NEUTRON SPECTRUM DETERMINATION BY ACTIVATION METHOD IN FAST NEUTRON FIELDS AT THE RB REACTOR

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ABSTRACT

The fast neutron fields of the RB reactor are presented in this paper. The activation method for spectrum determination is described and explained. The obtained results for intermediate and fast spectrum are given and discussed.

Introduction

The RB nuclear reactor [1] at the Nuclear Engineering Laboratory of the Institute of Nuclear Sciences "Vinča" is the first, zero power, bare, heavy water critical facility in Yugoslavia. The natural metal uranium fuel elements, the 2% enriched metal uranium fuel elements and 80% enriched uranium-dioxide fuel elements are available from 1975.

The fields of fast neutrons with "softened" fission spectrum are made by modifying the system: modified experimental fuel

channel EFC [2], coupled fast-thermal system in two configurations CFTS-1 and CFTS-2 [3] and coupled fast-thermal core HERBE [4].

One of the first tasks was to develop the method for absolute neutron spectrum determination for the whole energy range. The activation method [5,6,7] is improved and used for determining of neutron spectrum characteristics.

Fast Neutron Fields

The intensity of fast neutron flux in the RB reactor was upgraded in 1982 when a modified experimental fuel channel (EFC) was constructed. The EFC is formed inside of the standard RB reactor fuel channel (an aluminium tube 41/43 mm diameter and bottom hermetically sealed) from 10 modified 80% enriched UO_2 fuel segments. During fuel segment modification, central aluminium caliber with outermost "stars" are taken off and the rest of fuel segments is slipped on an aluminium tube 27/28 mm diameter, one to another, as closely as possible. All this arrangement is placed inside the standard fuel channel. Movable aluminium tube is placed inside the EFC experimental space (25/27 mm diameter) filled with aluminium expellers and sample supporters. Thus, the samples or detectors can be easily placed in the reactor or taken out. The EFC is placed in the especially designed reactor core with high epithermal neutron flux.

The coupled fast-thermal system at the RB reactor is also constructed for fast neutron fields investigation. The fast core of the CFTS-1 is formed of 80% enriched UO_2 fuel and the natural metal

uranium fuel elements forming a blanket. The central area of the fast core is cylindrical experimental space with a diameter 20 cm and a height of up to 120 cm. The thermal RB core (driver) has a standard lattice pitch of 12 cm from 2% enriched metal U fuel elements and 80% enriched UO_2 fuel elements in the D_2O moderator. In CFTS-2 this 80% enriched fast zone is removed and experimental zone is larger (30 cm diameter).

The coupled fast-thermal core HERBE is designed with the aim to improve experimental possibilities in fast-neutron fields. The requirements for minimum modifications in the RB construction and application of available fuel restricted design flexbility of the coupled system: the central fast core of natural uranium is surrounded by neutron filter zone (cadmium and natural uranium) and converter zone (enriched uranium fuel, without moderator). The coupling region is heavy water. Thermal core is formed of RB heavy water 80% enriched uranium lattice with 12 cm pitch.

Activation Method

The activation method has a few advantages compared with others, especially in the region below 10 keV. They are: simple construction, small dimensions, radiation and temperature resistance and good spatial resolution.

The intermediate and fast neutron spectrum are measured by activation technique, especially developed for our fast neutron fields. The method of resonance detectors for absolute values of intermediate and threshold detectors for absolute values of fast

spectrum are used for these measurements.

The foils used as resonance detectors are given in Table 1 and those used as threshold detectors are given in Table 2. The foils are irradiated at the predetermined positions in the fast fields. The absolute value of neutron flux is obtained with Au foils. Foil activities are measured by using gamma scintillation technique with especially designed γ-measuring lines and 4πβ absolute counting method, also developed in our Laboratory. The measuring results were evaluated by ACT code based on analytical relations accounting all necessary physical and geometrical corrections which returns foil saturated activity and neutron flux density. Intermediate spectrum is obtained by KRIFIT code and fast spectrum by HEFEST code on the basis of experimental results.

The code KRIFIT is based on the minimum mean square method using modified Gauss-Newton treatment. f_i $(i=1,...,n)$ are experimental values of function f with m variables x_l $(l=1,...,m)$ amd $k<n$ parameters a_j $(j=1,...,k)$ that has to be determined. The measured values of x_l variables in n different points give the function $f(x,a)=0$. The system of nonlinear equations is obtained by direct using of the minimum mean square method. The problem is solved by linear power series expansion of f_i functions that give value of Δa_j $(\Delta a_j=a_j-a_{j0})$. In the minimum square method the weighted sum of squares must be on minimum. When the weighted matrix is transponed to the moment matrix the obtained relation (Gauss method) is solved iterativelly.

The code HEFEST is based on method of maximal probability. The activation integral is treated as a relation of total probability

that connects probability $\Psi(E)$ with discrete aproximation of probability density $\xi(x)$. $a_i(E)$ is a discrete approximation of total probability density $a(x,E)$. In first approximation x has the distribution $\xi_1(x)=\xi_i$, while in second it has the distribution $\xi_2(x)=\int a_i(E)\Psi_t(E)dE$. ξ_i depends on experimental values and ξ_2 depends on model of distribution density $\Psi_t(E)$. The optimal model of distribution density is obtained by setting the values of ξ_1 equal to the values of ξ_2.

Detector	E_R (eV)	RI($10^{-24}cm^2$)	$T_{1/2}$
$^{176}Lu(n,\gamma)^{177}Lu$	0.142	900	6.71 d
$^{115}In(n,\gamma)^{116m}In$	1.457	3243	54 min
$^{197}Au(n,\gamma)^{198}Au$	4.906	1565	2.69 d
$^{186}W(n,\gamma)^{187}W$	18.80	350	24.1 h
$^{59}Co(n,\gamma)^{60}Co$	132.0	77	5.27 y

Table 1. The foils used for intermediate spectrum determination

Detector	E_{eff}(MeV)	$\sigma_{eff}(10^{-27}cm^2)$	$T_{1/2}$
$^{103}Rh(n,n')^{103m}Rh$	0.80	950	57 min
$^{115}In(n,n')^{115m}In$	1.15	302	4.5 h
$^{32}S(n,p)^{32}P$	2.65	252	14.3 d
$^{58}Ni(n,p)^{58}Co$	2.70	452	72 d
$^{54}Fe(n,p)^{54}Mn$	3.00	370	310 d

Table 2. The foils used for fast spectrum determination

Results

The intermediate spectra in EFC and HERBE are calculated by code KRIFIT and have the form given with relations (1) and (2), respectively.

$$\phi=\theta/E^{\alpha} \quad \theta=4.50\ 10^{9}\ n/(cm^{2}(\Delta u)) \tag{1}$$

In this relation $\alpha=1$ and Δu is the lethargy unit.

$$\phi=9.31\cdot10^{5}u-3.92\cdot10^{5}u^{2}+5.51\cdot10^{4}u^{3}-2.54\cdot10^{3}u^{4}-4.89\cdot10^{4} \tag{2}$$

Value for α in relation (2) is the same, while $u=\ln(E_0/E)$.

The fast spectra in EFC, CFTS-1 and CFTS-2 are calculated by code HEFEST and are given in Table 3.

E_n (MeV)	Fast neutron spectrum Φ (n/(cm^{2}s MeV))		
	EFC	CFTS-1	CFTS-2
1	5.33×10^{7}	1.3×10^{6}	1.26×10^{6}
2	3.32×10^{7}	2.8×10^{5}	2.71×10^{5}
3	1.79 107	1.1×10^{5}	1.06×10^{5}
4	9.11×10^{6}	6.3×10^{4}	6.11×10^{4}
5.5	3.12×10^{6}	4.5×10^{4}	4.30×10^{4}
6.5	1.49×10^{6}	1.2×10^{4}	1.16×10^{4}
7	1.03×10^{6}	6.8×10^{3}	6.59×10^{3}
8	4.84×10^{5}	2.9×10^{3}	2.81×10^{3}
9	2.26×10^{5}	1.5×10^{3}	1.45×10^{3}
10	1.05×10^{5}	1.0×10^{3}	9.69×10^{2}

Table 3. The fast neutron spectrum in fast neutron fields at the RB reactor

Conclusion

According to the obtained results, activation method is a capable tool in reactor physics nowadays. It is possible to use the described neutron fields for different irradiation studies, material studies, and dosimetrical purposes. There is only one limitation: the realised flux values cannot be larger then 10^{10} n/cm^2.

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