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FENDL NEUTRONICS BENCHMARK:

NEUTRON LEAKAGE SPECTRA FROM Be, Fe, Pb, PbLi SHELLS WITH 14MeV NEUTRON SOURCE

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Abstract

Following the recommendations of an IAEA Consultant's Meeting on "Preparation of Fusion Benchmarks in Electronic Format for Nuclear Data Validation Studies", the present report on benchmark experiments with 14-MeV neutrons on beryllium, iron, lead and lead-lithium alloy was prepared. It complements the experimental data available on-line from the IAEA Nuclear Data Section so as to enable any user to perform transport calculations for this experiment in order to validate nuclear data libraries, such as the Fusion Evaluated Nuclear Data Library (FENDL).

December 1994

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Introduction

(written by U. von Möllendorff, Kernforschungszentrum Karlsruhe, Germany, and S. Ganesan, IAEA Nuclear Data Section, Vienna, Austria)

The IAEA Nuclear Data Section has implemented a computerized collection of data from those integral neutronic experiments that are suitable to test libraries of evaluated fusion relevant nuclear data ("benchmark experiments"). In particular, the Fusion Evaluated Nuclear Data Library (FENDL), the reference library for the International Thermonuclear Experimental Reactor (ITER) project, should be validated using these experimental data. An IAEA Consultant's Meeting on "Preparation of Fusion Benchmarks in Electronic Format for Nuclear Data Validation Studies has given detailed recommendations for submissions of experimental data and parameters for this collection (see summary report INDC(NDS)-298, March 1994). It was pointed out that, in addition to numerical data, explanatory hard-copy material in the form of text and figures is indispensable to enable calculations to be made.

The present report which follows is such material. It complements the following files that are available by ftp command on-line from the IAEA:

ftp 161.5.2.2
user FENDL
cd FENDL/BENCHMARKS/RUSSIA
The 17 files in this directory correspond to this document.

File README.DOC begins (version of 14 February 1994)

NEUTRON LEAKAGE SPECTRA FROM Be, Fe, Pb, PbLi SHELLS WITH 14MeV NEUTRON SOURCE.

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Abstract.

Specification of experiment and numerical data according with recommendation of IAEA Consultants Meeting on "Preparation of Fusion benchmarks in electronic format for nuclear data validation studies" (held in 13-16 December 1993, IAEA, Vienna).

A. Benchmark Name and Type.

IPPE Fusion Bulk Shielding and Breeding/Multiplication Benchmarks; Time of Flight spectroscopy of neutrons leaking from spherical assembles.

B. System Description.

Neutron leakage energy spectra have been measured with shells made of Be, Fe, Pb and LiPb, the T(d,n) neutron source being located at its center.

The experimental configuration is actually 3-dimensional but may be approximated by 1-dimensional one. The 3-dimensional configuration will first described for the sake of generality and then more 1-dimensional configuration suitable for some transport code will be presented as well.

C. Three-dimensional configuration.

C1. Geometry of experiment. In Fig.1 the sizes and materials of main constructional elements of experimental facility are shown. The iron shadow bar was used for background measurements, thus experimental room scattering was taken into account.

C2. Shells. The drawing of Be, Fe, Pb and PbLi shells configurations are shown in Fig.2-5 and listed in the Table 1. R - outer radius of the shell, r - inner radius, d - diameter of the duct, used for input neutron generator beam tube. The PbLi assembly additionally is covered by 1mm thick stainless steel and has a special steel ring, that was used to lift the shell. In the case of Be, Fe, and Pb shells, the leakage spectra were measured at 3 angles. Since the deference between them is negligible the leakage spectra measured at these angles were averaged - the mean angles are listed in Table 1 as well.

Table 1. 3-dimensional model of the experiment.

Shell	R,cm	r,cm	d,cm	Chem.comp.	Nucl.dens*)	Det.Angles	Targ.Conf.
Be	11.0	6.0	6.2	Be(99.4%)	1.2360E+23	<8,30,60>=33	A
Fe	12.0	4.5	6.2	Fe(99%)	0.8374E+23	<8,40,75>=41	A
				Mn(0.45%)			
				Cr(0.3%)			
				C(0.15%)			
PbLi	20.0	6.0	5.0	Pb(83%)	0.2760E+23	40	B
				Li(17%)	0.0565E+23		
Pb	12.0	4.5	6.0	Pb(100%)	0.3300E+23	<8,30,60>=33	A

* - Number of nuclei per cubic centimeter.

C3. Neutron Source. Two target chamber configurations were used in measurements:

Configuration A (Fig.6a) was used with Be, Fe and Pb shells. Air cooled TiT target on 28mm in diameter by 0.7mm thick copper backing was placed in the target chamber, that is shown in the upper part of Fig.6. The kinematic of T(d,n) reaction, scattering of neutrons on Cu backing and target chamber materials result in complicated angular-energy distributions of source neutrons. These distributions were obtained by combination both experimental and calculated information. The yield, mean energy and it uncertainty for neutron source versus the emission angle, as well as a low energy energy spectrum of target scattered neutrons are shown in the Figs.7-10 and are stored in two files:

4AYEU3.DAT - dependence of Yield, average Energy and energy Uncertainty (FWHM/2) of source neutrons versus emission angle.

File structure:

1 and 2 lines - comments on file content and structure;
1st column - angle TET, degrees;
2nd column - number of neutrons per steradian per one T(d,n) neutron Y, 1/sr;
3rd column - mean neutron energy E, MeV;
4th column - energy spread FWHM/2 of T(d,n) neutrons at given angle, MeV.

4ASCT.DAT - angular isotropic low energy spectrum of neutrons SCaTtered by target chamber materials.

File structure:

1 and 2 lines - comments on file content and structure;
1st column - mid-point neutron energy E, MeV;
2nd column - number of neutrons per energy per one T(d,n) neutron S(E), 1/MeV.

Configuration B (Fig.6b) was used with PbLi shell. In this configuration air cooled TiT target on 11mm in diameter by 0.7mm thick copper backing was installed in the target chamber shown in the bottom part of Fig.6. The parameters of source neutrons are given in two files:

4BYEU3.DAT - dependence of Yield, average Energy and energy Uncertainty (FWHM/2) of source neutrons versus emission angle.

File structure: the same as 4AYEU3.DAT

4BSCT.DAT - angular isotropic low energy spectrum of neutrons SCaTtered by target chamber materials.

File structure: the same as 4ASCT.DAT

Normalization: Integral of neutron angular yield over 4*(pai) is equal 0.952 (Conf.A) and 0.977 (Conf.B). It means that 4.8% (Conf.A) and 2.3% (Conf.B) of T(d,n) neutrons are removed from 14MeV group to low energies due to inelastic scattering on target chamber materials. On other hand the integral under the spectrum of these neutrons is equal 0.031 (File 4ASCT.DAT) and 0.026 (4BSCT.DAT).

C4. Spectrometor Response Function. Time of flight spectrometer has energy finite resolution, on other hand the neutrons leaking from outer surface of the shell are scattered by collimator walls - all these factors influence on response function of the spectrometor. This function is shown in Fig.10 and included in two files, respectively for target chamber configurations A (Shells Be, Fe, Pb) and B (PbLi):

4ARES.DAT - spectrometor RESponse function at energy close to 14MeV for Be, Fe and Pb assembles.

File structure:

1 and 2 lines - comments on file content and structure

1st column - mid-point neutron energy E, MeV

2nd column - number of neutrons per energy R(E), 1/MeV

4BRES.DAT - spectrometor RESponse function at energy close to 14MeV for PbLi assembly.

File structure: the same as file 4ARES.DAT

Normalization: Integral under neutron spectra is equal 0.952 (Conf.A) and 0.977 (Conf.B), that correspond the number of "14MeV" neutrons escaping from target chamber. When these shapes will be used for folding the leakage spectrum with detector response function, they should be renormalized to 1.

At low neutron energies (less than 10MeV) the spectrometer response function could be approximated by Gauss distribution with FWHM parameter equal dE - overall spectrometer energy resolution dE:

FWHM = dE [MeV] = 2*E*SQRT((dt/t)**2+(dL/L)**2),

where t [ns] = 72.3*L/SQRT(E) - time of flight of neutron

dt [ns] = 3.5*SQRT(14/E) - time resolution of scintillater

L [m] = 3.8 - flight path

dL [m] = 2R - uncertainty of flight path = two shell radius

E [MeV] - neutron energy

C5. Data on neutron leakage spectra. Measured leakage spectra for Be, Fe, Pb and PbLi shells are included in the files (these leakage spectra, measured at one or averaged over a few angles, was multiplied by 4pai and normalized to one T(d,n) neutron):

4BE3D.DAT - neutron leakage spectra for Be shell
4FE3D.DAT - neutron leakage spectra for Fe shell
4PB3D.DAT - neutron leakage spectra for Pb shell
4PBLI3D.DAT - neutron leakage spectra for PbLi shell

Files structure:

First 2 lines - comments on file content and structure
1st column - leaking neutron energy E, MeV
2nd column - number of neutrons per energy per one T(d,n) neutron L(E), 1/MeV
3rd column - statistical relative uncertainty dL/L
4th column - total relative uncertainty dL/L.

D. One-dimensional configuration.

D1. Geometry. The principle differences of this configuration from 3-dimensional one are following:

i) Yield, energy and energy spread of source neutrons as well as leaking neutron flux are assumed to be angular independent;

ii) Shell duct is filled with the same material, thus assembly becomes spherical symmetric.

D2. Shells. Parameters of spherical symmetric assembly configurations are listed in Table 2.

Table 2. 1-dimensional model of experiment.

Shell	R, cm	r, cm	Chem. comp.	Nucl. dens*)	Angles	Target Conf.
Be	11.0	6.0	Be(99.4%)	1.2360E+23	4*(pai)	A
Fe	12.0	4.5	Fe(99%)	0.8374E+23	4*(pai)	A
			Mn(0.45%)			
			Cr(0.3%)			
			C(0.15%)			
PbLi	20.0	6.0	Pb(83%)	0.2760E+23	4*(pai)	B
			Li(17%)	0.0565E+23		
Pb	12.0	4.5	Pb	0.3300E+23	4*(pai)	A

* - Number of nuclei per cubic centimeter.

D3. Neutron Source. The neutron yield and average neutron energy are angular isotropic. The energy spread is approximated by the difference between forward and backward energies (calculated in 3-dim. model). Data are presented in Figs.7-10 and in next files for two target chamber configuration A (used in measurements with Be, Fe, Pb shells) and B (used with PbLi shell):

4AYEU1.DAT - dependence of Yield, average Energy and energy Uncertainty (FWHM/2) of source neutrons versus emission angle for target chamber type A.

File structure:

1,2lines - comments on file structure
1st column - angle TET, degrees
2nd column - number of neutrons per steradian Y, 1/sr,
3rd column - average neutron energy E, MeV
4th column - energy spread FWHM/2, MeV

4BYEU1.DAT - dependence of Yield, average Energy and energy Uncertainty (FWHM/2) of source neutrons versus emission angle for target chamber type B.

File structure: the same as file 4AYEU1.DAT

The angular isotropic low energy spectrum of neutrons scattered by target chamber materials are the same as for 3-dim.model (see item C2.) and presented in files 4ASCT.DAT (Conf.A) and 4BSCT.DAT (Conf.B).

D4. Spectrometor Response Function. The same files (4ARES.DAT and 4BRES.DAT) as for 3-dimensional model have to be used for 14MeV neutrons, at low energies - Gauss distribution with parameters presented above (see item C4.).

D5. Data on neutron leakage spectra. To obtain data for 1-dimensional model, corrections for the next nonspferical effects were made: (i) duct for beam tube, (ii) angular anistropy of leaking neutron flux and (iii) TOF flight spectroscopy with bulk samples. Corrected leakage spectra, that could be compared with outputs of one dimensional transport codes, are stored in files:

4BE1D.DAT - neutron leakage spectra for Be shell
4FE1D.DAT - neutron leakage spectra for Fe shell
4PB1D.DAT - neutron leakage spectra for Pb shell
4PBLI1D.DAT - neutron leakage spectra for PbLi shell

Files structure:

First 2 lines - comments on file content and structure
1st column - mid-point leaking neutron energy E, MeV
2nd column - number of neutrons per energy per one T(d,n) neutron L(E), 1/MeV
3rd column - statistical relative uncertainty dL/L
4th column - total relative uncertainty dL/L.

E. References.

The other details of the experiment, measuring procedures and data analyses could be find in the next publications (in the case of usage of present numerical data, please, refer to the publications 1 or 2, that cover the others ones):

1. S.P.Simakov, A.A.Androsenko e.a. "Neutron leakage spectra from Be, Al, Fe, Ni, Pb, Pb17Li, Bi, U and Th spheres with T(d,n) and 252-Cf neutron sources" Fusion Technology 1992, (C.Ferro, M.Gasparotto and H.Knoepfel, eds.), Elsevier, 1993, v.2, p.1489
2. S.P.Simakov, A.A.Androsenko e.a. "14MeV Facility and Research in IPPE". Report INDC(CCP)-351, IAEA, 1993; Voprocy atomnoy nauki i techniki. Seriya Yadernye konstanty, 1992, v.3-4, p.93
3. B.V.Devkin, B.G.Demenkov e.a. "Neutron leakage spectra from Al, Ni,Ti shells with 14MeV neutron source". Voprocy atomnoy nauki i techniki. Seriya Yadernye konstanty, 1992, v.1, p.48 (in russian);
4. B.V.Devkin, B.V.Zhuravlev e.a. "Measerement of neutron leakage spectra from iron shell with 14MeV neutron central source". Voprocy atomnoy nauki i techniki. Seriya Yadernye konstanty, 1990, v.2, p.5 (in russian);
5. A.A.Androsenko, P.A.Androsenko e.a. "Measurements and comparison with calculations of neutron leakage spectra from U, Pb, Be spheres with central 14MeV neutron source" Kernenergie, 1988, v.10, p.422
6. A.A.Androsenko, P.A.Androsenko e.a. "Neutron leakage spectra from U, Pb, Be spheres at 14MeV neutron energy". Proc of Int. Conf. on neutron Physics (Kiev, Sept.,1987). Neutron Physics, Moscow, 1988, v.3, p.194 (in russian)
7. S.P.Simakov. "Compilation of measurements of neutron leakage spectra from spherical assemblies with T(d,n) and 252-Cf central sources". Report INDC/P(93)-49, IAEA, 1993; Voprocy atomnoy nauki i techniki. Seriya Yadernye konstanty, 1993, v.1, p.43 (in russian);

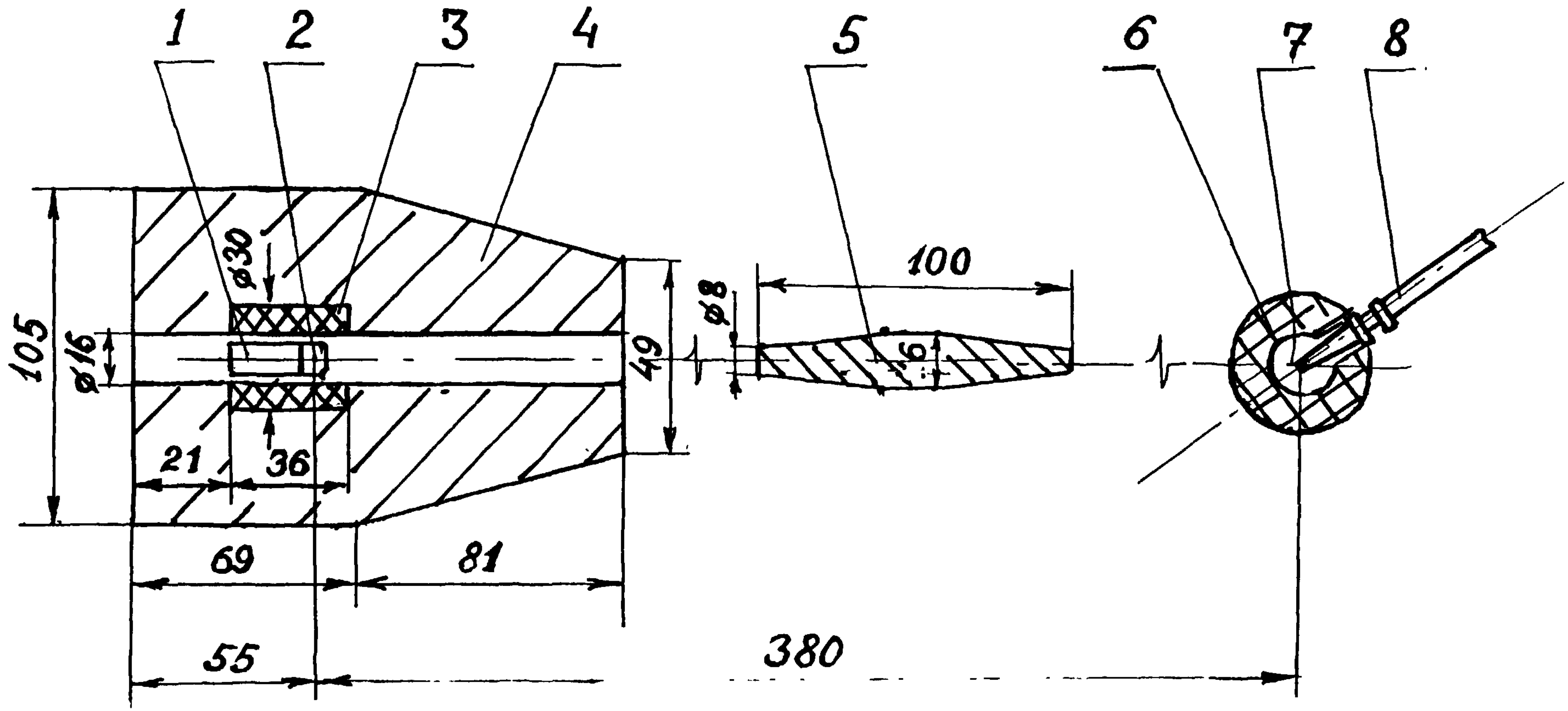

Fig. 1. Experiment set-up (sizes are given in centimeters):
1 - photomultiplier, 2 - crystal scintillator, 3 - lead shielding, 4 - paraffin shielding, 5 - shadow bar, 6 - sphere, 7 - target assembly, 8 - beam tube.

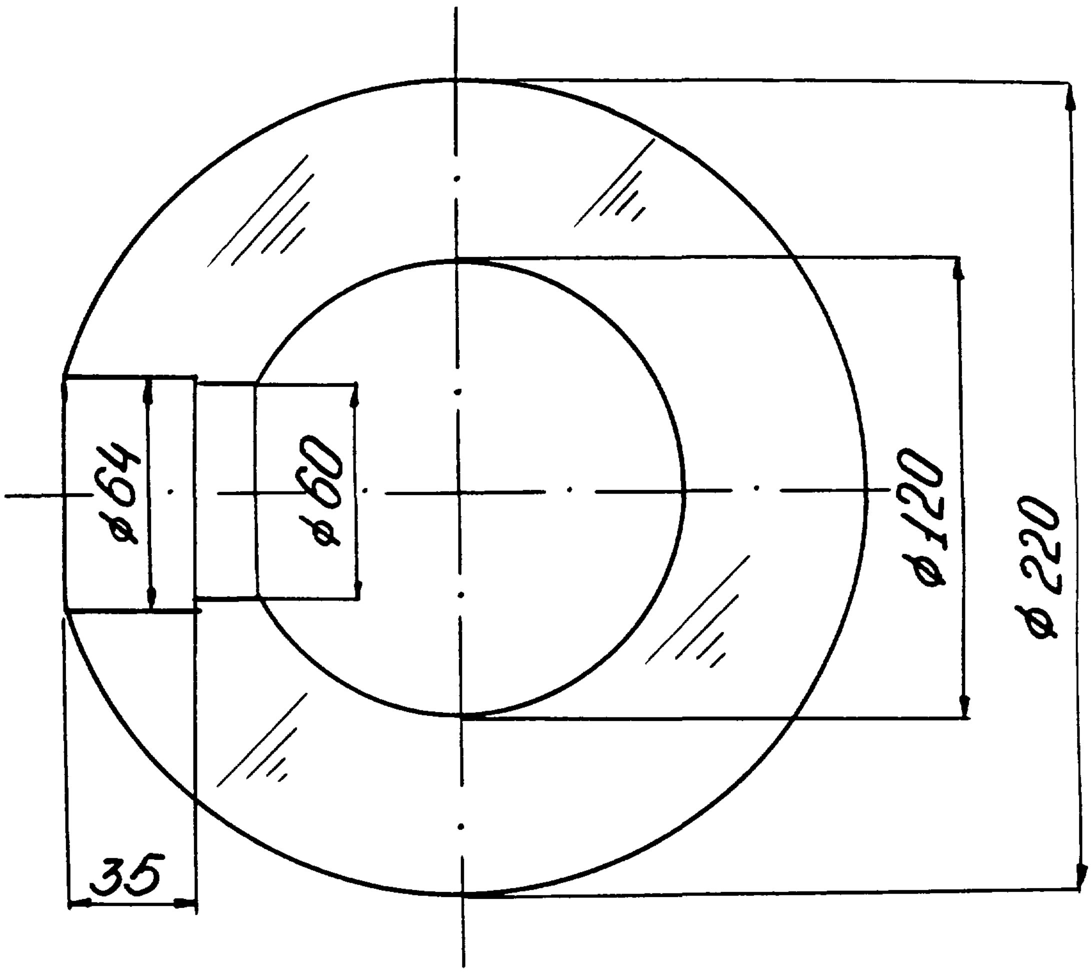

Fig. 2. Geometry of Be assembly (sizes are given in millimeters).

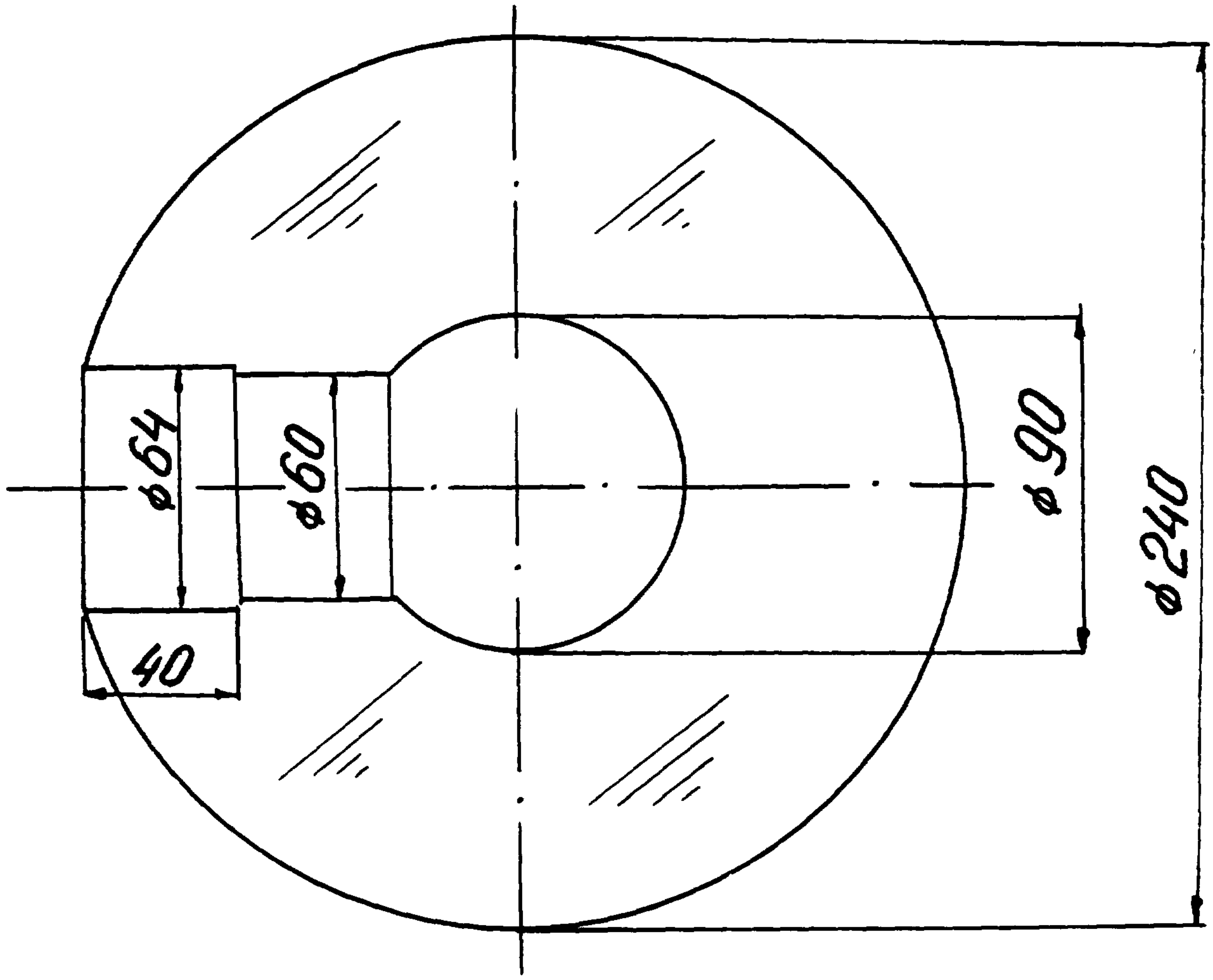

Fig.3. Geometry of Fe assembly (sizes are given in millimeters).

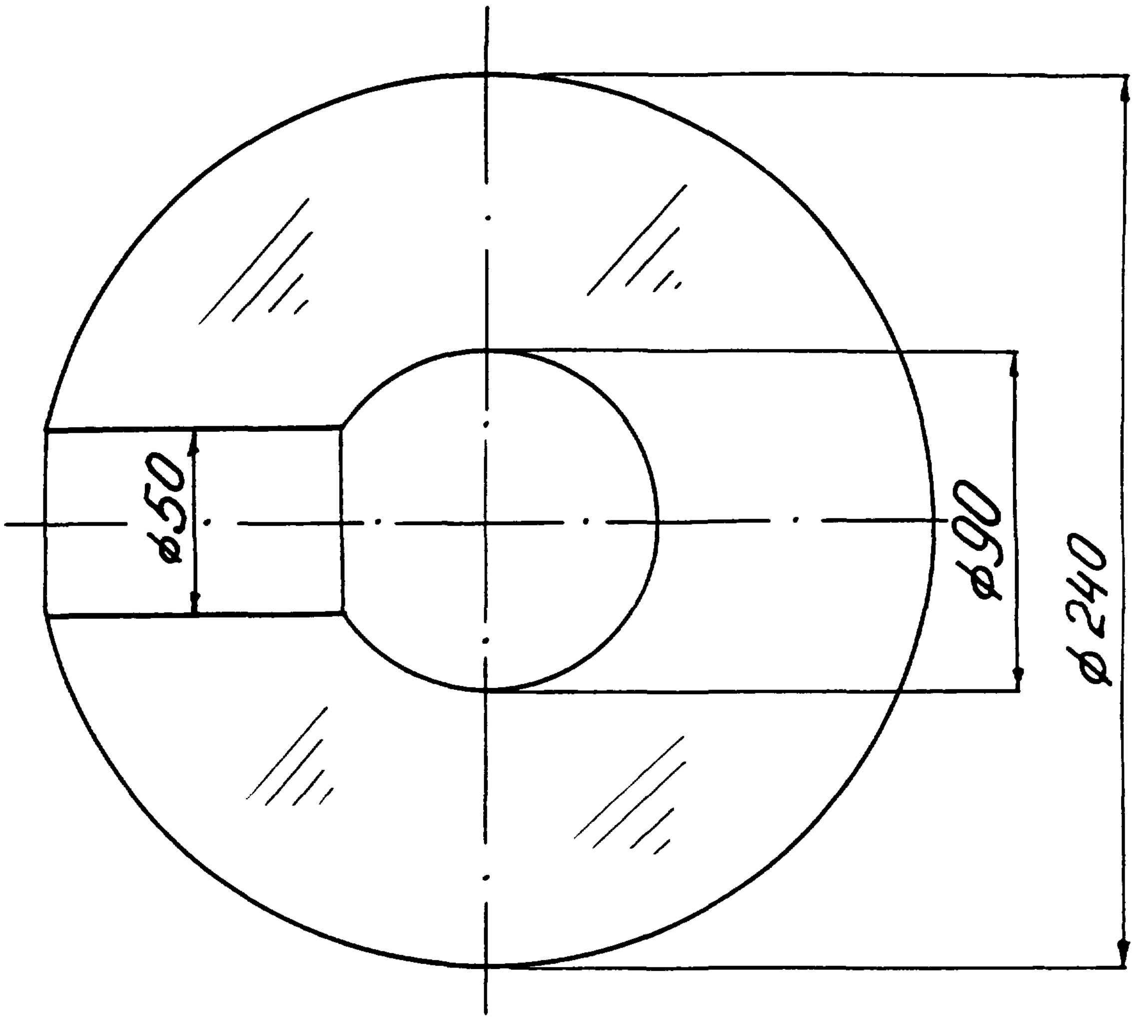

Fig. 4. Geometry of Pb assembly (sizes are given in millimeters).

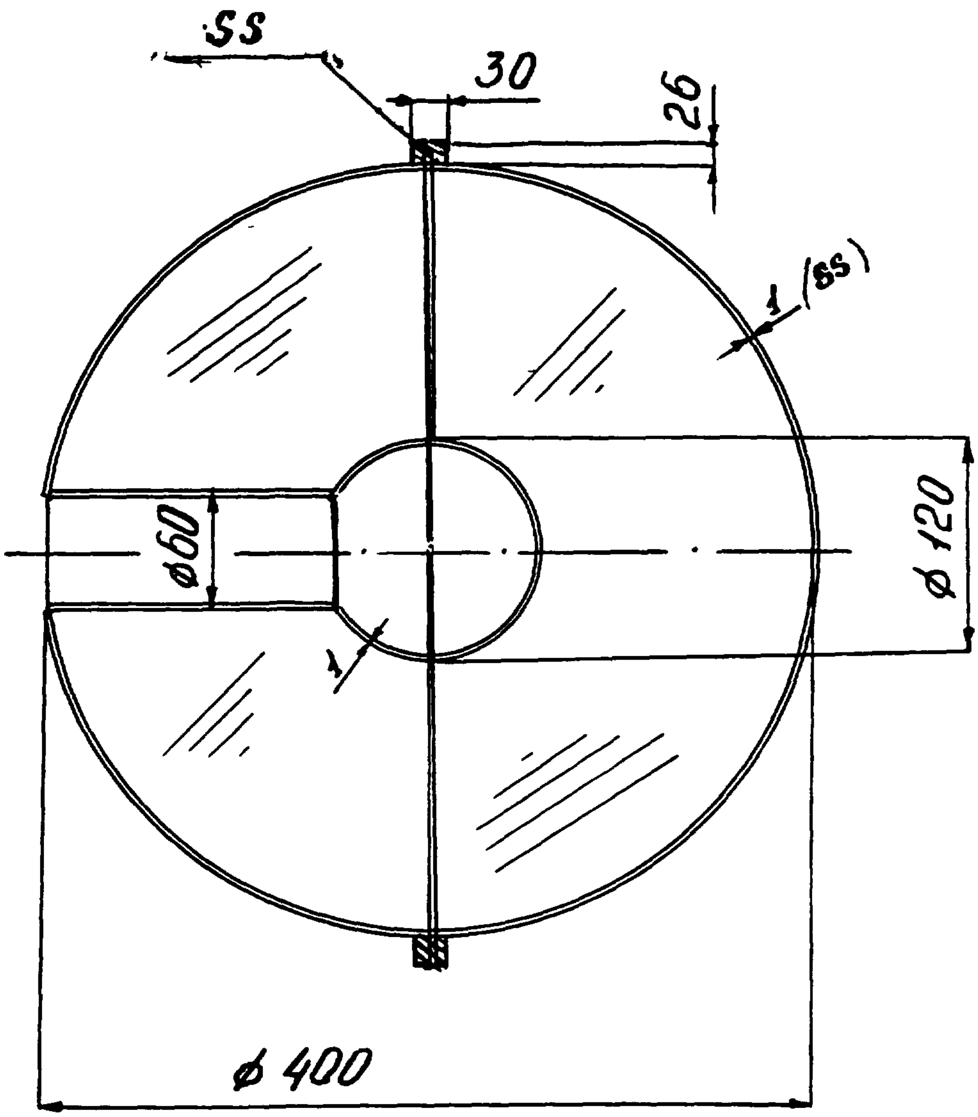

Fig.5. Geometry of PbLi assembly (sizes are given in millimeters). Shell was covered outside and inside by 1mm thick stainless steel and had a steel ring to mount it.

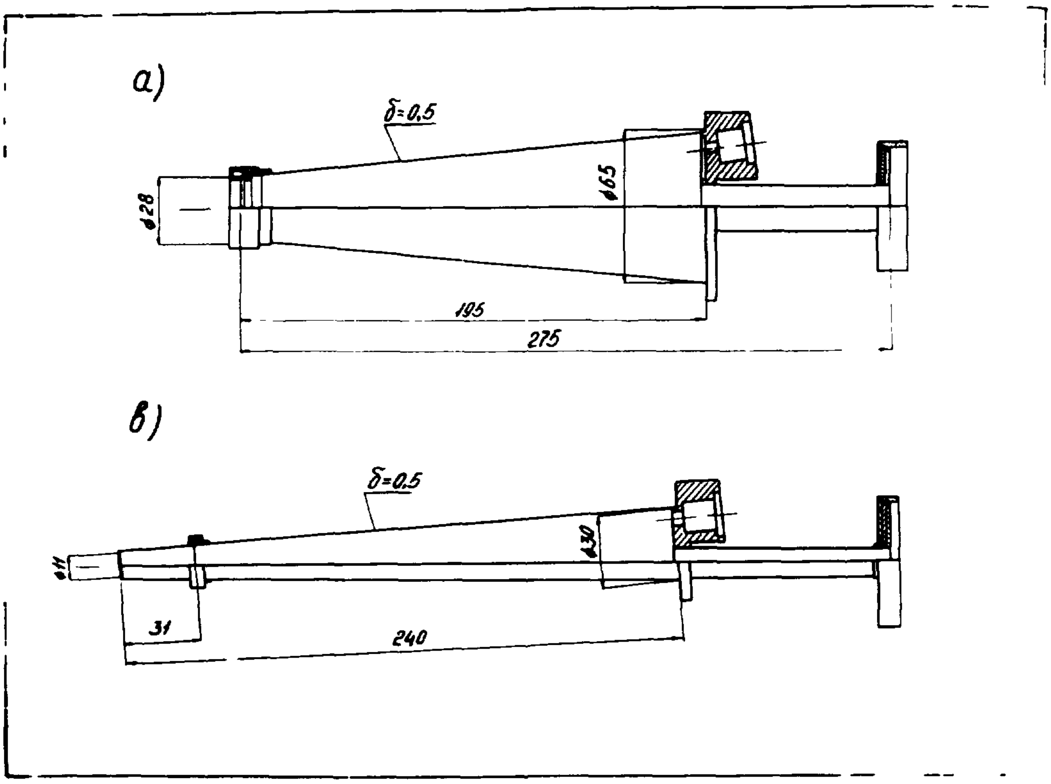

Fig.6. Geometry of target chamber (sizes are given in millimeters):

A - 28mm diameter TiT target, used in measurements with Be, Fe, and Pb shells;

B - 11mm diameter TiT target, used with PbLi shell.

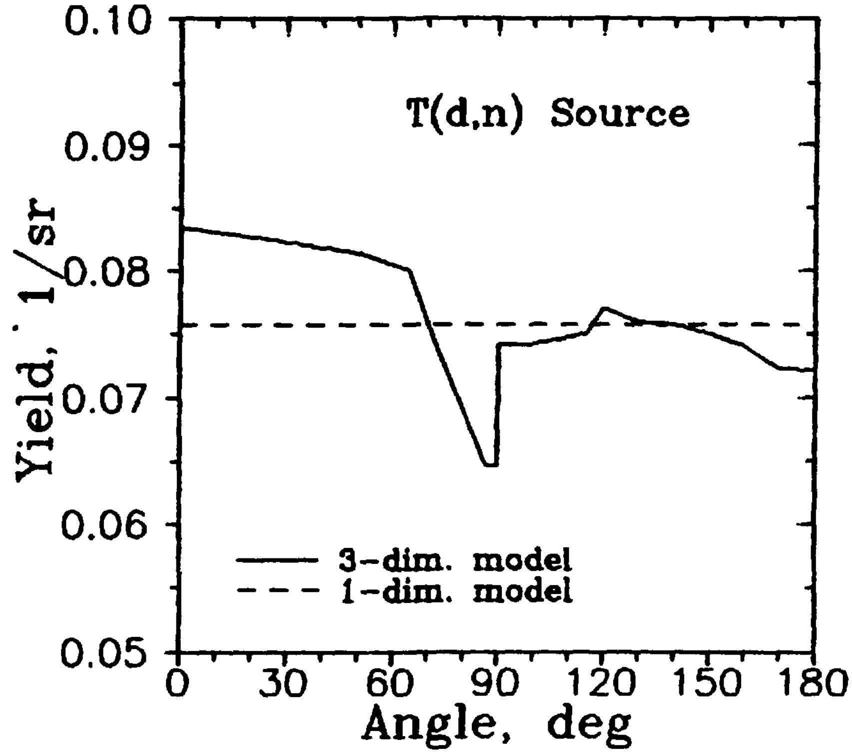

Fig.7. Yield of T(d,n) neutrons versus emission angle.

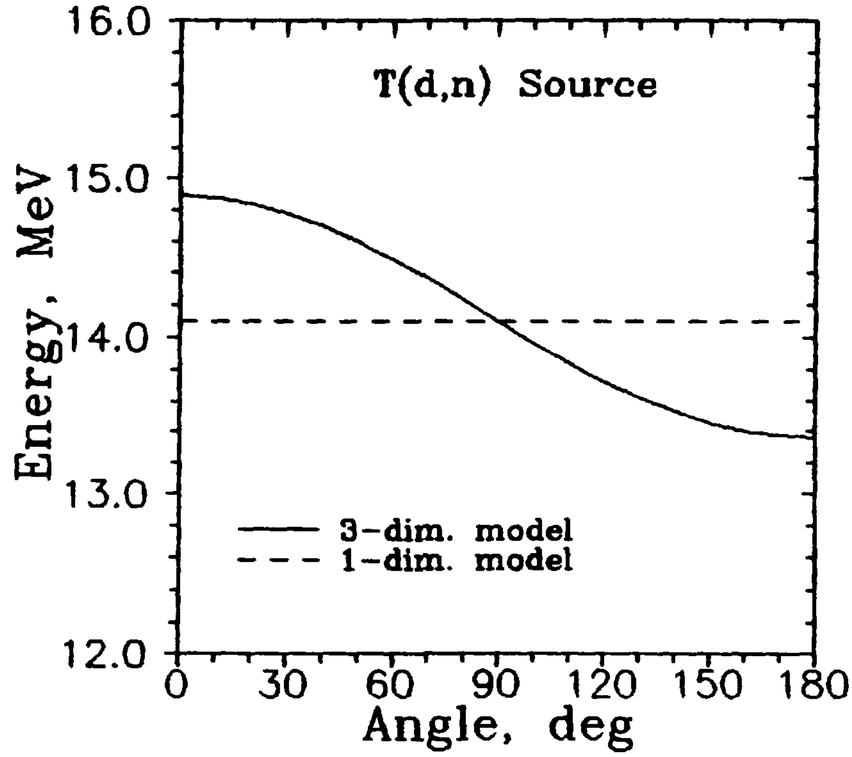

Fig.8. Mean energy of T(d,n) neutrons versus emission angle.

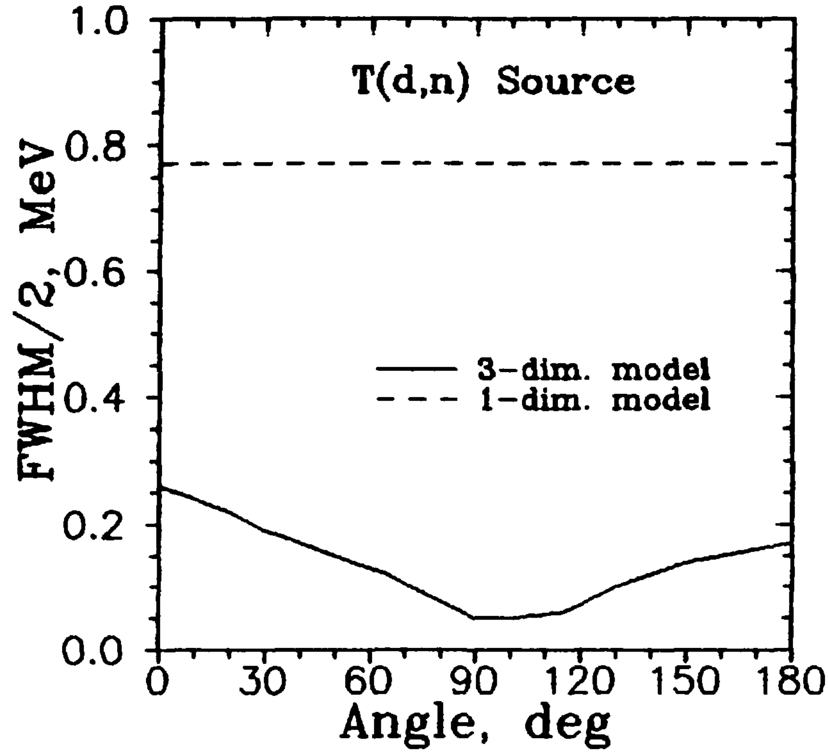

Fig. 9. Energy spread of T(d,n) neutrons versus emission angle.

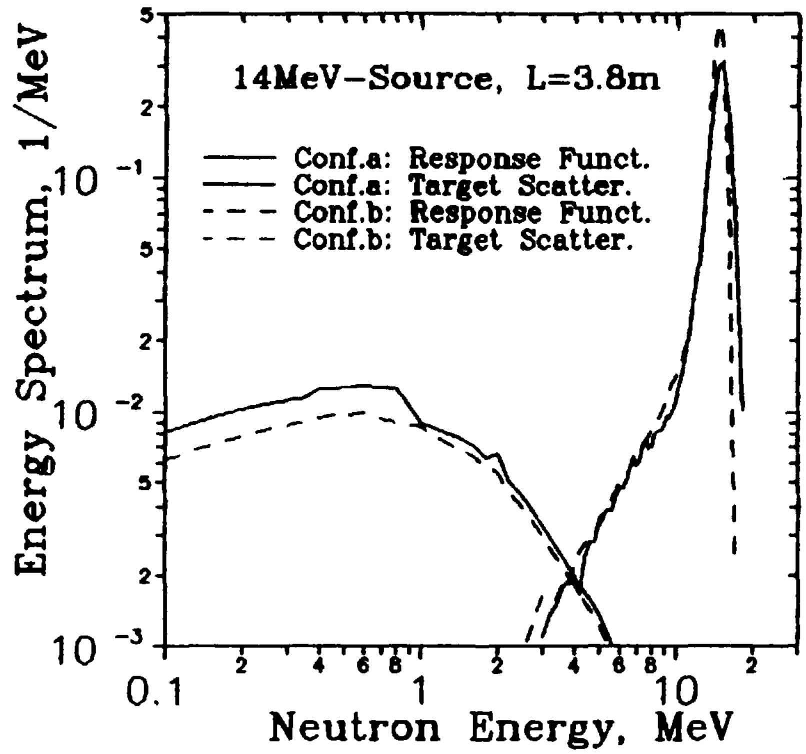

Fig. 10. Energy spectrum of neutrons scattered by target chamber and spectrometer response function for target configurations shown in Fig. 6 A and B.