The Determination of Neutron Energy Spectrum in Reactor Core C1 of Reactor VR-1 Sparrow

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ABSTRACT

This contribution overviews neutron spectrum measurement, which was done on training reactor VR-1 Sparrow with a new nuclear fuel. Former nuclear fuel IRT-3M was changed for current nuclear fuel IRT-4M with lower enrichment of 235U (enrichment was reduced from former 36% to 20%) in terms of Reduced Enrichment for Research and Test Reactors (RERTR) Program. Neutron spectrum measurement was obtained by irradiation of activation foils at the end of pipe of rabit system and consecutive deconvolution of obtained saturated activities. Deconvolution was performed by computer iterative code SAND-II with 620 groups' structure. All gamma measurements were performed on Canberra HPGe. Activation foils were chosen according physical and nuclear parameters from the set of certificated foils. The Resulting differential flux at the end of pipe of rabit system agreed well with typical spectrum of light water reactor. Measurement of neutron spectrum has brought better knowledge about new reactor core C1 and improved methodology of activation measurement.

1. Introduction

Training reactor VR-1 Sparrow is unique nuclear facility in Czech Republic. Its task is to be used in preparation future expert in the field of nuclear physics, to train inspectors for IAAE and to improve public knowledge about nuclear reactors and nuclear science generally. Finally, VR-1 belongs to the class of pool light water reactors with natural cooling and its main advantage is possibility to do very fast change in composition of reactor core and small starting time of the reactor. VR-1 is equipped by two horizontal and few vertical dry canals for purpose of experiments. Unfortunately, small value of neutron flux density in reactor core (cca. 2-3E13 m^{-2} s^{-1}) brings rather strong limitation to reactor applications. Maximum thermal power of reactor is 5 kW. The reactor VR-1 is managed by the Department of Nuclear Reactors, Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague. In 2005 was former nuclear fuel IRT-3M changed for current nuclear fuel IRT-4M with lower enrichment of ^{235}U (enrichment was reduced from former 36% to 20%) in terms of program RERTR. This resulted in increase of uranium mass in reactor core and in change of neutron spectrum characteristic. Because knowledge of neutron spectrum was needed for right evaluation of some experiments on VR-1 (mainly neutron activation analysis), the measurement of neutron spectrum was done.

2. Measurement setup

Neutron spectrum measurement was obtained by irradiation of integral activation detector in forms of foils from pure metal elements and consecutive deconvolution of obtained saturated activities. Used elements were chosen according their physical and nuclear properties. Nine different elements were measured (see Table 1) and cadmium cover was used in another two cases for highlighting of fast and epithermal part of neutron spectrum. Foils were irradiated at the end of pipe of rabit system, which is the main position for irradiation of samples for neutron activation analysis, too. This position is indicated on Fig. 1 (coordinates C3) and is situated approximately in middle of fuel assemblies. Pipe transportation system is pneumatic equipment that enables very fast transportation (in order of seconds) of irradiated samples

from reactor to gamma spectroscopy laboratory. All activation foils were irradiated for time from 10 minutes to 1 hour on stable reactor power from 100W to 1kW. After irradiation were the samples transported to the gamma spectroscopy laboratory equipped with HPGe detector from Canberra Company (energy resolution 1.8 keV and relative efficiency 25%) with software Genie-2000 v.3.0. Following measurement of activities lasted from 5 minutes to tens hours according to relevant decay constant. Energy and efficiency calibration of HPGe detector was done by certificated ^{137}Cs and ^{152}Eu etalon. Due to small fluence rate and dominance of thermal neutrons in reactor were observed only (n,γ) reactions (radiation capture) and (n,p) reactions. On base of data received from HPGe detector were computed reaction rates for each reaction consequently and then they were used as input data for deconvolution process.

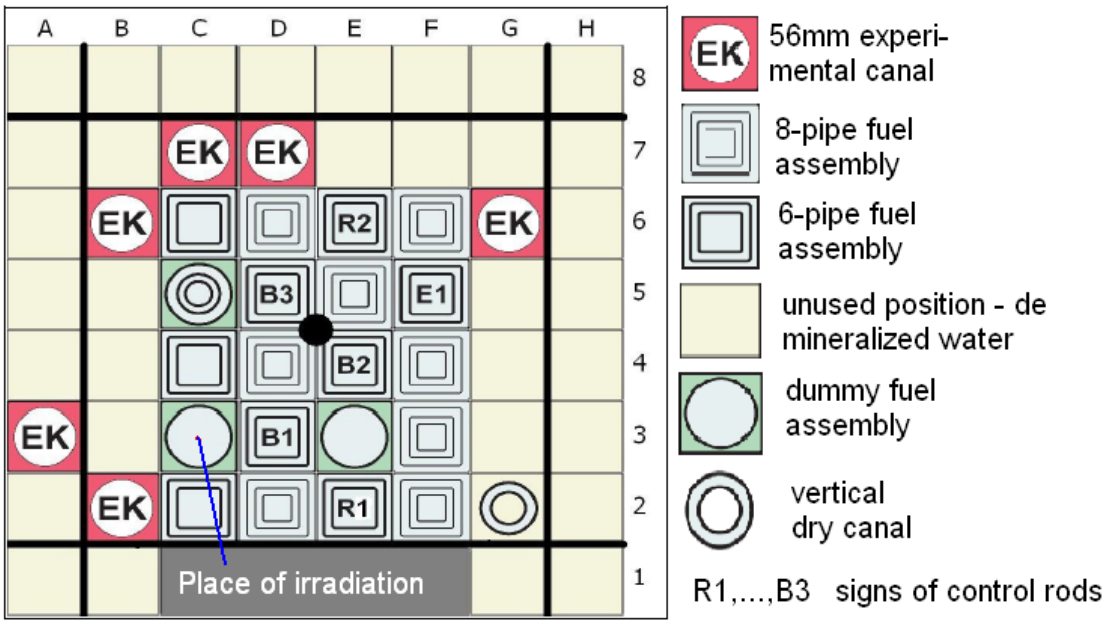

Fig. 1 Composition of reactor core, end of pipe of rabit system is in position C3

3. Neutron spectrum calculation

Deconvolution was performed by computer iterative code SAND-II with 620 groups' structure. This code was newly acquired and replaced old version of SAND-II modified at Nuclear Research Institute Řež. Former version worked in 113 groups' structure. Because the reaction rates are not enough for finding solution (only N equations for N reactions, but 620 unknown flux values in 620 energy interval), a prior information about spectrum was also needed. SAND-II required neutron spectrum approximation in input data. Monte Carlo code MCNP-4C was used for computing of this first approximation. Because the original reaction cross section library in SAND-II had not cover whole set of reactions chosen for measurement, the original library was filled out by cross sections for following reactions: ^{64}Ni(n,γ)^{65}Ni, ^{186}W (n,γ) ^{187}W and ^{51}V(n,γ)^{52}V. Values of new cross sections were computed by program NJOY99 from ENDF-VIB library. During the process there were revealed difference between cross sections from original SAND-II library and new ones computed for the same reactions, mainly in resonance area. Comparison with dosimetry library IRDF-2002 showed agreement between IRDF2002 and NJOY99 results therefore was the original library replaced. Comparison of calculations for both libraries was done, too. On Fig.2 can be seen

cross section gained from SAND-II original library, NJOY99 calculation and IRDF2002 library (it almost covers NJOY99 results).

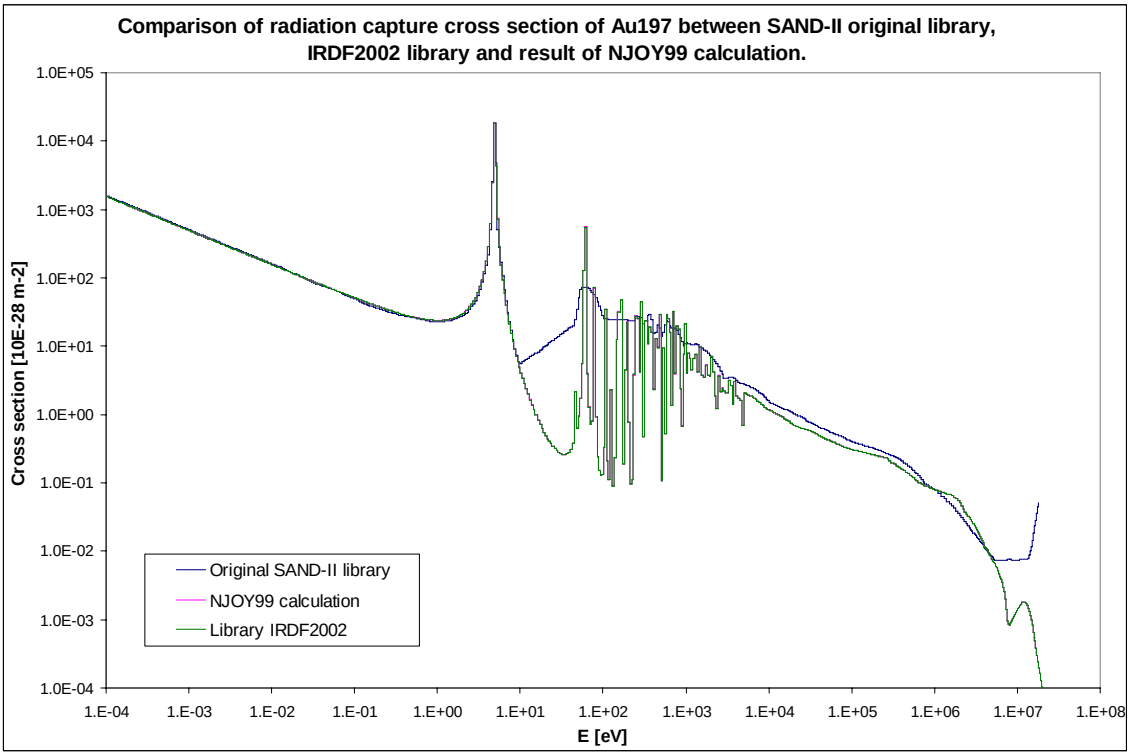

Fig. 2 Comparison of cross sections for Au197(n,g)Au198 reaction

4. Result

Summary of reaction rates is in Table 1 and resulting fluence rate for different energy area are showed on Table 2 below.

Table 1 Summary of reaction rates

Reaction	Measured reaction rate	Calculated reaction rate	Ratio of measured and calculated reaction rate	Deviation of measured to calculated reaction rate [%]
AU197(N,G)AU198 with Cd cover	5.28E-17	5.09E-14	1.0369	3.69
MN55(N,G)MN56 with Cd cover	9.71E-16	9.75E-16	0.9962	-0.38
IN115(N,G)IN116M	Discarded			
NI58(N,P)CO58	4.91E-17	4.92E-17	0.9968	-0.32
SC45(N,G)SC46	3.39E-14	3.18E-14	1.0688	6.88
AU197(N,G)AU198	1.43E-13	1.64E-13	0.8708	-12.92
MN55(N,G)MN56	1.72E-14	1.62E-14	1.0647	6.47
CU63(N,G)CU64	4.85E-15	5.34E-15	0.9075	-9.25
W186(N,G)W187	6.19E-14	6.34E-14	0.9765	-2.35
V51(N,G)V52	5.92E-15	6.00E-15	0.932	-6.8
NI64(N,G)NI65	2.05E-15	1.78E-15	1.1498	14.98
Average deviation				8.38

Table 2 Summary of fluence rate

Spectrum area	Energy	Fluence rate [cm^{-2} s^{-1}]
Thermal	10E-4eV – 0,5eV	1,38E+09
Epithermal	0,5eV – 0,1MeV	7,99E+08
Fast	> 0,1MeV	6,74E+08
All	> 10E-4eV	2,85E+9

Calculation was terminated after five iterations, because difference between results of two following step did not exceed 1.5%. This shows the suitability of first approximation and worthiness of MCNP calculation. Indium foil was discarded during SAND-II calculation due to excessive deviation. Reason is not known, but crude failure in measurement is probably responsible. Mean standard deviation of result was 8.38% and deviation of single reaction did not exceed 15%, which illustrate a good consistency of experimental data. Results are in good agreement with expectations based on former operational experience of reactor VR-1 Sparrow, too. Resulting differential spectrum is shown on Fig. 3. The great „jumps" at the beginning and end of spectra are caused by very bad statistics of MCNP calculation for these areas, because there is very small number of neutrons. Results for calculations with original and new libraries showed only light difference both in shape and precision (probably because of dominance in thermal area).

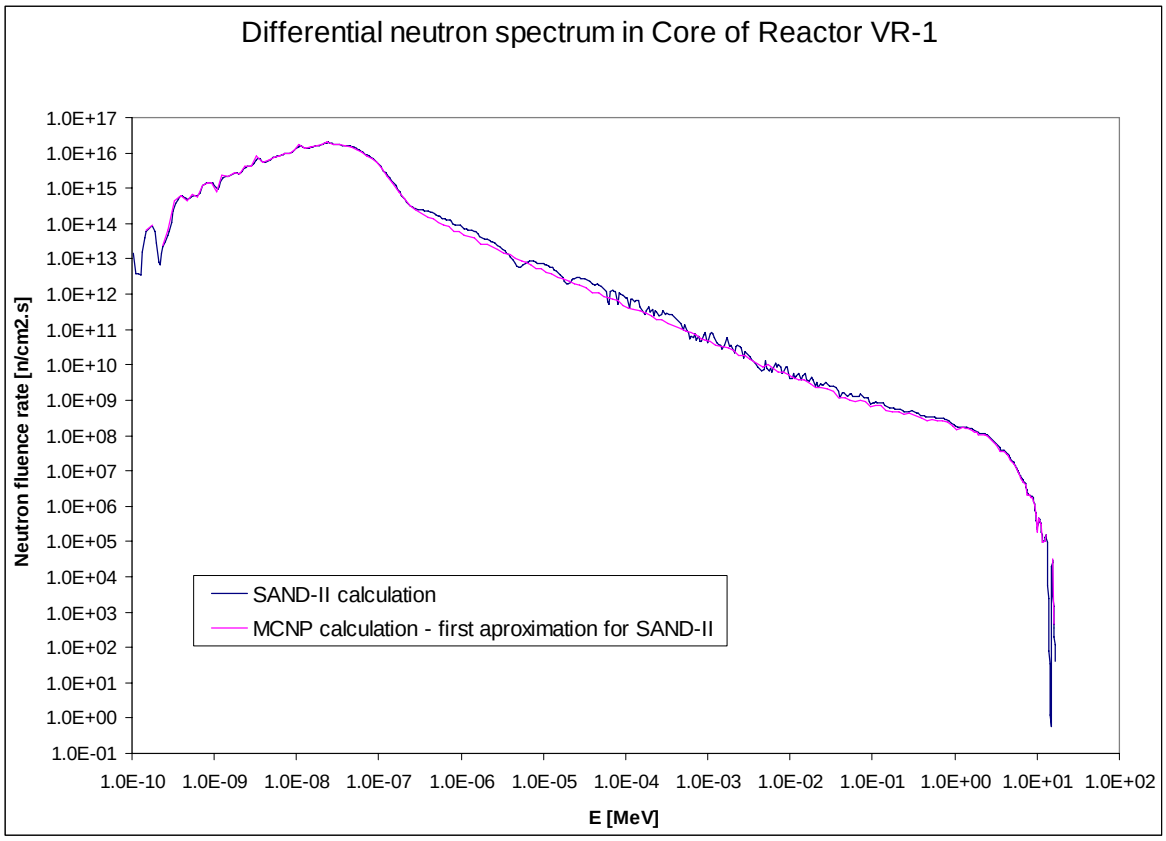

Fig. 3 Differential neutron spectrum

5. Conclusion

Resulting spectrum confirmed the expected high ratio of thermal neutrons in spectra and very low share of fast neutrons. The differential flux at the end of pipe of rabit system agreed well with typical spectrum of light water reactor. Good visible was 1/E area. Measurement of neutron spectrum has brought better knowledge about new reactor core C1 (although this composition of core was replaced by a new one) and improved methodology of activation measurement. This measurement gave also a new impulse to investigation of problematic of neutron spectrum adjustment and lead to purchasing new computer codes, which could also supply statistic evaluation of results.

References

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