Evaluation of the potential of parametric neutron activation analysis in the cadmium-shielded irradiation position of the RINGAS system at the SAFARI-1 research reactor

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June 29, 2012

Abstract

This project involves a comparative study between calculated and measured induced radioactivity in element standards upon irradiation with neutrons in the cadmium-shielded irradiation position of the RINAS system of the SAFARI-1 research reactor. The calculated induced radioactivity is based on deterministic calculations using modeled neutron flux and energy data in combination with energy dependent neutron cross-section data available from literature. A wide variety of element standards (e.g. As, Au, Al, Ba, Cu, Co, Cr, Cd, Ca, Fe, I, Ni, Na, Sn, Se, Mo, Zn) will be irradiated for 10 seconds each and the induced activity measured with a calibrated gamma-spectrometry system at various decay times after the irradiation to allow for short-, intermediate- and long-lived radionuclides expected to be generated upon mainly epithermal and fast neutron irradiation. Comparison of the actual measured and simulation-based calculated induced activities will give an indication as to whether parametric neutron activation analysis in principle can be used successfully at the cadmium-shielded irradiation position of the RINGAS system. In addition, discrepancies between the results obtained can make a valuable contribution to the further refinement of the reactor simulation software.

1 Introduction

Neutron activation analysis provides a qualitative and quantitative measurement of elements in a wide variety of mainly solid samples by irradiating the samples with neutrons and measuring the characteristic gamma-radiation from the radionuclides formed during the irradiation at certain times after the end of the irradiation. The induced types of neutron reactions vary from element to element and nuclide to nuclide but as a rule of thumb the lighter elements are more prone to react with low-energy neutrons while the heavier elements favor the intermediate and higher energy neutrons. Accordingly, if one wants to determine the heavier toxic elements in e.g.

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foodstuffs one normally chooses a cadmium or boron shielded irradiation position to suppress the induced activity of typically dominant elements found in foodstuffs like sodium, aluminium, chlorine , manganese, copper, potassium and bromine. Accordingly, this part of the study concentrates on the comparison of measured and modeled induced activities in the cadmium-shielded irradiation position of the SAFARI-1 research reactor used for neutron activation analysis.

2 Reactor Configuration

The reactor has an 8 × 9 core lattice, which houses 26 MTR-type fuel elements, 5 control rods and 1 regulating rod as shown in Figure 1. Besides the in-core irradiation facilities such as the hydraulic rabbit (in position G9) and the RINGAS system (bare-tube in position A3 and the cadmium covered one in A4) and the isotope production rigs (positions B6, D6 and F6) the reactor is also equipped with a number of horizontal beam tubes, which are amongst others for neutron radiography and neutron diffraction [1-3].

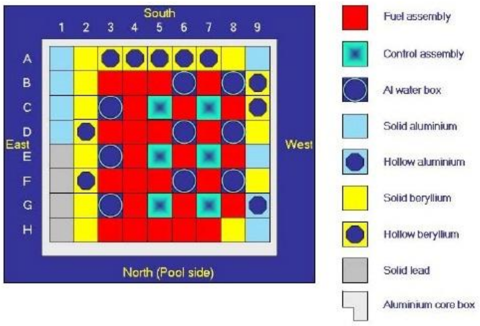

Figure 1: SAFARI-1 reactor core layout

3 Basics behind the Method

The neutron spectrum as modeled from the available simulation software applicable to the SAFARI-1 core for the bare-tube and cadmium-shielded position of the RINGAS system used for activation analysis is shown in Figure 2 [4]. It should be mentioned that these spectra were modeled at a certain point in time and variations with time can be expected due to the burn-up of the fuel and accordingly the positions of the regulator rods, but will perfectly serve the first order evaluation of the experiment. In principle one expects more or less only a vertical shift in the spectra.

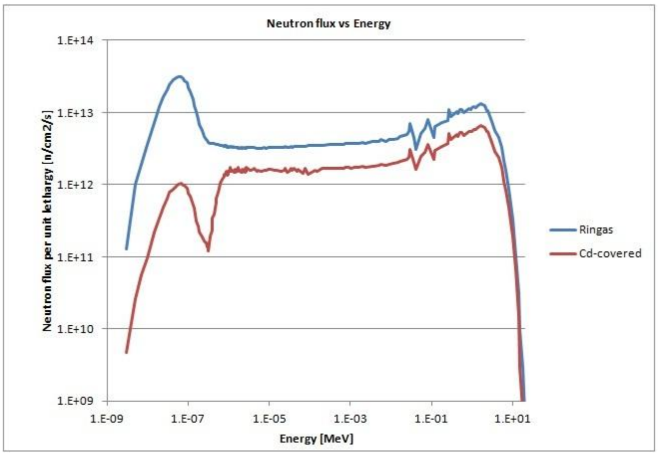

Figure 2: MCNP model of neutron flux

From literature one can obtain the cross-sections of the various neutron induced reactions, of which an example is shown in Figure 3. Using the FISPACT calculation software one can thus obtain the activities of a variety of neutron induced reactions. An example is given in Table 1 for Hafnium when irradiated for 10 seconds in the RINGAS system of the SAFARI-1 research reactor. From this, together with the half-life of the nuclide induced one can evaluate the potentially best nuclide of interest to provide the highest sensitivity (although the gamma-energy and -intensity as well as the detector efficiency also have to be taken into consideration, which is beyond the scope of this short communication).

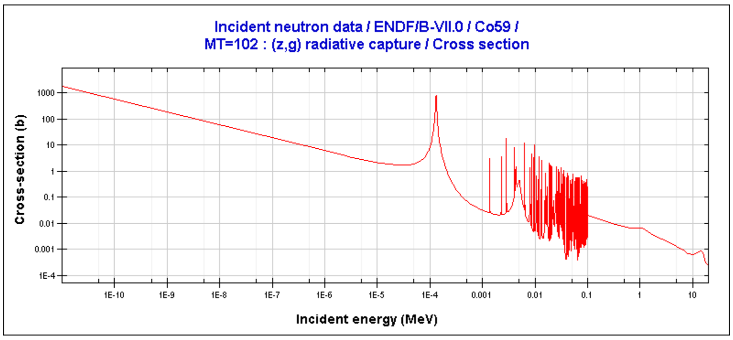

Figure 3: The energy-dependent cross-section of ^{59}Co

Table 1. Multiple reactions of Hafnium

Element	Nuclide formed	Activity (Bq/g)	Half -life(s)
Hf	^{179m}Hf	1.80E+12	1.87E+01
	^{178m}Hf	6.06E+09	4.00E+00
	^{177m}Hf	5.58E+09	1.08E+00
	^{180m}Hf	5.59E+06	1.98E+04
	^{181}Hf	1.73E+06	3.66E+06
	^{177m}Yb	2.41E+05	6.41E+00
	^{177n}Hf	2.10E+05	3.08E+03
	^{175}Hf	1.28E+05	6.05E+06
	^{176m}Yb	4.49E+04	1.14E+01
	^{179n}Hf	4.49E+04	2.17E+06
	^{177}Yb	7.04E+02	1.14E+01
	^{180}Lu	1.53E+02	3.42E+02

4. Results and Discussion

Some preliminary results are shown in Table 2 and Appendix A, to provide some insight in the feasibility to perform parametric neutron activation analysis at the cadmium-covered irradiation position of the RINGAS system of the SAFARI-1 research reactor. The results were obtained from experimental values of five individual samples of element standards of aluminium, barium, sodium and selenium.

Table 2.A comparison of experimental and simulated calculated activities

Date of irradiation	Element	Nuclide	Reaction	Experiment/Fispact ratio	
				Average	Median
28-Mar-12	Al	Mg-27	(n,p)	1.18E+00	1.07E+00
30-Mar-12	Ba	Ba-137m	multiple	1.04E+00	1.04E+00
10-Apr-12	Na	F-20	(n,α)	2.56E+00	2.49E+00
10-Apr-12	Na	Ne-23	(n,p)	1.87E+00	1.84E+00
10-Apr-12	Se	Se-7m	multiple	3.31E+00	3.23E+00

From these preliminary results in can be seen that there might be merit to envisage parametric neutron activation either directly with reference standards for quality assurance purposes or as a quality check on the so-called comparator technique where element reference standards are irradiated alongside the samples of interest to determine the element concentrations of the elements to be analyzed for. The actual simulated neutron flux data at the date of the experiment should be applied to obtain a more accurate insight.
More data will be evaluated to provide a final view on the applicability of the parametric technique as an alternative to the comparator techniques as well as

the potential use of the data to optimize the reactor core modeling software.

Appendix A

Reaction of interests			Half-life [s]	Energy keV	Element mass [μg]	Experimental results [Bq/g] Value	Uncertainty	Theoretical results [Bq/g]
Al-27	(n,p)	Mg-27	5.68E+02	843.76	51.0	7.11E+06	2.81E+06	9.15E+06
Al-27	(n,p)	Mg-27	5.68E+02	843.76	51.8	1.57E+07	2.00E+06	9.15E+06
Al-27	(n,p)	Mg-27	5.68E+02	843.76	50.8	9.75E+06	1.76E+06	9.15E+06
Ba-138	(n,2n)	Ba-137m	1.53E+02	661.66	208.2	8.44E+07	2.17E+06	7.98E+07
Ba-138	(n,2n)	Ba-137m	1.53E+02	661.66	181.7	8.51E+07	2.23E+06	7.98E+07
Ba-138	(n,2n)	Ba-137m	1.53E+02	661.66	198.9	8.07E+07	2.10E+06	7.98E+07
Ba-138	(n,2n)	Ba-137m	1.53E+02	661.66	213.2	8.20E+07	2.10E+06	7.98E+07
Na-23	(n,α)	F-20	11.20E+00	1633.60	50.2	1.35E+08	1.70E+07	5.41E+07
Na-23	(n,α)	F-20	11.20E+00	1633.60	51.2	1.28E+08	1.73E+07	5.41E+07
Na-23	(n,α)	F-20	11.20E+00	1633.60	51.0	1.38E+08	1.81E+07	5.41E+07
Na-23	(n,α)	F-20	11.20E+00	1633.60	51.8	1.57E+08	2.02E+07	5.41E+07
Na-23	(n,α)	F-20	11.20E+00	1633.60	51.5	1.34E+08	1.71E+07	5.41E+07
Na-23	(n,p)	Ne-23	37.24E+00	440.00.00	50.2	1.05E+08	7.14E+06	6.00E+07
Na-23	(n,p)	Ne-23	37.24E+00	440.00.00	51.2	1.16E+08	7.41E+06	6.00E+07
Na-23	(n,p)	Ne-23	37.24E+00	440.00.00	51.0	1.11E+08	7.31E+06	6.00E+07
Na-23	(n,p)	Ne-23	37.24E+00	440.00.00	51.8	1.23E+08	8.00E+06	6.00E+07
Na-23	(n,p)	Ne-23	37.24E+00	440.00.00	51.5	1.07E+08	7.03E+06	6.00E+07
Se-77	(n,n')	Se-77m	17.36E+00	162.00.00	50.1	5.21E+10	2.16E+09	1.49E+10
Se-77	(n,n')	Se-77m	17.36E+00	162.00.00	50.1	4.79E+10	1.99E+09	1.49E+10
Se-77	(n,n')	Se-77m	17.36E+00	162.00.00	49.9	4.81E+10	2.00E+09	1.49E+10
Se-77	(n,n')	Se-77m	17.36E+00	162.00.00	50.3	4.75E+10	1.98E+09	1.49E+10
Se-77	(n,n')	Se-77m	17.36E+00	162.00.00	50.3	5.12E+10	2.13E+09	1.49E+10

5. References

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