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Gamma spectrometry of short living fission products in fuel pins

Marie Švadlenková [a,*], Lenka Heraltová [b], Vlastimil Juříček [a], Michal Košťál [a], Evžen Novák [a]

[a] Research Centre Rez, Ltd., Hlavni 130, 250 68 Husinec-Rez, Czech Republic
[b] Czech Technical University, Faculty of Nuclear Sciences and Physical Engineering, Brehova 7, 115 19 Prague 1, Czech Republic

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ABSTRACT

A method of measurement and analysis of gamma spectra of short living fission products of lightly irradiated fuel pins has been developed at facilities at the LR-0 zero-power experimental reactor. Experimental and computational methods of the peak area correction for radioactive decay are described. Selection of energy peaks suitable for deriving power distribution in the core was performed.

1. Introduction

The zero-power light-water research reactor LR-0 is used mainly for measurements of physical neutron characteristic of VVER and PWR-type reactors (see a scheme of the LR-0 reactor in Fig. 1). The advantage of the LR-0 is in its versatility, which allows carry out experiments with variable numbers of fuel assemblies in reactor core, variable fuel enrichment or variable concentration of H_3BO_3 in moderator and many others [1].

One of the main tasks of the LR-0 is the measurement of parameters that can be used in reactor dosimetry. It is similar to the using of other low power reactors, e.g., [2–5]. Reactor dosimetry topics demand a correct description of the power distribution in the reactor, especially in its marginal parts. For this reason the LR-0 is used for the determination of neutron fluence distribution in fuel pins and fuel assemblies through measurements of the fission products activity induced in the fuel. The increase of the induced activity in a particular region of the reactor is directly related to the density of uranium fission in the same region and therefore to the fuel pin activity increasing. The determination of neutron fluence and power distribution in the reactor core is possible by means of axial and radial measurements of fuel pin gamma activity. The distribution of fission products activities in fuel pins is measured by two methods at LR-0:

- Integral method—in a specific energy interval, using a scintillation detector with one-channel analyzer [6]
- Spectrometric method—where the spectrum of gamma radiation is measured, while individual energy peaks and radionuclides are analyzed.

The spectrometric method described here uses an HPGe semiconductor detector with multi-channel analyzer and the analysis of gamma spectra after short-time fuel pin irradiation in the LR-0 reactor is performed.

2. Materials and methods

2.1. Fuels pins

Fuel pin cladding is an alloy composed of zirconium (98.97%), niobium (1%) and hafnium (0.03%) with average density of 6.44 g cm^{-3}. Fuel column (inside the cladding) with length of 1250 mm is composed of uranium pellets of cylindrical annulus shape with inner radius of 1.4 mm and with outer radius of 7.5 mm. The height of the pellet is about 9.7 mm. The uranium fuel is enriched by ^{235}U in the range from 1.6 to 4.4 wt%. The corresponding fuel density is between 10.33 and 10.35 g cm^{-3}. A diagram of the fuel pin is in Fig. 2.

After the reactor shut-down, selected irradiated fuel pins are transferred (under the radiation protection measure for handling with irradiated pins) to a fuel pin workplace. The place is located close to a laboratory for gamma scanning of the fuel pins and is not influenced by the radiation of the reactor.

* Corresponding author. Tel.: +420 2661 725 79.
E-mail address: Marie.Svadlenkova@cvrez.cz (M. Švadlenková).

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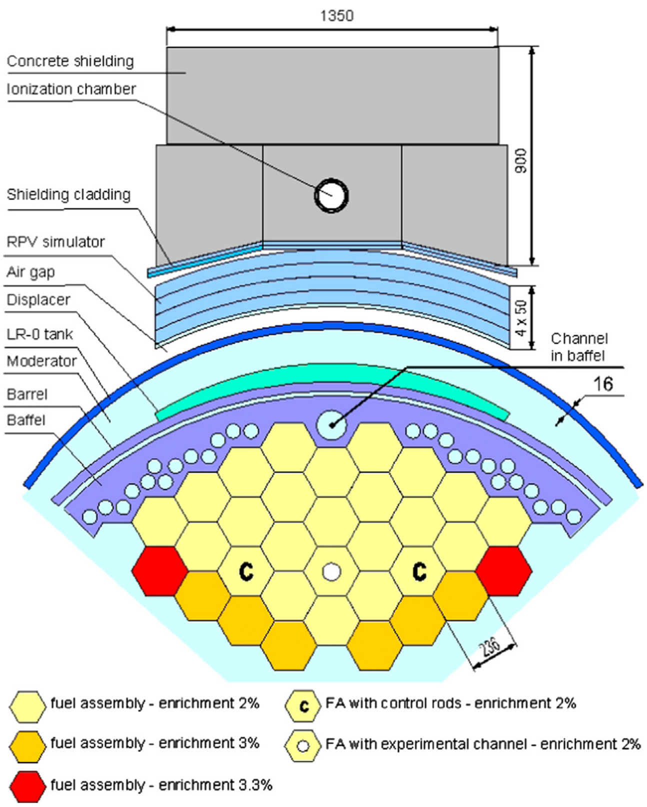

Fig. 1. The scheme of the LR-0 reactor—horizontal cross-section.

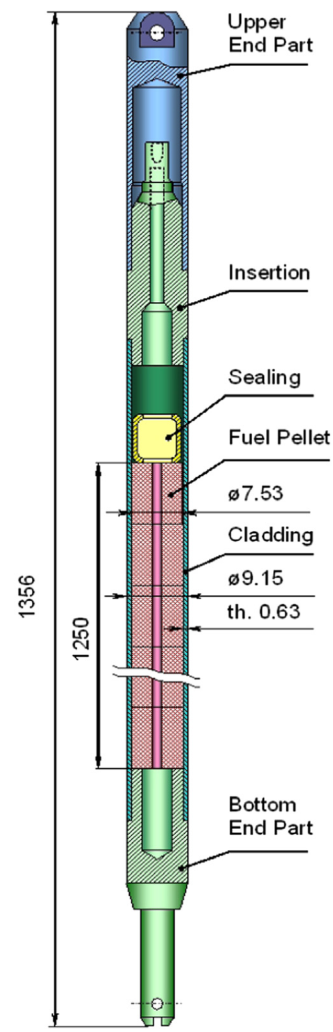

Fig. 2. Diagram of the LR-0 fuel pin of VVER type; three times shortened in comparison with real VVER pin.

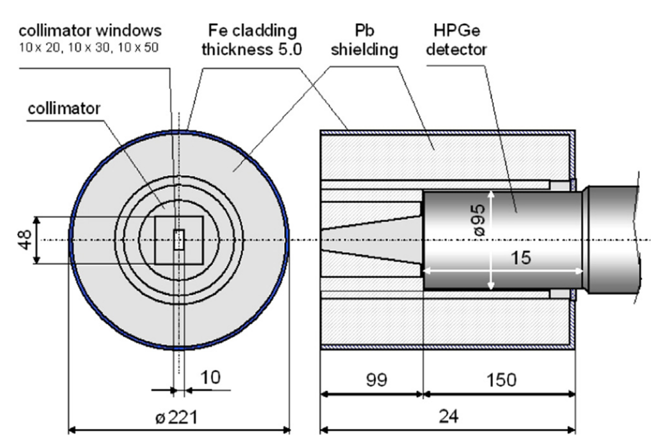

Fig. 3. The position of the HPGe detector in the shielding.

2.2. *Equipment for gamma scanning of fuel pins*

A spectrometric device with coaxial high purity germanium detector HPGe (Ortec, GEM70) and multichannel analyzer DSA 2000 (Canberra) is used for the measurement of fuel pins. HPGe crystal has diameter of 74.6 mm and length of 87.9 mm, FWHM resolution at 1.33 MeV is about 2 keV and the Peak-to-Compton ratio for ^{60}Co is approximately 75:1. The DSA-2000 analyzer is 100% controlled by computer using Genie 2000 [7] spectroscopy software platforms via the in-built Ethernet interface.

The HPGe detector is horizontally attached to a cryostat (resp. Dewar vessel) and is inserted into a massive lead shielding with a collimator. The width of the collimator window is of 1 cm and the height is adjustable to 2, 3, or 5 cm, which makes it possible to measure gamma radiation from a specific part of the fuel pin. In some cases, a two-layer plate (lead with thickness of 3.3 mm and copper with thickness of 1 mm) is inserted between the fuel pin and the collimator window. The plate absorbs mainly low energy component of gamma spectrum and thus reduces the number of photons incident on the detector. As a result, the dead time of the detector is decreased which is desirable for more irradiated pins.

The position of the HPGe detector in the shielding is depicted in Fig. 3. The shielding with collimator was optimized, so that only the gamma photons of the fuel pin part that faces directly the collimator window are registered. Nevertheless, since the shielding is not ideal and its throughput is not zero, the gamma radiation from fuel pin parts above and below the collimator window still falls partly on the detector. Therefore, experiments and MCNP calculations were performed in order to determine the extent of throughput of the shielding and the corresponding correction coefficients (see below).

The experimental arrangement for scanning of fuel pins is shown in Fig. 4. The equipment consists of stand, precise helices, stepper motor, coupling and special fixing for fuel pin. Fuel pin is hung on a holder and can perform sequential axial movement around the collimator window.

Fuel pin movement and positioning are controlled by special software DASAVR (RC Rez) with an accuracy of 0.5 mm. Fuel pin measured in a given position performs a rotary movement to average possible inhomogeneity of irradiation in its cross-section. This inhomogeneity plays a role for fuel pins at the periphery of the core. The calculation result for peripheral pins is in Fig. 5