Comparison of MCNP Calculation and Measurement of Neutron Fluence in a Channel for Short-Time Irradiation in the LVR-15 Reactor

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Abstract

The main purpose of this work was to evaluate the neutron energy distribution in a channel of the LVR-15 reactor used mostly for short-time neutron activation analysis. Twenty types of activation monitors were irradiated in this channel equipped with a pneumatic facility with a transport time of 3.5 s. The activities measured and the corresponding reaction rates were used to determinate the neutron spectrum. The reaction rates were compared with MCNP calculations to confirm the results.

The second purpose of this work was to verify our nuclear data library used for the reaction rate calculations. The experiment results were also incorporated into our database system of neutron energy distribution at the reactor core.

KEYWORDS: MCNP code, neutron fluence, reaction rate, activation monitor, comparison

1. Introduction

The Nuclear Research Institute Rez plc (NRI) is a part of the research complex situated at Rez near Prague and operates two experimental nuclear research reactors. First, denoted LVR-15 is a medium power multipurpose reactor, which offers services in many fields (such as material research, production of radioisotopes for the radio-pharmaceuticals, production of radiation doped silicon, neutron capture therapy etc.). Second, denoted LR-0, is a low power reactor mostly designed for model experiments of power reactors and their dosimetry. High demands on specification of irradiation conditions and the broad range of applications in the reactor LVR-15 require precise specification of the irradiation parameters and more accurate processing of experimental data [1]. Proper determination of neutron fluence is an essential part of the accurate evaluation of experiments.

2. Experimental conditions

The experiment aimed at measuring particularly radionuclides with short half-lives ($T_{1/2} < 1$ day). Twenty types of activation monitors were irradiated in a precisely defined position in channel H-1 used for short-time irradiation in neutron activation analysis. This channel is located in the corner of the reactor core and is surrounded by Be reflector. Each type of monitors was irradiated separately without a Cd cover and most types were irradiated also with the Cd cover (disc shaped capsules with wall thickness of 1 mm). The irradiation time for the monitors without the Cd was normally 180 s. Some monitors were irradiated only for 20 s due to high-expected activities. The maximum irradiation time for monitors with the Cd cover was 60 s. The measured activity for the end of the irradiation as reference time, the mass of foils and the time of irradiation for all monitors are summarized in Tab. 1. A detailed description of the experiment was presented at the IRRMA-6 [2].

The gamma activities were measured with a coaxial HPGe detector (Canberra) with relative efficiency of 18 % and FWHM resolution 1.8 keV for 1332 keV photons of ^{60}Co. The detector is placed in a shielding box with 5 cm thick lead walls. The calibration of the detector and the method of the measurement are in accordance with “ASTM E181-98(2003) Standard Test Methods for Detector Calibration and Analysis of Radionuclides”. The Genie 2000 software (Canberra) was used for the evaluation.

Table 1: Summary of the measured activities, mass and irradiation time for monitors (elements) used.

			Without Cd cover			With Cd cover		
Element	**Target nuclide**	**Radio-nuclide**	**Mass**	**Irradiation time**	**A**	**Mass**	**Irradiation time**	**A**
			(mg)	(s)	(Bq)	(mg)	(s)	(Bq)
Mg	^{24}Mg	^{24}Na	1.97	180	6.78E+02	Not irradiated		
	^{25}Mg	^{25}Na	1.97	180	5.80E+04			
	^{26}Mg	^{27}Mg	1.97	180	1.10E+06			
Al	^{27}Al	^{24}Na	2.94	180	8.19E+02	4.12	60	2.98E+02
	^{27}Al	^{27}Mg	2.94	180	3.10E+05	4.12	60	1.78E+05
	^{27}Al	^{28}Al	2.94	180	1.96E+08	4.12	60	2.76E+06
Sc	^{45}Sc	^{46}Sc	3.58	180	4.83E+03	3.51	60	2.08E+01
Ti	^{46}Ti	^{46}Sc	12.32	180	1.09E+01	Not irradiated		
	^{47}Ti	^{47}Sc	12.32	180	3.82E+02			
	^{48}Ti	^{48}Sc	12.32	180	1.10E+02			
	^{50}Ti	^{51}Ti	12.32	180	8.32E+06			
Mn	^{55}Mn	^{56}Mn	3.20	20	5.47E+05	3.05	20	1.36E+04
Fe	^{54}Fe	^{54}Mn	209.38	180	1.86E+02	204.78	60	6.39E+01
	^{56}Fe	^{56}Mn	209.38	180	1.30E+05	204.78	60	4.27E+04
	^{57}Fe	^{57}Mn	209.38	180	<MDA	204.78	60	6.35E+04
	^{58}Fe	^{59}Fe	209.38	180	6.56E+03	204.78	60	5.92E+01

(cont.)

Table 1 (continued): Summary of the measured activities, mass and irradiation time for monitors (elements) used.

			Without Cd cover			With Cd cover		
Element	**Target nuclide**	**Radio-nuclide**	**Mass**	**Irradiation time**	**A**	**Mass**	**Irradiation time**	**A**
			(mg)	(s)	(Bq)	(mg)	(s)	(Bq)
Co	^{59}Co	^{60}Co	3.49	180	2.41E+02	3.34	60	<MDA
	^{59}Co	^{60m}Co	3.49	180	3.31E+07	3.34	60	5.83E+05
Ni	^{58}Ni	^{57}Ni	15.64	180	1.08E+01	Not irradiated		
	^{58}Ni	^{58}Co	15.64	180	8.75E+02			
	^{60}Ni	^{60}Co	15.64	180	7.12E+01			
	^{64}Ni	^{65}Ni	15.64	180	8.00E+05			
Cu	^{63}Cu	^{60}Co	12.13	20	1.94E+00	11.31	60	1.35E+00
	^{63}Cu	^{64}Cu	12.13	20	2.47E+06	11.31	60	1.96E+05
	^{95}Cu	^{66}Cu	12.13	20	9.99E+07	11.31	60	7.96E+06
Zr	^{94}Zr	^{94}Y	16.54	180	6.40E+02	Not irradiated		
	^{94}Zr	^{95}Zr	16.54	180	2.11E+04			
Nb	^{93}Nb	^{92m}Nb	9.05	180	1.87E+01	Not irradiated		
	^{93}Nb	^{94m}Nb	9.05	180	2.09E+09			
Ag	^{107}Ag	^{108}Ag	3.49	180	5.47E+07	1.98	60	9.05E+05
	^{109}Ag	^{110m}Ag	3.49	180	7.53E+01	1.98	60	3.76E+00
In	^{115}In	^{115m}In	3.87	20	2.00E+02	3.64	60	2.64E+02
	^{115}In	^{116m}In	3.87	20	7.32E+06	3.64	60	3.31E+06
Sb	^{121}Sb	^{122}Sb	3.60	180	1.45E+04	3.46	60	2.50E+03
	^{121}Sb	^{122m}Sb	3.60	180	1.64E+05	3.46	60	3.52E+04
	^{123}Sb	^{124}Sb	3.60	180	2.97E+02	3.46	60	4.83E+01
La	^{139}La	^{140}La	3.88	180	1.50E+04	3.84	60	1.67E+02
Eu	^{151}Eu	^{152}Eu	3.65	20	3.64E+02	3.55	60	3.38E+02
	^{151}Eu	^{152m}Eu	3.65	20	1.85E+06	3.55	60	8.87E+04
Lu	^{175}Lu	^{176m}Lu	4.48	20	3.24E+04	4.39	20	2.19E+02
	^{176}Lu	^{177}Lu	4.48	20	4.21E+05	4.39	20	2.24E+05
W	^{180}W	^{181}W	3.45	180	<MDA	3.65	60	5.55E+03
	^{186}W	^{187}W	3.45	180	4.92E+02	3.65	60	<MDA
Ir	^{191}Ir	^{192}Ir	3.26	180	1.82E+01	Not irradiated		
	^{193}Ir	^{194}Ir	3.26	180	4.15E+02			
Au	^{197}Au	^{198}Au	3.25	180	2.68E+05	3.31	60	2.12E+04

3. Determination of the neutron spectrum

The neutron fluence rate spectrum was determined by computer calculation using the SAND II code with the IRDF90 dosimetry library. The adjustment procedure was designed according to "ASTM E944-02 Standard Guide for Application of Neutron Spectrum Adjustment Methods in Reactor Surveillance, E706 (IIA)". The fluence rates at 10 MW reactor power for different energy intervals are listed in Tab. 2. The standard deviation of the fluence rates calculated by the SAND II code was 3 %.

Table 2: Fluence rates at 10 MW reactor power.

Energy	Fluence rate ($m^{-2}.s^{-1}$)
(0 , 0.5 eV)	3.38E+17
(0.5 eV , 10 KeV)	1.49E+17
(10 keV , 0.1 MeV)	3.50E+16
(0.1 MeV , 20 MeV)	1.08E+17
(0.5 MeV , 20 MeV)	6.64E+16
(1 MeV , 20 MeV)	4.52E+16

4. MCNP Calculation

The Monte Carlo code is one of the most widely used universal codes for the radiation transport simulation [3]. But unfortunately MCNP requires a lot of computer time to obtain the correct results with an average statistical error (2 σ) of less than 5 %. The running time varies depending on the kind of reactions. The calculations by MCNP4C (with the DLC-200 cross-section library) for all monitors without the Cd cover took almost 40 days and even then some reactions had a statistical error of more than 10 % (non-standard reactions).

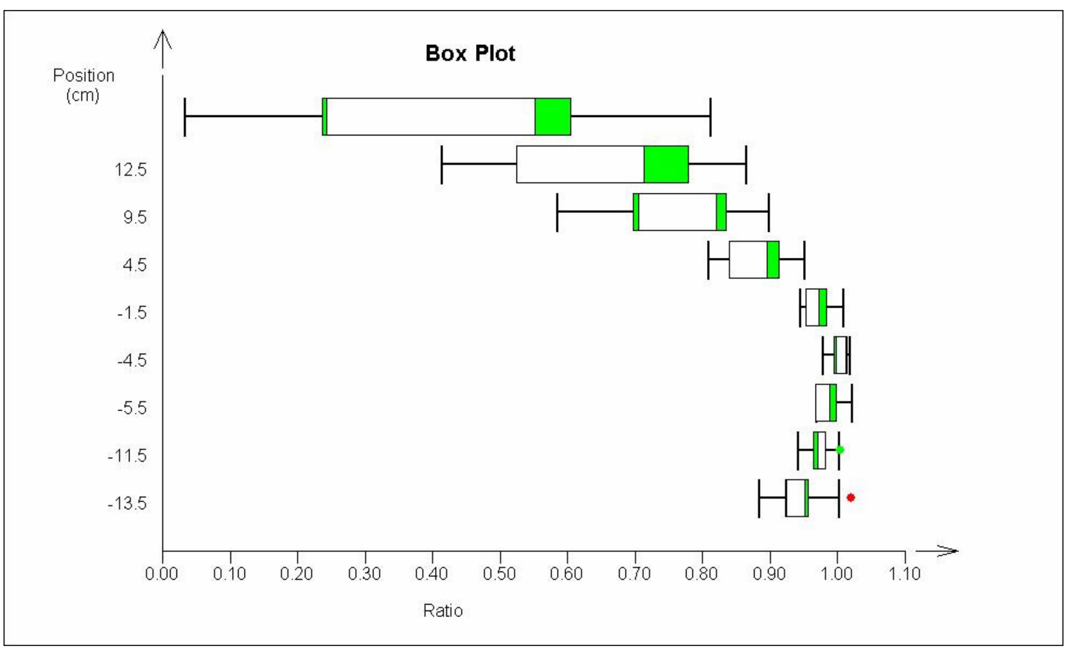
5. Comparison

The calculations by MCNP code were made within a range from -13.5 cm to 19.5 cm along the vertical direction (z-axis) of the channel H-1 with a step of 1 cm. At first we wanted to find the corresponding position along the z-axis (MCNP calculations) to the known position of the measurement. We tested groups of data where variables were the ratios of the MCNP-calculated reaction rates to the measured reaction rates. The neutron reactions calculated by MCNP with a standard deviation of less than 10 % were included in the statistical data processing. Linear regression was used to express the functions of the calculated reaction rates on the z-axis.

The ANOVA statistical method can be used for simultaneous comparison of the means in several groups. ANOVA assumes that the variables are normally distributed within the groups and that the variances do not significantly differ in individual groups. The box plot (diagnostic graph for ANOVA) is useful for displaying the mean and spread of a set of data. The green (shadowed) boxes represent the middle 50 % of the data. The left-hand side and right-hand side of the boxes are the 25th and 75th percentiles. The white boxes represent the confidence intervals for means. Values outside of the lines are considered outliers. Box plots displayed side-by-side allow comparison of the average and spread of all groups.

The results for different positions are shown in Fig. 1. The position of -4.5 cm has the smallest variances and value 1 is inside the white box (confidence interval).

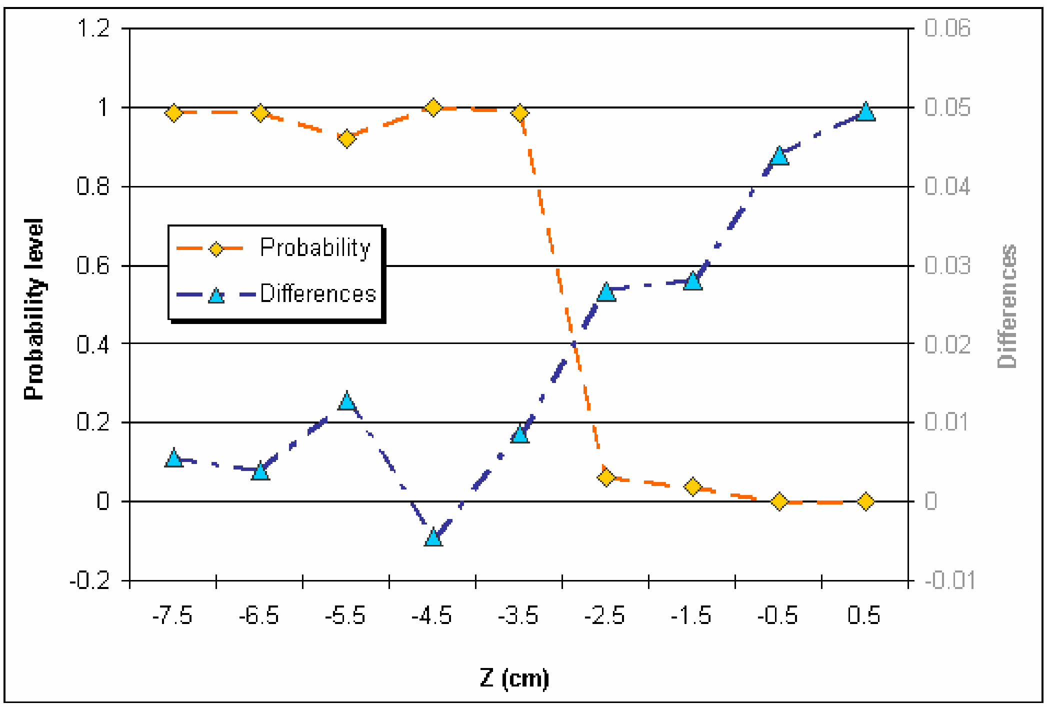
Figure 1: Box plots for different groups.



We tested the hypothesis that the ratios are normally distributed and means equal 1 to find the irradiation position. Scheffe's test can be used to determine the significant differences between group means. The differences relative to the value of 1 are shown in Fig. 2, as well as the probabilities of each position. These are the results for a range from -7.5 cm to 0.5 cm. We expected the true value in this interval. The maximum of the probability level is at the position -4.5 cm. The smallest difference is also at the position -4.5 cm. This point corresponds to the irradiation position. This confirms the fact that the irradiation position in channel H-1 is slightly below the center of the reactor core.

The data were processed by statistical software QC.Expert [4].

Figure 2: Differences and probability - Scheffe's test.



6. Conclusion

ANOVA and Scheffe's test confirm that the irradiation position in channel H-1 is -4.5 cm under the center of the reactor core. Comparison of the calculations and the measurement allows us to check and correct our nuclear data library. The results of the experiment were included in our database system of the neutron energy distribution.

References

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