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Neutron energy spectrum adjustment using deposited metal films on Teflon in the miniature neutron source reactor

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HIGHLIGHTS

- Neutron energy spectrum in the MNSR using DMFTs was experimentally estimated.
- The usability of DMFTs in the measurement of neutron energy spectrum was studied.
- STAY'SL was used for neutron spectrum adjustment (input one calculated by the MCNP).
- Comparison of theoretically calculated and adjusted spectra shows a good agreement.
- DMFTs can be used in the MNSR reactors as thermal and resonance neutron detectors.

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ABSTRACT

The focus of this article was on the experimental estimation of the neutron energy spectrum in the inner irradiation site of the miniature neutron source reactor (MNSR), using, for the first time, a selected set of deposited metal films on Teflon (DMFTs) neutron detectors. Gold, copper, zinc, titanium, aluminum, nickel, silver, and chromium were selected because of the dependence of their neutron cross-sections on neutron energy. Emphasis was placed on the usability of this new type of neutron detectors in the total neutron energy spectrum adjustment. The measured saturation activities per target nucleus values of the DMFTs, and the calculated neutron spectrum in the inner irradiation site using the MCNP-4C code were used as an input for the STAY'SL computer code during the adjustment procedure. The agreement between the numerically calculated and experimentally adjusted spectra results was discussed.

1. Introduction

Neutron flux distribution in nuclear reactors is most often characterized with foil activation detectors because of their small size, which allows them to be used in the core and the irradiation channels of nuclear reactors, and to measure their induced activity under neutron irradiation with ease. Having a precise knowledge of the neutron energy spectrum is essential to perform various fundamental and experimental studies in fields such as nuclear physics, nuclear engineering and technology, and medical sciences and health physics research on the treatment of cancer by neutron irradiation. Evaluation of neutron energy spectrum in reactor irradiation sites is also necessary for the analysis of irradiation characteristics. The aforementioned knowledge is necessary for the user to determine the induced activity of the irradiated samples in these sites and to precisely analyze the unknown samples using the neutron activation analysis (NAA) technique.

2. Historical review

Neutron spectrum adjustments in different types of reactors using different adjustment codes and traditional neutron threshold and activation detectors with nominal thickness (range 0.0254–0.254 mm) are illustrated in Table 1. Element use frequencies within 10 selected publications presented in Table 1 are shown in Fig. 1. Neutron radiative capture, that is, (n,γ) nuclear reaction, which is sensitive to neutrons in the thermal and resonance regions without and with cadmium cover, respectively, is used for the different elements presented in Table 2. The commonly used threshold reactions, (n,α), (n,p), (n,2n), (n,n'), and (n,f), which are sensitive to neutrons in the intermediate and fast

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Table 1
Metal foil activation detectors and adjustment and neutron spectrum calculation codes used for the determination of energy neutron spectrum.

Reactor type	Adjustment codes	Neutron spectrum calculation codes	Metal foil activation detectors	Reference
Budapest Technical University nuclear reactor	SANDBP	LWR type WWR reactor spectrum (49 energy groups)	Dy, Al, Sc, Fe, Ni, In, Mn, Au, Ti	(Zsolnay and Szondi, 1982)
Pakistan Research Reactor-1(PARR-1)	MSITER	WIMS-D/4, CITATION	Au, Cu, Mn- Cu, Fe, Al, Ni, Mg	(Malkawi and Ahmad, 2000)
Pakistan Research Reactor-1(PARR-1)	SANDBP, MSANDB, MSITER, MIEKEB	WIMS-D/4, CITATION	Au, Cu, Mn- Cu, In, Fe, Al, Ni, Mg, Ti, U	(Malkawi and Ahmad, 2001)
Pakistan Research Reactor-1(PARR-1)	MSITER, SANDBP	WIMS-D/4, CITATION	Au, Cu, Mn, In, Fe, Al, Ni, Mg, Ti, U	(Malkawi and Ahmad, 2002)
Kalpakkam Mini (KAMINI) reactor	SAND-II	SMAXY, COMESH	Au, Mn, In,	(Mohapatra and Mohanakrishnan, 2002)
Heavy Water Neutron Irradiation Facility of the Kyoto University Research Reactor	NEUPAC	Two-dimensional transport code, DOT 3.5	Au, Mg, In, Fe, Al, Ni, Ti	(Sakurai and Kobayashi, 2004)
Arkansas Nuclear One power plant (ANO), JOYO MK-II	MINUIT, STAYNL, MSANDB,	–	Au, Cu, Mn, In, Fe, Al, Ni, Ti, W,As, Nb, U	(Seghour and Seghour, 2005)
Yalina Booster facility	SAND-II	MCNP	Cd, Co, Ti, Fe, Cu, F in CF2, Pb, Mg, Al, Zn, Au, In	(Tesinsky, 2006)
IPEN/MB-01	SANDBP	Hammer-Technion cellular code	Au, Sc, In, Ni, Mg, Ti, U	(Ulysses and Fernando, 2007)
Pakistan Research Reactor-2(PARR-2)	STAYNL	WIMS-D/4, CITATION	Au, Al, Ni, Mg, Co	(Iqbal et al., 2008)

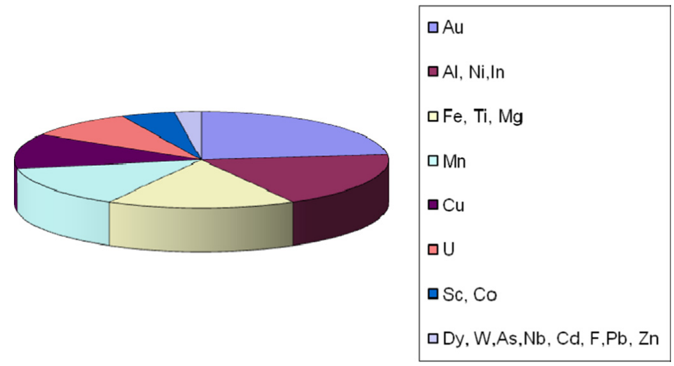

Fig. 1. Element use frequency of neutron activation and threshold detectors.

regions, of different elements are shown in Table 3, and their threshold energies are presented in Table 4.

In this study, a new type of neutron detectors, deposited metal films on Teflon DMFTs, was used instead of the traditional metal foils for neutron energy spectrum adjustment in the miniature neutron source reactor MNSR. The neutron energy spectrum, which was used as pre-information in the adjustment procedure, was calculated by the MCNP-4C code, whereas the STAY'SL code was used for the neutron spectrum adjustment calculations. The MNSR description could be found in many publications (Abrefah et al., 2010; Iqbal et al., 2008; Khattab and Sulieman, 2010; Malkawi and Ahmad, 2002; Omar et al., (2001); Rovni et al., 2011; Seghour and Seghour, 2005).

3. Preparation of the input file for the STAY'SL code

In general, unfolding codes change by iterative processes, from the initial spectrum (calculated by the reactor physics codes and their associated data libraries) to the best spectrum adjusted by the minimum deviation between experimental and calculated saturation activities per target nucleus of the different irradiated foils. A ratio of calculated to the experimental nuclear reaction rates, which is used to modify the irradiated foil-covered initial neutron spectrum around several energy ranges, is obtained from an iterative process. The STAY'SL program resolves the neutron spectrum adjustment problem by the generalized least squares method in linear space. Pre-information spectrum is adjusted to make it consistent with the actual one characterized by a set of measured reaction rates of activation detectors. In the case of the least-squares analysis code STAY'SL, iterations are not required because they would not make the solution more reasonable (Perey, 1977a). The solution is obtained by minimizing the chi-square value based on the input data. The out-put STAY'SL code is obtained based on the input data (the activation data, the input spectrum, and the dosimeter cross-sections and their uncertainties). Therefore, the solution reflects the uncertainties in all of the input data. However, the input data are assumed to be uncorrelated with each other (Perey, 1977b). The neutron energy spectrum as pre-information required for the adjustment code is calculated in the inner irradiation site of the MNSR using the MCNP-4C code. This code makes an interpolation where there is no covering energy range (Seghour and Seghour, 2005; Ulysses and Fernando, 2007). Vertical cross-section of the MNSR, a tank-in-pool-type research reactor, is depicted in Fig. 2. A detailed description of this reactor can be found in the reactor safety analysis report (CIAE, 1993).