MEASUREMENTS OF CROSS SECTIONS OF THE $^{109}Ag(n,2n)^{108m}Ag$, $^{151}Eu(n,2n)^{150}Eu$, and $^{153}Eu(n,2n)^{152}Eu$ REACTIONS AT NEUTRON ENERGY 14 MeV *

(Progress report)

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Abstract: The cross sections of the reactions producing long-lived nuclides: ^{108m}Ag, ^{150}Eu, and ^{152}Eu have been measured at neutron energy about 14 MeV. An activity of irradiated samples was measured with a Ge(Li)-detector. Isotopically pure samples were used.

INTRODUCTION

In fusion reactors the materials should be used, that do not produce large quantity of long-lived radioactivity at irradiation by 14-MeV neutrons. The IAEA specialists' meeting recommended to pay espesial attention to a number of reactions which are important in this respect. In the present work the cross sections of three reactions of this list were measured.

EXPERIMENTAL DETAILS

The samples were irradiated at neutron generators NG-400, where fluence about 10^{13} n·sm^{-2} was received by the samples, and NG-200 (fluence about 10^{14} n·sm^{-2}). The first irradiation at low beam current was performed in order to clear up the real background conditions, to choose the optimal parameters of the cycle: irradiation - cooling - measurement, and to refine some other experimental details.

The irradiation of the samples was carried out at the arrangement shown in Fig. 1. The construction consisted of four assemblies that were placed at 0°, 60°, 90°, and 120° with respect to the beam. Every assembly contained three isotopes studied, i.e. ^{109}Ag, ^{151}Eu and ^{153}Eu and also five neutron monitor foils made of ^{93}Nb (two foils), ^{90}Zr, ^{58}Ni, and ^{197}Au. The characteristics of the used samples are given in Table 1. The average distance from the sample to the target was 45 mm. At the angle 90° 7000 mg of the natural europium's oxide (Eu_2O_3) were also placed.

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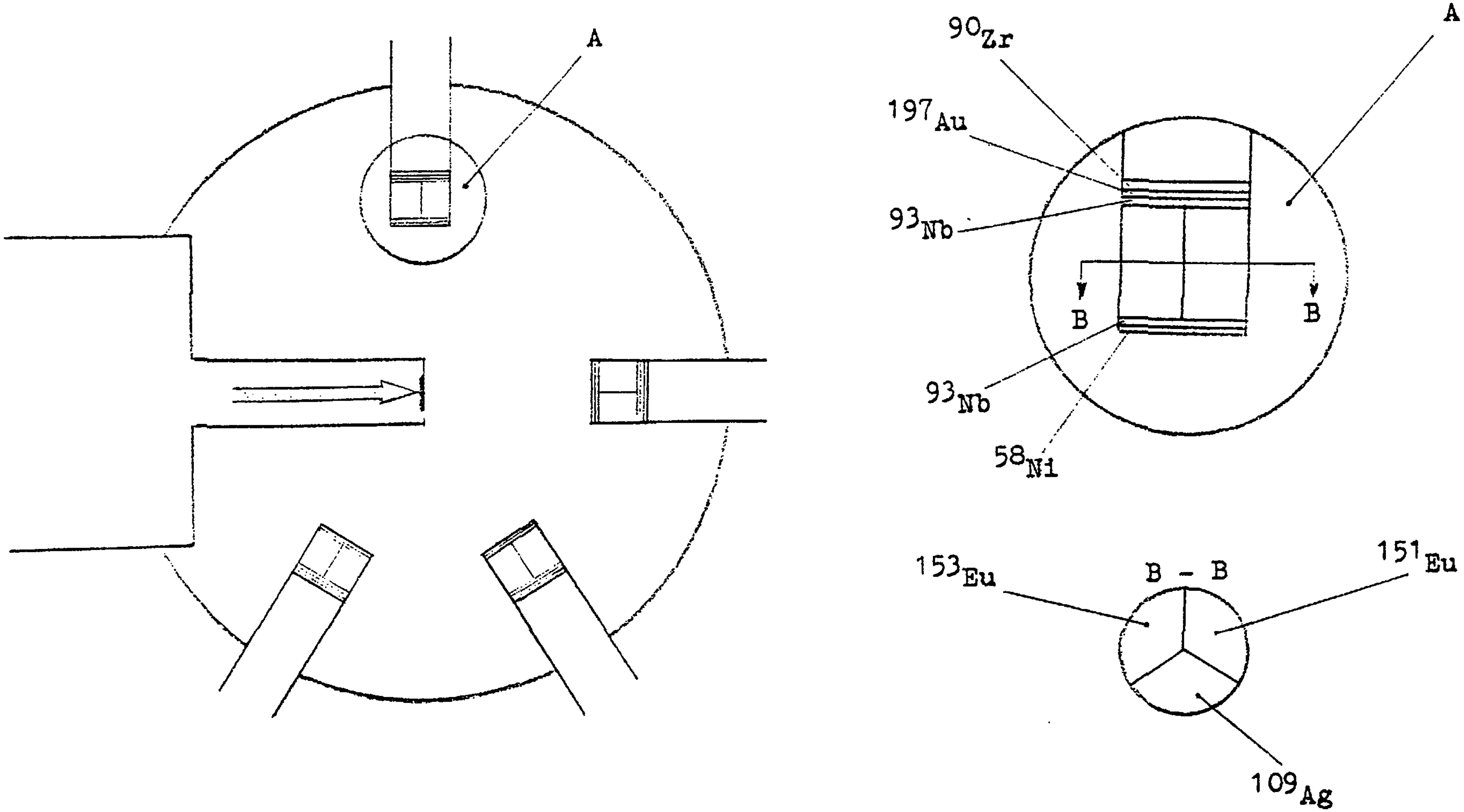

Fig. 1. The experimental arrangement at the NG-400.

Table 1. Isotopic abundance of the samples

Enriched isotope	Chemical form	Isotopic abundance	Pure weight
^{109}Ag	Ag	^{109}Ag - 99.4% ^{107}Ag - 0.6%	4·1250 mg
^{151}Eu	Eu_2O_3	^{151}Eu - 97.5% ^{153}Eu - 2.5%	4·500 mg
^{153}Eu	Eu_2O_3	^{153}Eu - 99.2% ^{151}Eu - 0.8%	4·500 mg

The neutron flux was measured with a long counter and a plastic scintillator counter. To maintain the neutron flux constant the accelerating voltage was gradually increased during irradiation (from 240 kV at the beginning to 280 kV at the end).

The $^{93}Nb(n, 2n)^{93m}Nb$ reaction was used as a standard for neutron fluence determination. The cross section of this reaction was shown to change no more then ±1% in the neutron range 14.1 - 14.8 MeV /1/. an the uncertainty of the evalution of the cross section at 14.7 MeV is 1.6% /2/.

A simultaneous use of foils made of other materials schould increase reliability of the results. Besides, in this case the mean energy of neutrons passed through the sample may be deduced experimentally, since the cross sections of the $^{58}Ni(n, 2n)^{57}Ni$, $^{58}Ni(n, p)^{58}Co$ and $^{90}Zr(n, 2n)^{89}Zr$ reactions depend on the energy quite differently.

The irradiation's arrangement at NG-200, where the neutron fluence about 10^{14} $n \cdot sm^{-2}$ was achieved, differed only in inessential details. There were used two assemblies at 15° and 55°.

The flux, the mean energy, and the energy dispersion of neutrons at the given angle in the laboratory system were calculated by a program using the recommended data on the $^3H(d, n)^4He$ reaction in the centre of mass system /4/. The program accounted for the real characteristics of the beam (energy, current) and of the target (sorbing material, its thickness, quantity of the absorbed tritium).

The induced gamma-ray activity was measured with a Ge(Li)-detector. Its energy resolution was 2.7 keV and the peak efficiency was 7.9% at 1332 keV gamma-ray energy. Fragments of the measured spectra are shown in Fig. 2-3.

The data were processed by a multichannel analyzer NOKIA LP 4900B, which had a set of programs for treatment of gamma-ray spectra, for de-

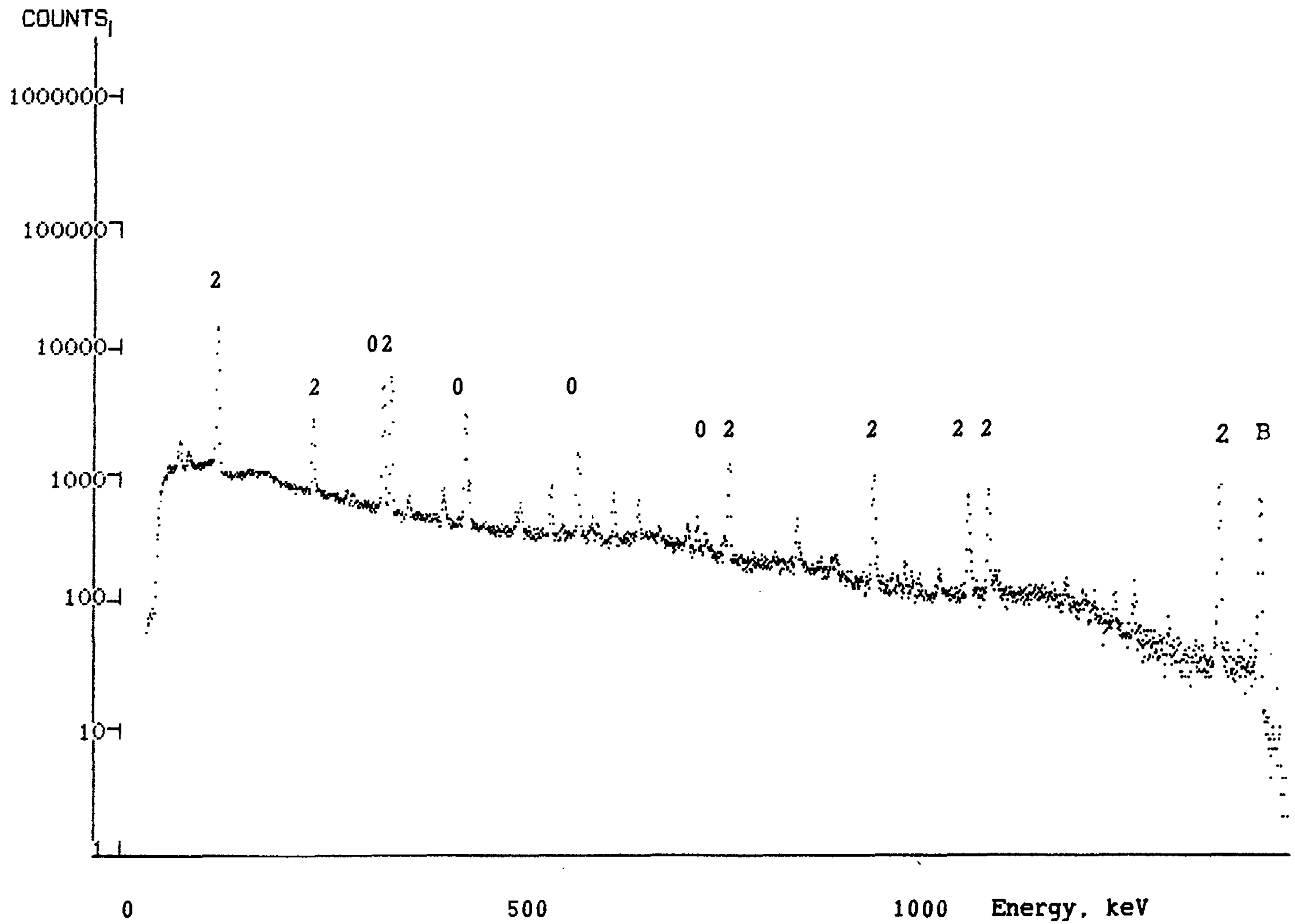

Fig. 2. The γ-ray spectrum from natural europium irradiated by 14.1 MeV neutrons (90^{o}). Cooling is 55 days. Lines from ^{150}Eu are labeled by "0", from ^{152}Eu - by "2"; "B" - background.

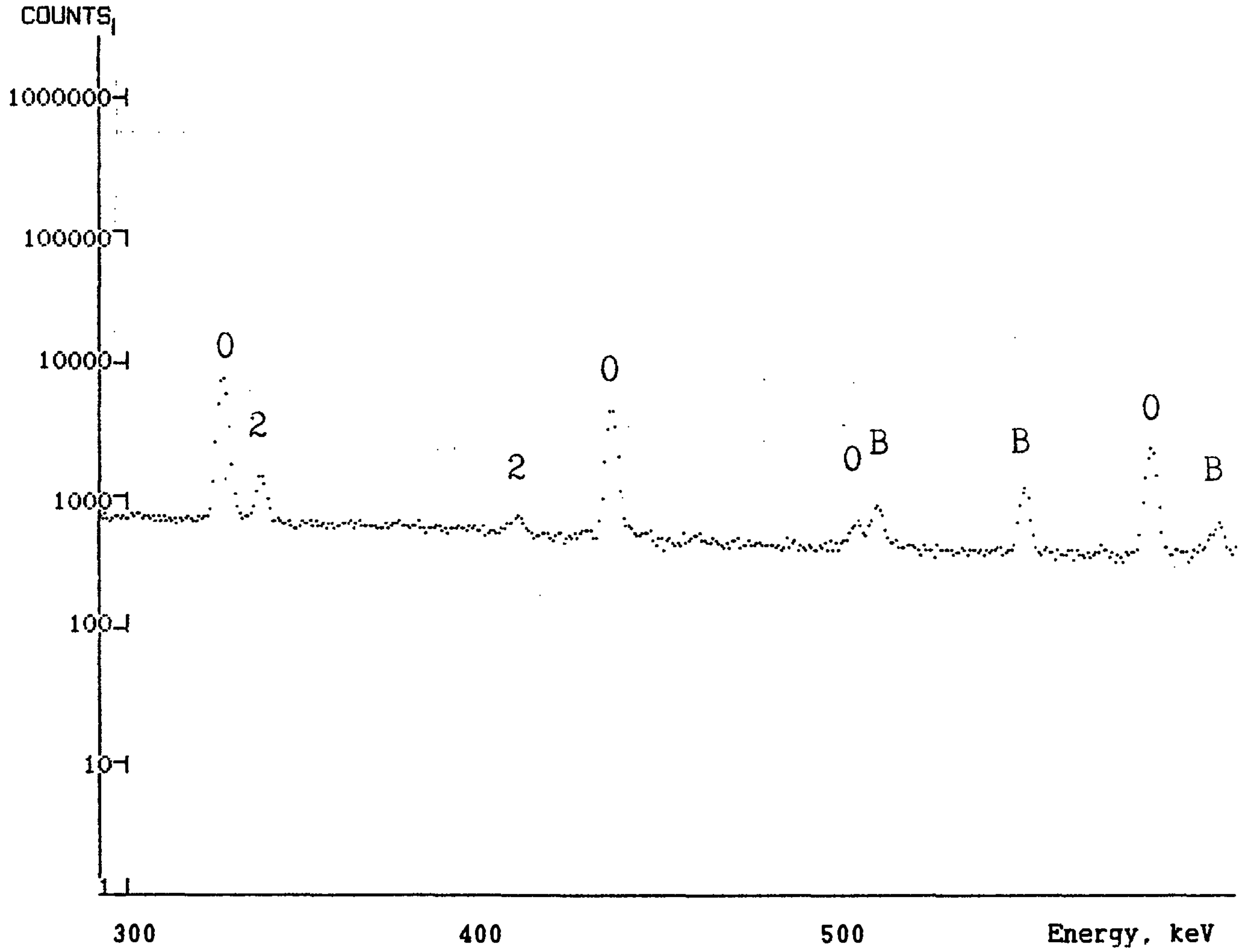

Fig. 3. Fragment of the γ-ray spectrum ^{151}Eu irradiated by 14.1 MeV neutrons (90^{o}). Cooling is 55 days. Lines from ^{150}Eu are labeled by "0", from ^{152}Eu - by "2"; "B" - background.

termination of the spectrometer calibration parameters, and for calculation of volume source activity.

In the present work all gamma-activities were measured in a standard, good calibrated geometry, in which the sample centre was placed at a distance of 62 mm from the effective centre of the detector. The accuracy of the detector efficiency determination and of the source size correction were checked with a number of standard gamma-ray sources. It has been found that the sum uncertainty for these two values does not exceed 3.2% under the experimental conditions used.

RESULTS AND DISCUSSION

The measured cross sections are listed in Table 2. The mean neutron energy given in the first column was obtained by the mentioned program calculation. The mean energy values deduced from a comparison

Table 2. Results of cross sections measurement at neutron energy about 14 MeV

Mean neutron energy (MeV)	Cross section (mb)			
	$^{109}Ag(n,2n)^{108m}Ag$	$^{151}Eu(n,2n)^{150}Eu$	$^{153}Eu(n,2n)^{152}Eu$	$^{93}Nb(n,2n)^{92m}Nb$
13.7	186(36)	1077(85)	1585(120)	457(9)
14.1	200(39)	1162(93)	1463(110)	461(9)
14.5	204(37)	1147(83)	1482(115)	466(9)
14.9	208(37)	1090(84)	1740(145)	459(9)

Table 3. Nuclide decay data

Radionuclide	γ-ray energy (keV)	Yield (%)	Half-life (Y)
^{108m}Ag	433.937(5) 614.281(6) 722.938(8)	0.905(6) 0.899(21) 0.909(21)	127(21)
^{150}Eu	333.971(12) 439.401(15) 584.274(12)	0.960(30) 0.804(34) 0.526(33)	35.80(10)
^{152}Eu	344.281(2) 778.91(1) 964.131(9) 1408.011(14)	0.2658(19) 0.1296(7) 0.1462(6) 0.2085(8)	13.33(4)

of the ^{57}Ni, ^{58}Co, and ^{89}Zr, activities do not contradict to the calculated ones, but have insufficiently high accuracy. This is connected with the fact, that the cross sections of the corresponding reactions are not known with the necessary precision yet. It may be seen, for example, in Handbook on Nuclear Activation Data /3/.

It should be noted, that the data on the $^{93}Nb(n,2n)^{92m}Nb$ cross section /5, 6/ contained in Ref. /3/ have also rather low accuracy (5-10%) and are in a not very good agreement with the evaluation /2/. Therefore, we decide to measure the cross section of this reaction relative to the well studied cross section of $^{27}Al(n,\alpha)^{24}Na$ /7/. For this purpose, in an arrangement similar to that shown in Fig. 1, some short-time irradiations were conducted, in which the aluminium foils are placed close to the niobium ones. The obtained in such a way

$^{93}Nb(n, 2n)^{92m}Nb$ cross sections are shown in the last column of Table 2. Thev aooear to be constant within 2% in the relevant energy reoion. according to /1/, and the mean value obtained by us is 461 mb. This differs slightlv from the evalution /2/. By neutron fluence determination we have used the cross section value of 461 mb in the whole energv interval 13.7 - 14.9 MeV. assuming its error is 2%.

In Table 3. the gamma-rav energies and vields are shown, that were used at the ^{108m}Ag, ^{150}Eu. and ^{152}Eu. activitv determination. The data were taken from Refs. /8 - 10/. Everv of the listed in Table 3 gamma-lines was searched in the corresponding soectrum. and from its area the radionuclide activitv was deduced. Then the mean-weighted value was calculated and the corresponding cross section was obtained.

The main uncertainties of the cross sections listed in Table 2 are the following:

- the uncertaintv of the effective fluence determination (including a possible irregularity of the sample mass disiribution) < 6%;
- the uncertaintv of the induced activitv determination - up to 15% for verv weak peaks;
- the half-life uncetaintlv - up to 17% for the ^{108m}Ag.

In order to imorove the accuracv of the results efforts should be made to increase the neutron fluence received bv samples and to obtain a more orecise value of the ^{108m}Ag half-life.

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