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Calibration of spent fuel measurement assembly

Michal Koleska [a,b,*], Ladislav Viererbl [a], Milan Marek [a]

[a] Centrum Výzkumu Řež s.r.o (Research Centre Rez), 25068 Husinec-Rez 130, Czech Republic
[b] Department of Nuclear Reactors, Czech Technical University in Prague, V Holešovičkách 2, 180 00 Prague, Czech Republic

HIGHLIGHTS

- Calibration of research reactor spent fuel measurement assembly.
- On-site prepared ^{110m}Ag isotope used for the measurement.
- Calculated self-shielding factor for the IRT-2M fuel.
- Applicable to other research reactor fuel geometries.

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ABSTRACT

The LVR-15 research reactor (Czech Republic) had been converted from the highly enriched IRT-2M to the low enriched IRT-4M fuel. For the possibility of the independent pre-transport evaluation of IRT-2M burnup, a spectrometric system was developed. This spectrometric system consists of the fuel holder, the collimator and the portable Canberra Big MAC HPGe (High Purity Germanium) detector. In order to have well reproducible and reliable experimental data for modeling of the measurement system, calibration with the ^{110m}Ag isotope with known activity was performed. This isotope was chosen for having energies similar to isotopes measured in fuel assemblies. The ^{110m}Ag isotope was prepared by irradiating of the silver foil in LVR-15 research reactor; its activity was evaluated in the LVR-15's spectrometric laboratory. From the measured data, an efficiency curve of the spectrometric system has been determined. The experimental data were compared to the calculation results with the MCNPX model of the spectrometric system.

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1. Introduction

The LVR-15 reactor (Marek et al., 2008) has recently undergone the conversion from highly enriched IRT-2M fuel to low enriched IRT-4M type. The successful conversion of the LVR-15 research reactor did not mean only the fuel exchange, but also the transport of the entire amount of highly enriched spent nuclear fuel back to the country of origin, the Russian Federation. For the verification of calculated fuel burnup, the new spectrometry assembly was designed and fabricated for the use with IRT-2M and IRT-4M fuel (Table 1).

2. Experimental setup

The spectrometry assembly for spent fuel measurement (Fig. 1) is located by the radioactive waste pool "A" of the LVR-15 reactor. The assembly comprises the movable fuel holder, and the detector (Viererbl et al., 2011). The fuel holder, which is placed beneath the collimator, is designed to accommodate the fuel assembly with dimensions $71.5 \times 71.5 \times 882$ mm^3. The holder is located on the rail, which allows the fuel assembly movement along the longitudinal axis; thus the entire height of the fuel assembly (FA) may be scanned.

The collimator is 3856 mm long aluminum tube; its upper and lower parts contain totally 6 Pb shields with inner holes with 7 mm, 7.5 mm and 8 mm diameter. In the upper part, portable Canberra Big MAC HPGe (High Purity Germanium) detector is used for detection. The distance from the center of the fuel assembly to the center of the detector is 4000 mm.

The relative calibration curve of the spectrometry assembly was carried out with ^{134}Cs and ^{154}Eu in the fuel (Burian et al., 2010). The knowledge of the detection efficiency for the free 3 m distance geometry was used for rough absolute position of the curve. The free geometry detection efficiency was in the initial guess extrapolated according to the $1/r^2$ relation. While the relative calibration is precisely applicable for burn-up evaluation by the ^{134}Cs/^{137}Cs ratio method (Table 2), an absolute calibration is needed for the evaluation

* Corresponding author at. Centrum Výzkumu Řež s.r.o., 25068 Husinec-Rez 130, Czech Republic. Tel.: +420 266 172 036.
E-mail address: michal.koleska@cvrez.cz (M. Koleska).

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Table 1
IRT-2M and IRT-4M fuel properties.

	IRT-2M	IRT-4M
Enrichment	36% ^{235}U	19.7% ^{235}U
Total length	882 mm	882 mm
Active length	580 mm	600 mm
Section square – head	71.5×71.5 mm^2	71.5×71.5 mm^2
Section square	67×67 mm^2	69.6×69.6 mm^2
Total mass of the assembly		
4/8 tubes	3.7 kg	6 kg
3/6 tubes	3.2 kg	5.2 kg
Mass of ^{235}U		
4/8 tubes	230 g	300 g
3/6 tubes	198 g	263.8 g
Tube wall thickness	2 mm	1.6 mm
Cladding thickness	2×0.4 mm	2×0.3 mm
Fuel material	UO_2–Al	UO_2–Al
Fuel plate thickness	0.64 mm	0.7 mm

Fig. 1. Top view of the spectrometry assembly with the fuel in the fuel holder (horizontal), collimator and the detector holder located in pool "A".

with single-radionuclide method. The uncertainty estimation for the ratio method is $\pm 2\%$.

3. Measurement

While the free geometry calibration can be easily done using the radioactive standards, calibration of the described spectrometry assembly becomes more complicated. The complicated geometry of the spent fuel and unknown distribution of measured radionuclides makes it very difficult to provide easily reproducible calibration source. The energy calibration in the energy range of the measured fission products can be easily covered by suitable radionuclides. Criteria for the calibration radionuclide were chosen as follows:

- Energy range similar to major radionuclides measured in spent fuel.
- Commercial availability of the high purity foil.
- Isotope half-life.
- On-site preparability.

These requirements were met by a 0.1 mm thick Ag foil with the declared purity of 99.99% in which ^{110m}Ag was generated by neutron activation.

From the Ag foil, two samples were cut (Table 3). The activation of both samples was carried out by irradiation in irradiation capsule placed to the irradiation position H5/3 of the LVR-15 reactor. The first (smaller) sample was irradiated for 30 min and afterwards measured with the well-calibrated detector in close geometry. According to this measured activity, required irradiation time for the second sample was calculated. After the irradiation and measuring the activity of the second sample in the close geometry, it was used for measurement with the spectrometry assembly.

The activated foil used for calibration was mounted to the outer surface of the dummy fuel assembly. The dummy fuel assembly has outer dimension same as the IRT-2M fuel ($71.5 \times 71.5 \times 880$ mm^3), but it is fabricated from the pure aluminum only.

The dummy was then installed to the spent-fuel position of the spectrometry assembly, while the foil was oriented to the gap between the fuel dummy and the collimator. After the installation, a series of measurements along the dummy longitudinal axis was performed (Fig. 2). These results aim to show the collimating characteristics. These characteristics were proved due to the strong measured activity drop when source moved along

Table 3
Reference ^{110m}Ag sources used for spectrometric assembly calibration.

#	Size (mm × mm)	Weight (mg)	Irradiation time (hour@10 MW)	Activity (Bq)	Uncertainty (Bq)
1	3×3	11.29	0.5	1.02E+06	2.31E+03
2	10×10	1,28.63	13	1.32E+08	4.49E+05

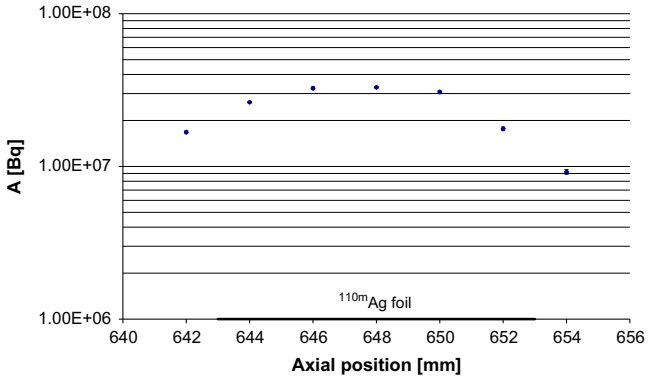

Fig. 2. Axial measurement of the fuel dummy with the ^{110m}Ag foil.

Table 2
Fuel burnup determined by ^{134}Cs/^{137}Cs ratio method.

FA ID	Operational data			Measurement				
	Load	Unload	Calc. Burn up	^{134}Cs		^{137}Cs		^{134}Cs/^{137}Cs
	Date	Date	(MW d/kg U)	*A* (Bq)	σ (%)	*A* (Bq)	σ (%)	
39.141	11.03.2009	08.07.2009	59.14	2.80E+08	2.13	1.61E+09	0.53	1.74E−01
40.181	05.02.2010	24.07.2011	90.84	1.20E+09	0.55	3.43E+09	0.40	3.48E−01
40B188	27.08.2010	24.07.2011	119.60	2.24E+09	0.43	4.69E+09	0.36	4.77E−01
40B184	01.04.2010	24.07.2011	147.26	3.00E+09	0.38	5.08E+09	0.36	5.92E−01
49B133	10.10.2008	27.04.2010	179.25	5.11E+09	0.40	7.02E+09	0.33	7.28E−01
49B131	11.08.2008	05.03.2010	188.61	6.13E+09	0.30	7.89E+09	0.33	7.77E−01

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