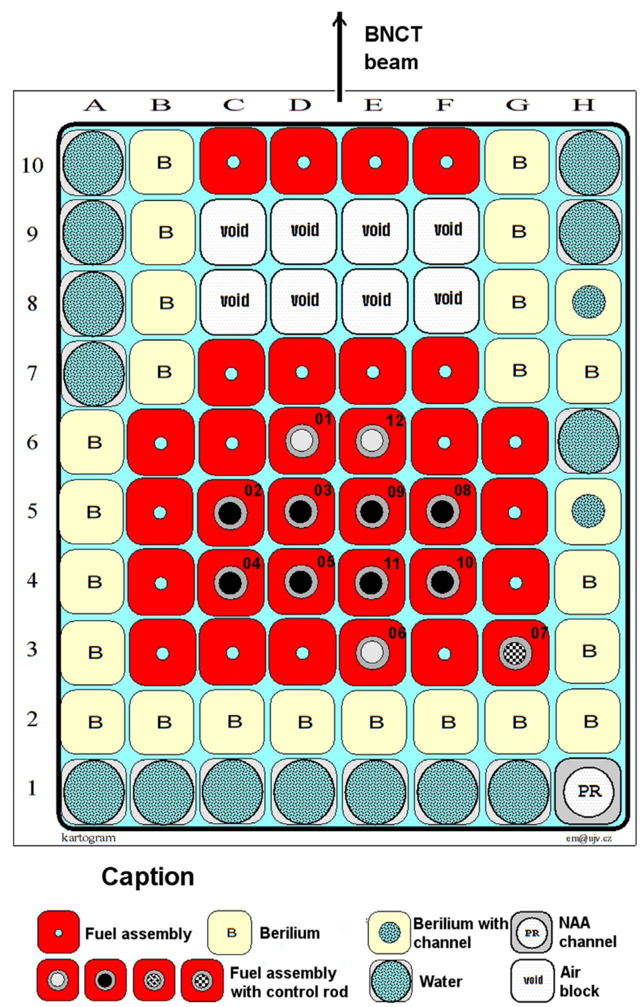

Fig. 2. The horizontal cross section of LVR-15 core optimized for BNCT. The fuel assemblies in C10–F10 positions functioning as a booster for the BNCT filter and beam.

3. Results

3.1. Fuel conversion

Figure-of-merits describing the neutron characteristics of the LVR-15 beam with different fuel enrichment in the reactor core are