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Distr. L**INDC****INTERNATIONAL NUCLEAR DATA COMMITTEE****BENCHMARKS ON NEUTRON LEAKAGE FROM IRON AND  
BERYLLIUM SLABS AND SPHERES**

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Sofia, Bulgaria

July 1997

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**IAEA NUCLEAR DATA SECTION, WAGRAMERSTRASSE 5, A-1400 VIENNA**

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July 1997

## **BENCHMARKS ON NEUTRON LEAKAGE FROM IRON AND BERYLLIUM SLABS AND SPHERES**

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### **Abstract**

Five benchmarks, recommended by the IAEA for nuclear power engineering have been calculated for an assessment of the iron and beryllium neutron data from the recent FENDL-1 version. The FENDL/MG-1.0 multigroup data processed in the IAEA by NJOY code are in VITAMIN-J energy structure in MATXS format. These data have been converted to ANISN format by TRANXS code, ported by us to PC version and collected to binary library by LIBFENDL code, that we have created especially for this purpose. Neutron transport calculations have been carried out by the codes ANISN, GRTUNCL and DORT.

Two benchmarks important for fusion application correspond to the 14 MeV neutron transmission through iron sphere shell (Simakov S.P. et al, IPPE, Obninsk) and iron slabs (Y. Oyama and H. Maekawa, FNS/JAERI). The benchmark on neutron leakage from 25 cm radius iron sphere with  $^{252}\text{Cf}$  source is intended to test the FENDL-1 iron data for LWR application. The comparison of the measured and calculation results show a disappointing lack of consistency when material thickness exceeds 20 cm.

Modeling of the angular neutron leakage from 14 MeV source transmitted through beryllium slabs (H. Maekawa and Y. Oyama at FNS/JAERI) and scalar neutron leakage spectra through sphere shell (Simakov S.P. et al in IPPE, Obninsk) is important to study out the multiplication properties of beryllium as a fusion blanket material. The measured and calculated results are in relatively good consistency.

## ***1. Introduction***

The IAEA Nuclear Data Section has implemented a computerised collection of data from those integral neutronic experiments („benchmark experiments“) that are suitable to test libraries of evaluated fusion relevant nuclear data. In particular, the Fusion Evaluated Nuclear Data Library (FENDL), for the International Thermonuclear Experimental Reactor (ITER) project, should be validated using these experimental data.

The scope of the work is to test the multigroup FENDL/MG-1.0 data by benchmark experiments. These data are available by FTP command on-line from the IAEA via INTERNET. The FENDL/MG-1.0 data are in fine-group pseudo-problem-independent format and that is why could be applied for fusion as well as for fission calculation.

Five benchmarks of neutron transport from 14 MeV or fission ( $^{252}\text{Cf}$ ) source, of interest for nuclear power engineering for estimation of Iron and Beryllium neutron data of the recent FENDL/MG-1.0 version, have been used for neutron data testing in the neutron transport calculations. The benchmark of Beryllium is significant for an assessment of its multiplication properties as a fusion blanket material. The testing of Iron data is very important not only for fusion but for fission application too as a construction and shield material.

## ***2. Generating of Multigroup Neutron Constants from FENDL in ANISN format by pre-processing TRANSX code.***

The ENDF/B-VI data have been processed in IAEA by the NJOY code [1] into fine-group pseudo-problem-independent format. The FENDL/MG-1.0 multigroup data [2] are in VITAMIN-J energy structure (175 neutron and 42 gamma groups), P<sub>5</sub> approximation and MATXS format (every nuclide separately). The multigroup FENDL data (FENDL/MG) are available by FTP command on-line from IAEA. All nuclides needed for the benchmarks calculations have been transmitted via INTERNET. We have converted these data to ANISN format by TRANSX code [3]. The TRANSX code has been ported by us to PC version. Binary library including all transmitted nuclides has been generated by LIBFENDL code, created especially for this purpose. This library [4] is described in Table 2.1 and contains data in format appropriate for the GIP code [5].

Table 2.1 Binary library description

ID	ELEMENT	ID	ELEMENT	ID	ELEMENT
1	h1	49	cr52	97	ni58
7	cnat	55	cr53	103	ni60
13	o16	61	cr54	109	ni61
19	al27	67	mn55	115	ni62
25	sinat	73	fe54	121	ni64
31	snat	79	fe56	127	p31
37	tinat	85	fe57	133	be9
43	cr50	91	fe58		

### ***3. Calculation of 14 MeV-Neutron Transmission Through Iron Sphere***

The testing of Iron data is very important because the steel is base constructive material for fusion and fission reactors. The Iron data from ENDF/B-IV and ENDF/B-V provide underestimated neutron flux values in energy range above 1 MeV. That is why after several improvements over the mentioned libraries of estimated data the ENDF/B-VI version has been created.

The first calculated benchmark important for fusion application corresponds to the 14 MeV neutron transmission through 7.5cm thickness Iron sphere shell (Simakov S.P. at al, IPPE, Obninsk [8]). To take into account the detector spectrum response the neutron scalar flux spectrum calculation results have been additionally processed by created especially for this purpose code DETRES. The unfolded calculation results and folded with the response function vs experimental ones and C/E ratio are plotted in Fig. 1, 2. The discrepancy of calculated and measured results in broad groups presented in Table 1 does not exceed 34% [4]. This discrepancy is observed for the energy range 4.81-10.2 MeV and is related with the relatively high C/E ratio values for the energies close to 14 MeV peak (Fig. 2).

#### ***4. Calculation of 14 MeV-Neutron Transmission Through Iron Slabs.***

The next benchmark corresponds to the 14 MeV neutron transmission through the Iron slabs with 5.0, 20.0, 40.0, and 60 cm thickness (Y. Oyama and H. Maekawa, FNS/JAERI [9]). Neutron angular flux spectra transmitted through the slabs have been calculated by two-dimensional codes GRTUNCL and DORT. Binary DORT code scalar flux and GRTUNCL code first collision source output files have been processed by created code ANGAVE. The code ANGAVE simulates the averaging properties of detector space response and serves to be obtained the measured values in the experiment.

The calculation results vs experimental ones are plotted in Fig. 3-21. The comparison of integral calculated and experimental flux results in corresponding energy ranges is presented in Tables 2-5.

In the benchmark description [9] available via INTERNET the experimental results presented for the 60 cm slab are the same as for the 40 cm slab that is why no comparison with calculations has been performed.

The discouraged bad consistency of calculated and measured results have been obtained for the leakage of 14 MeV neutrons from slabs with thickens greater than 20cm.

It is obvious that the last FENDL/MG-1.0 (MATXS) version for Iron data processed by TRANXS code is not enough reliable for neutron transmission calculations.

#### ***5. Recalculation of Iron Sphere Benchmark with Cf-source with New FENDL Data. Comparison of the Results from the Calculations by Different Cross Section Libraries.***

The benchmark for neutron leakage from 25 cm radius Iron sphere with  $^{252}\text{Cf}$  source at its center [6] posses to test FENDL/MG-1.0 Iron data for LWRs application in reactor pressure vessel (RPV) calculations for light water reactors (VVER/PWR). We have recalculated this benchmark but no differences have been observed against the results obtained with previous FENDL/MG-1.0 library version [7]. The calculation results for leakage spectra in energy range above 1 MeV, as in the case of the Iron slabs with thickness greater than 20 cm, are in very bad consistency with experimental ones. This consistency is worse than for other cross section libraries (even based on ENDF/B-IV data), Fig. 22 [4].

## ***6. Calculation of 14 MeV-Neutron Transmission Through Berillium Sphere.***

Benchmark calculation of the 14 MeV neutron transmission through Beryllium 6 cm thickness sphere shell, measured by Simakov S.P. et al in IPPE, Obninsk [8] has been carried out. Neutron transport calculations for the neutron scalar flux leakage spectrum from the sphere have been carried out by one-dimensional code ANISN [10]. As in the case of Iron sphere, the neutron transport calculations results obtained by the one-dimensional code ANISN have been processed by code DETRES to simulate the detector spectrum response contribution. The calculated results are in relatively good consistency with experimental ones and with other authors calculations performed by Monte-Carlo method [11].

Our calculation results without folding and with folding by the response function vs experimental ones as well as C/E ratio are plotted in Fig. 23, 24. The obtained results for integral neutron flux in broad energy groups applied in [11] are presented in Table 6. The same results but in broad energy groups applied in [12] are presented in Table 7.

The measured and calculated results for 14 MeV neutron leakage scalar flux of Beryllium sphere benchmark are in relative good consistency. Again as in the case of the Iron sphere the higher discrepancies are observed at the vicinity of the 14 MeV peak (Fig. 23)

## ***7. Calculation of 14 MeV-Neutron Transmission Through Beryllium Slabs.***

The next benchmark corresponds to the 14 MeV neutron transmission through Beryllium slabs with 5.08, 15.24 cm thickness (Y. Oyama and H. Maekawa, FNS/JAERI) [14]. Neutron angular flux spectra transmitted through the slabs have been recalculated [12] by the two-dimensional codes GRTUNCL and DORT [5] and by the neutron cross section data files: JENDL-2 [13] and FENDL [2]. Binary DORT code scalar flux and GRTUNCL code first collision source output files have been processed by created code ANGAVE to obtain the values measured by experiment. The code ANGAVE simulates the detector space response function averaging properties.

The calculation results vs experimental ones are plotted in Fig. 25-33. The comparison of integral calculated and experimental flux results for JENDL and FENDL in corresponding energy ranges is presented in Tables 8, 9. The ratio values C/E of calculated to measured fluxes show that the FENDL results are in better consistency than the JENDL

ones with experimental data Fig. 34, 35. Only for energy range above 10 MeV the scattered neutrons of FENDL results are in large inconsistency with experimental results.

### ***8. Conclusion***

Benchmark calculations for the Iron as an constructive/shield material and the Beryllium as an multiplying material have been performed. The calculation has been carried out with the multigroup neutron cross section library data FENDL/MG-1.0 processed by TRANSX code and especially prepared code LIBFENDL for working binary library generation in ANISN format. The discrete ordinate codes ANISN, GRTUNCL and DORT have been used for transport calculations.

Transport codes results have been processed by especially created codes to simulate detectors responses.

The obtained results supply additional information to the results summarised in [15] for FENDL/MG-1.0 library qualification. Our results reaffirm the conclusions presented in [15] that some improvements for Beryllium FENDL/MG-1.0 data are needed. Regarding the Iron FENDL/MG-1.0 data as it follows from the results obtained for deep penetration tasks it is obvious that very serious modifications are needed. It is in contradiction to the FENDL/MC-1.0 results [15].

### ***Acknowledgement.***

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## **10. Tables**

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Table 1. Iron sphere, T=7.5 cm

Energy range, MeV	Experiment	Calculation	Cal/Exp
0.19-0.5	0.1255	0.1540	1.228
0.5-1.96	0.3218	0.3673	1.141
1.96-4.81	0.1003	0.1170	1.166
4.81-10.2	4.285E-02	5.743E-02	1.340
10.2-19.47	0.3641	0.3210	0.882

Table 2. Iron slab, D=5 cm

## Calculational results

Angle	E>10.183	4.8102-10.183	1.9557-4.8102	0.507-1.9557	0.0974-0.507
0.00	3.711E-04	4.157E-06	8.631E-06	1.544E-05	4.234E-06
24.9	5.171E-06	1.201E-06	2.901E-06	6.182E-06	2.403E-06
41.8	3.887E-06	1.202E-06	2.988E-06	6.593E-06	2.528E-06
66.8	3.141E-06	1.142E-06	2.955E-06	7.121E-06	2.634E-06

## Experimental results

Angle	E>10.183	4.8102-10.183	1.9557-4.8102	0.507-1.9557	0.0974-0.507
0.00	4.628E-04	5.800E-06	1.190E-05	2.080E-05	5.000E-06
24.9	9.174E-06	1.096E-06	4.490E-06	7.900E-06	1.830E-06
41.8	5.176E-06	1.015E-06	4.639E-06	8.770E-06	1.910E-06
66.8	2.197E-06	9.230E-07	4.837E-06	1.0153E-05	2.120E-06

## Calculation/Experiment

Angle	E>10.183	4.8102-10.183	1.9557-4.8102	0.507-1.9557	0.0974-0.507
0.00	8.018E-01	7.167E-01	7.253E-01	7.421E-01	8.468E-01
24.9	5.637E-01	1.096E+00	6.460E-01	7.825E-01	1.313E+00
41.8	7.510E-01	1.185E+00	6.441E-01	7.518E-01	1.324E+00
66.8	1.430E+00	1.237E+00	6.109E-01	7.014E-01	1.243E+00

Table 3. Iron slab D=20 cm

## Calculational results

angle	E>10.183	4.8102-10.183	1.9557-4.8102	0.507-1.9557	0.0974-0.507
0.00	2.232E-05	2.451E-07	7.370E-07	4.855E-06	4.446E-06
12.2	1.017E-06	1.991E-07	6.558E-07	4.505E-06	4.393E-06
24.9	7.046E-07	1.778E-07	5.997E-07	4.262E-06	4.231E-06
41.8	3.953E-07	1.389E-07	4.888E-07	3.711E-06	3.838E-06
66.8	1.708E-07	8.507E-08	3.154E-07	2.582E-06	2.877E-06

Table 3. (continued) Iron slab D=20 cm

## Experimental results

angle	E>10.183	4.8102-10.183	1.9557-4.8102	0.507-1.9557	0.0974-0.507
0.00	5.054E-05	9.700E-07	3.370E-06	1.176E-05	4.040E-06
12.2	1.245E-05	6.100E-07	2.980E-06	1.025E-05	3.730E-06
24.9	2.942E-06	4.910E-07	2.830E-06	1.0057E-05	3.560E-06
41.8	1.280E-06	3.800E-07	2.484E-06	9.406E-06	3.450E-06
66.8	3.480E-07	2.130E-07	1.600E-06	6.634E-06	2.484E-06

## Calculation/Experiment

angle	E>10.183	4.8102-10.183	1.9557-4.8102	0.507-1.9557	0.0974-0.507
0.00	4.416E-01	2.527E-01	2.187E-01	4.128E-01	1.100E+00
12.2	8.169E-02	3.264E-01	2.201E-01	4.395E-01	1.178E+00
24.9	2.395E-01	3.621E-01	2.119E-01	4.238E-01	1.188E+00
41.8	3.088E-01	3.655E-01	1.968E-01	3.945E-01	1.112E+00
66.8	4.908E-01	3.994E-01	1.971E-01	3.892E-01	1.158E+00

Table 4. Iron slab D=40 cm

## Calculational results

angle	E>10.183	4.8102-10.183	1.9557-4.8102	0.507-1.9557	0.0974-0.507
0.00	5.200E-07	5.521E-09	2.207E-08	5.895E-07	1.596E-06
12.2	3.322E-08	5.309E-09	2.174E-08	5.820E-07	1.594E-06
24.9	1.873E-08	4.446E-09	1.870E-08	5.196E-07	1.496E-06
41.8	8.479E-09	3.197E-09	1.395E-08	4.102E-07	1.292E-06
66.8	3.333E-09	1.867E-09	8.403E-09	2.597E-07	9.087E-07

## Experimental results

angle	E>10.183	4.8102-10.183	1.9557-4.8102	0.507-1.9557	0.0974-0.507
0.00	2.494E-06	1.130E-07	5.760E-07	3.872E-06	2.368E-06
12.2	8.704E-07	7.070E-08	4.939E-076	3.539E-06	2.236E-06
24.9	3.089E-07	6.990E-08	4.514E-07	3.4728E-06	2.399E-06
41.8	1.123E-07	4.270E-08	3.844E-07	2.8036E-06	1.988E-06
66.8	1.178E-07	1.165E-07	2.218E-07	1.7589E-06	1.103E-06

## Calculation/Experiment

angle	E>10.183	4.8102-10.183	1.9557-4.8102	0.507-1.9557	0.0974-0.507
0.00	2.085E-01	4.886E-02	3.832E-02	1.523E-01	6.739E-01
12.2	3.817E-02	7.509E-02	4.402E-02	1.645E-01	7.129E-01
24.9	6.064E-02	6.360E-02	4.142E-02	1.496E-01	6.236E-01
41.8	7.551E-02	7.487E-02	3.630E-02	1.463E-01	6.499E-01
66.8	2.829E-02	1.602E-02	3.789E-02	1.476E-01	8.239E-01

Table 5. Iron slab D=60 cm

## Calculational results

angle	E>10.183	4.8102-10.183	1.9557-4.8102	0.507-1.9557	0.0974-0.507
0.00	1.225E-08	1.207E-10	5.511E-10	5.301E-08	3.368E-07
12.2	8.901E-10	1.196E-10	5.494E-10	5.277E-08	3.367E-07
24.9	4.357E-10	9.870E-11	4.619E-10	4.532E-08	3.108E-07
41.8	1.837E-10	7.040E-11	3.370E-10	3.411E-08	2.612E-07
66.8	7.211E-11	4.100E-11	1.996E-10	2.092E-08	1.786E-07

## Experimental results

angle	E>10.183	4.8102-10.183	1.9557-4.8102	0.507-1.9557	0.0974-0.507
0.00	2.494E-06	1.130E-07	5.760E-07	3.872E-06	2.368E-06
12.2	8.704E-07	7.070E-08	4.939E-076	3.539E-06	2.236E-06
24.9	3.089E-07	6.990E-08	4.514E-07	3.4728E-06	2.399E-06
41.8	1.123E-07	4.270E-08	3.844E-07	2.8036E-06	1.988E-06
66.8	1.178E-07	1.165E-07	2.218E-07	1.7589E-06	1.103E-06

Table 6. Beryllium sphere, T=5.0 cm

Energy range, MeV	Experiment	Experiment*	Calculation	Cal/Exp	Cal/Exp*	Cal**/Exp*
0.35-0.7	6.1979E-02	9.6000E-02	7.4084E-02	1.195	0.7719	0.78
0.7-3.0	0.1720	0.2000	0.2145	1.247	1.073	0.81
3.0-10.0	0.1542	0.1900	0.2114	1.371	1.113	1.005
10.0-15.0	0.3403	0.6900	0.5063	1.488	0.7338	0.99
15.0-19.47	0.2042	-	9.5334E-02	0.467	-	-

\*A.Androsenko et al. [13]

\*\*BLANK code, ENDF/B-IV [13]

Table 7. Beryllium sphere, T=5.0 cm

Energy range, MeV	Experiment	Calculation	Cal/Exp
0.39-0.51	3.083E-02	3.483E-02	1.130
0.51-1.96	0.1620	0.1971	1.217
1.96-4.81	8.174E-02	0.1182	1.446
4.81-10.18	0.1183	0.1566	1.324
10.18-18.62	0.5399	0.5950	1.102

Table 8. C/E for Beryllium slab, T=5.08 cm

Energy region MeV	20-10.183		10.183-1.956		1.956-0.507		0.507-0.0974	
Angle deg	JENDL	FENDL	JENDL	FENDL	JENDL	FENDL	JENDL	FENDL
0.0	1.063	1.040	1.018	0.823	1.029	0.845	0.817	1.076
24.9	0.943	0.380	1.035	0.864	1.039	0.921	0.761	1.021
41.8	0.807	0.772	1.184	0.966	1.100	0.956	0.824	1.092
66.8	0.656	1.389	1.383	1.051	1.191	0.987	0.831	1.077

Table 9. C/E for Beryllium slab, T=15.24 cm

Energy region MeV	20-10.183		10.183-1.956		1.956-0.507		0.507-0.0974	
Angle, deg	JENDL	FENDL	JENDL	FENDL	JENDL	FENDL	JENDL	FENDL
0.0	1.037	0.956	0.935	0.724	1.117	0.787	0.941	0.831
12.2	0.771	0.221	0.975	0.752	1.183	0.834	1.076	0.951
24.9	0.944	0.393	1.009	0.773	1.205	0.843	1.073	0.944
41.8	0.699	0.582	1.049	0.788	1.203	0.830	1.094	0.956
66.8	0.739	1.081	1.141	0.823	1.260	0.849	1.107	0.959

## **11. Figures**

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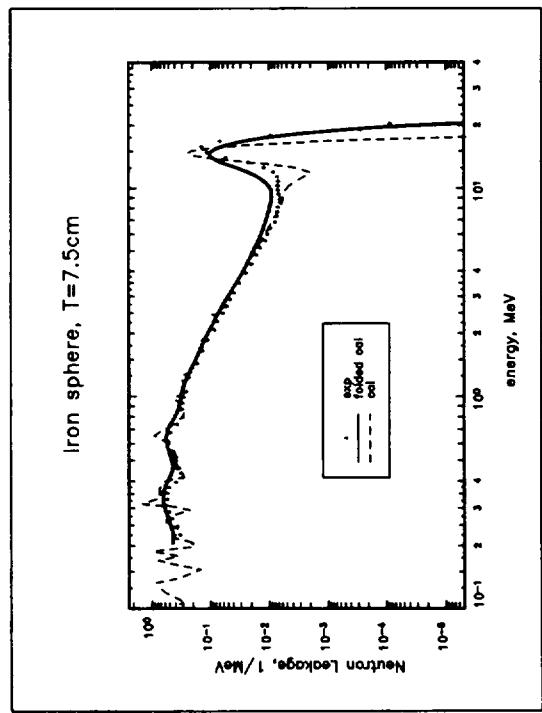


Fig. 1

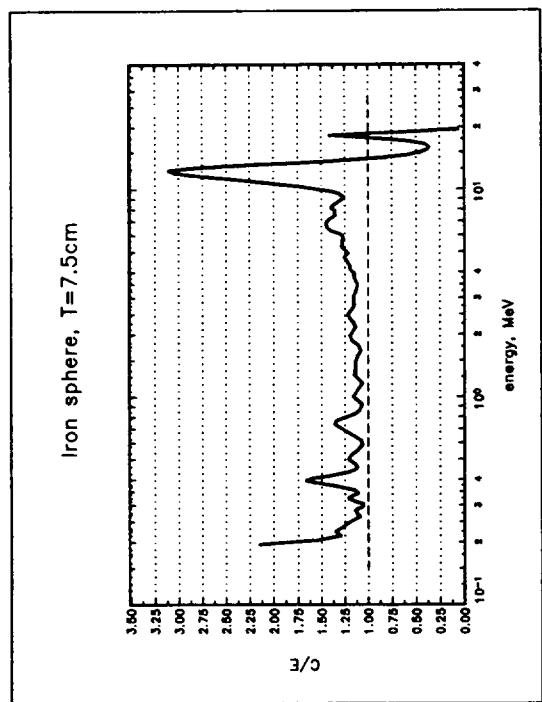


Fig. 2

## FNS slab TOF - experiment

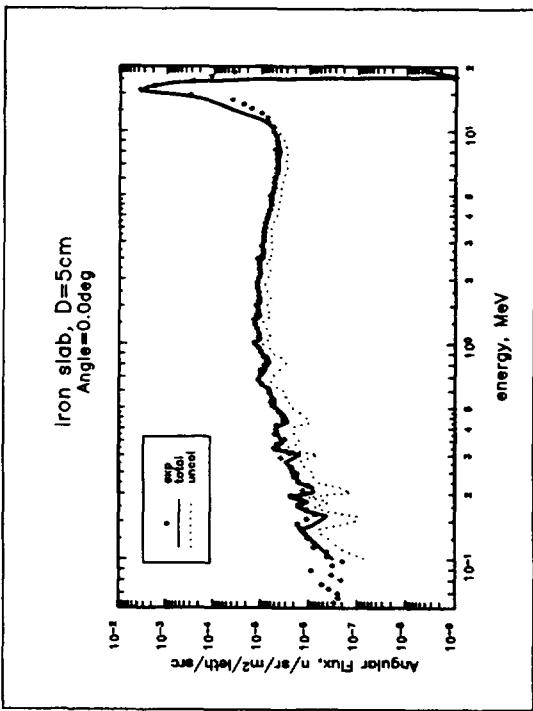


Fig. 3

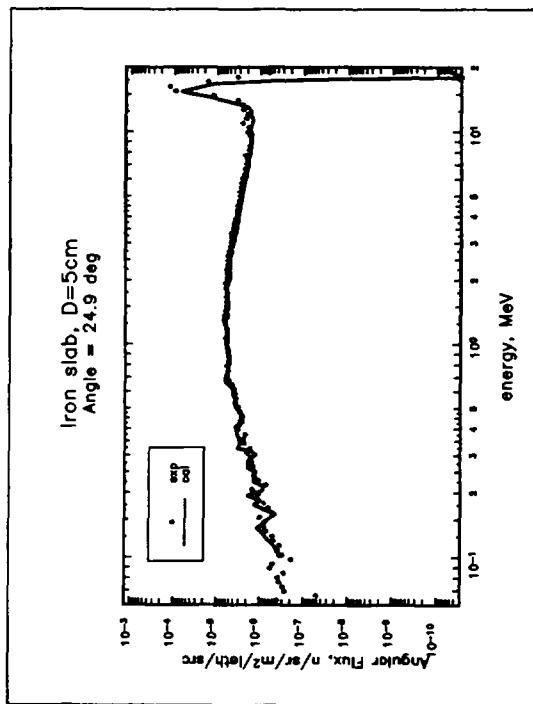


Fig. 4

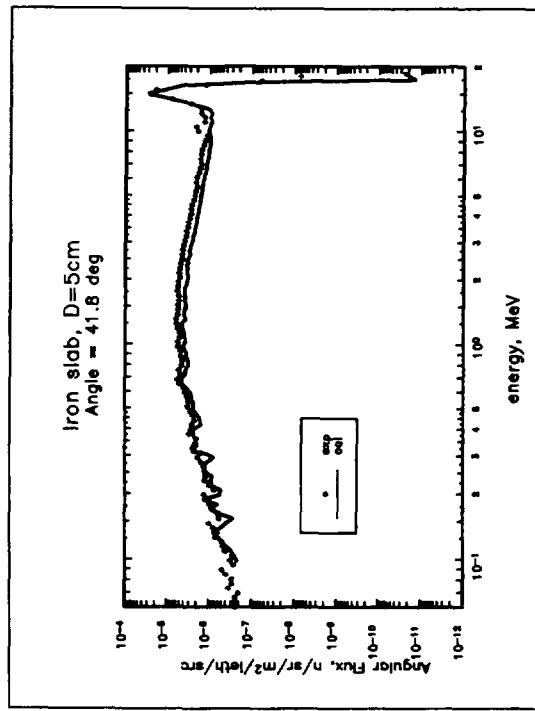


Fig. 5

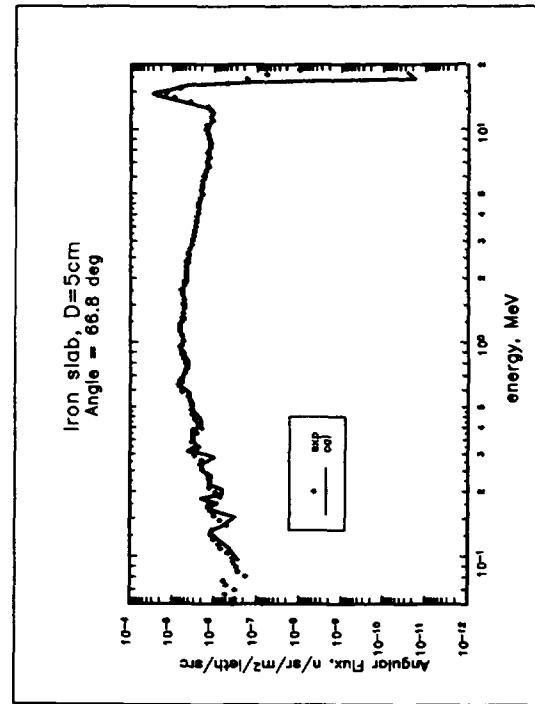


Fig. 6

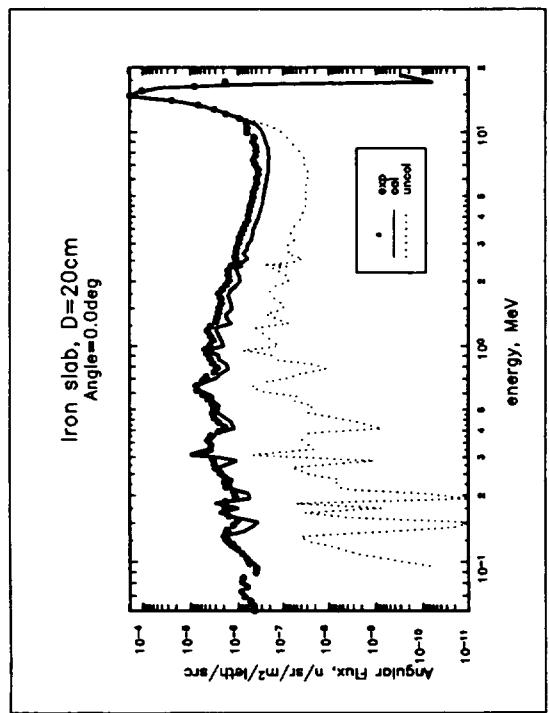


Fig. 7

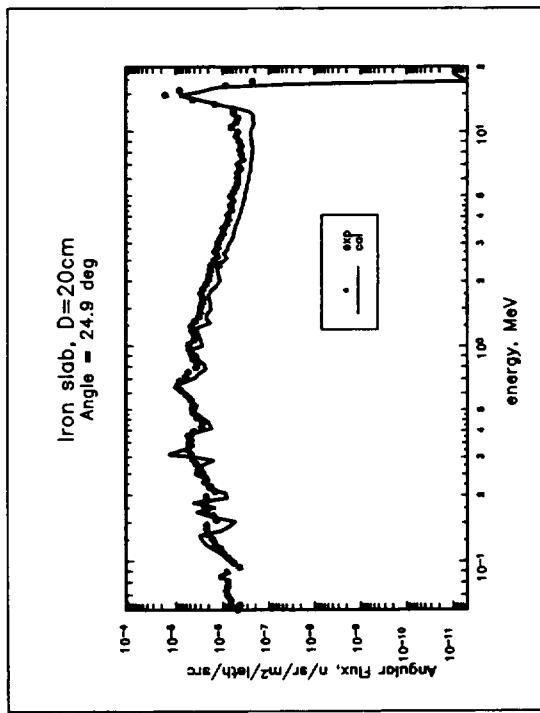


Fig. 9

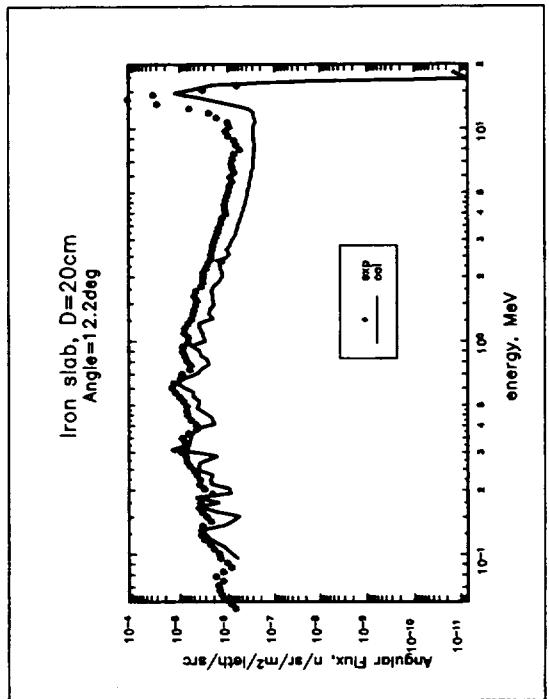


Fig. 8

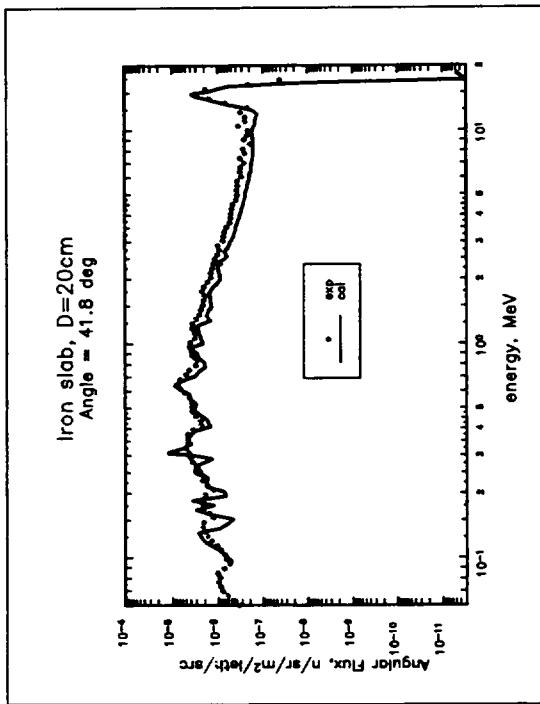


Fig. 10

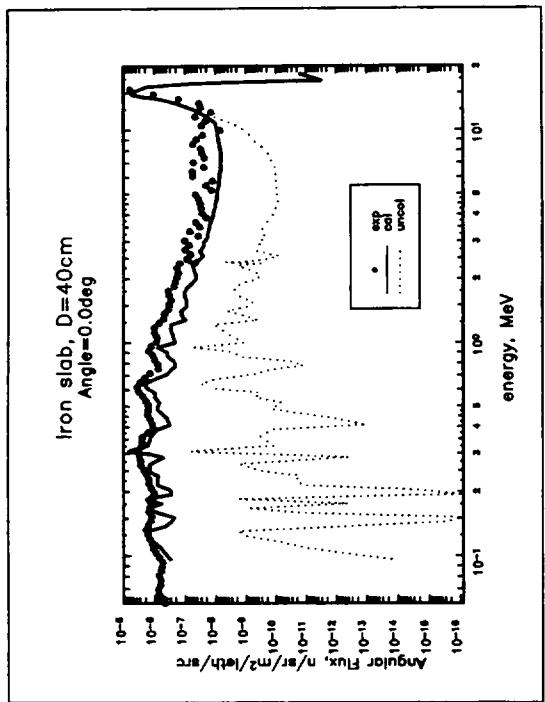
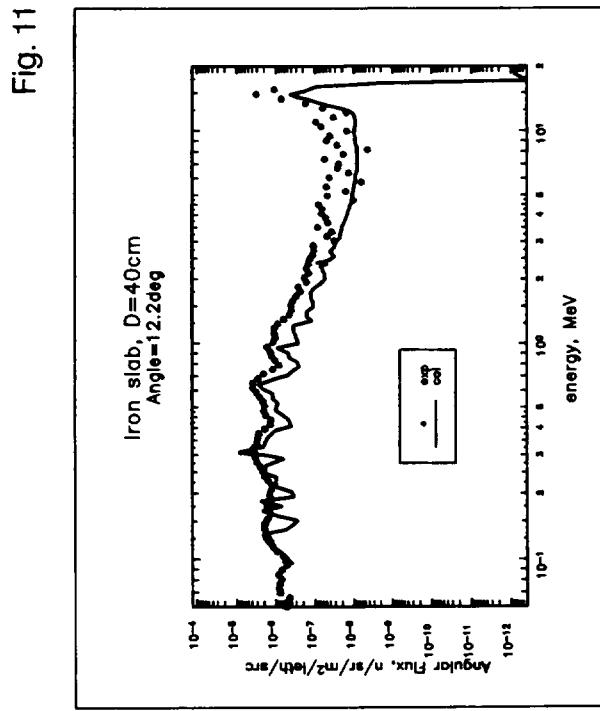
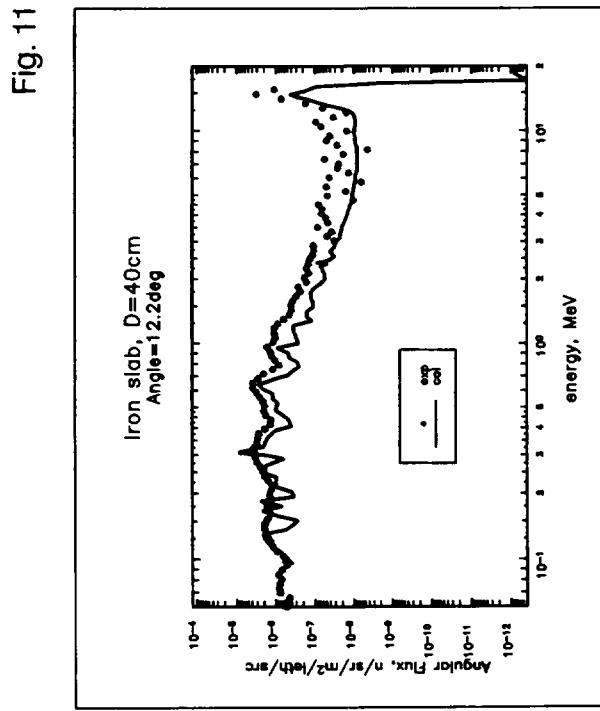
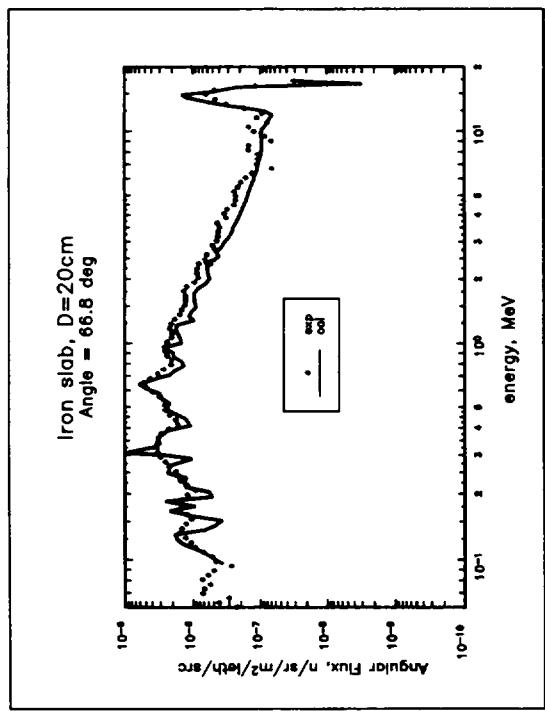


Fig. 12

Fig. 11

Fig. 13

Fig. 14

## FNS slab TOF - experiment

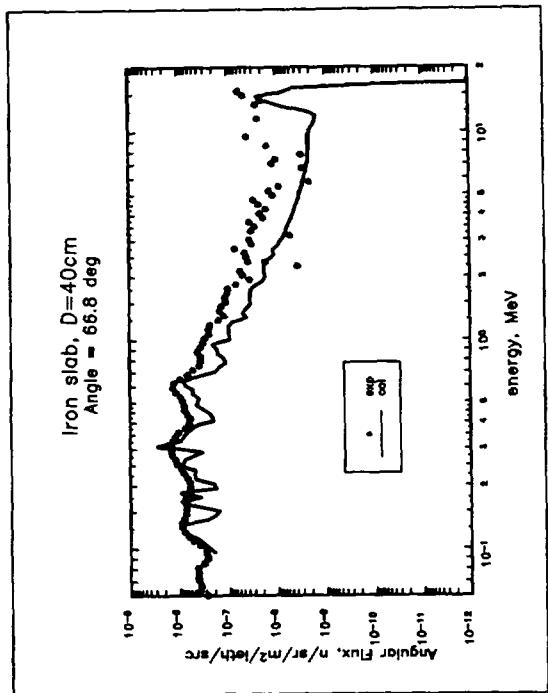


Fig. 15

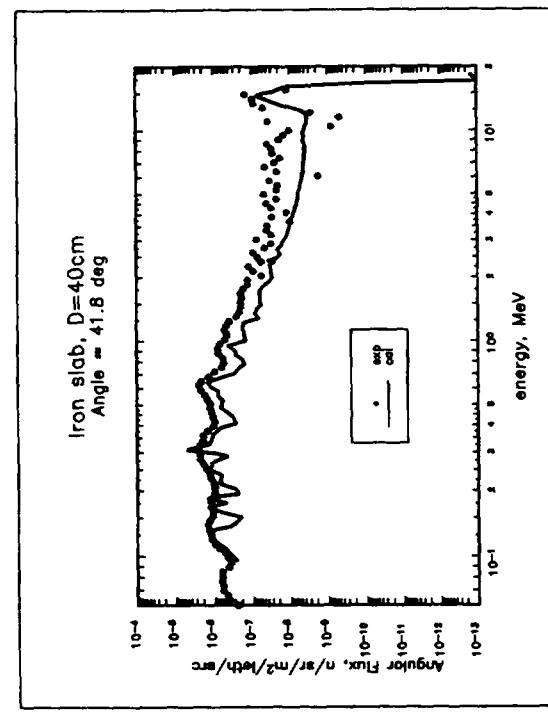


Fig. 16

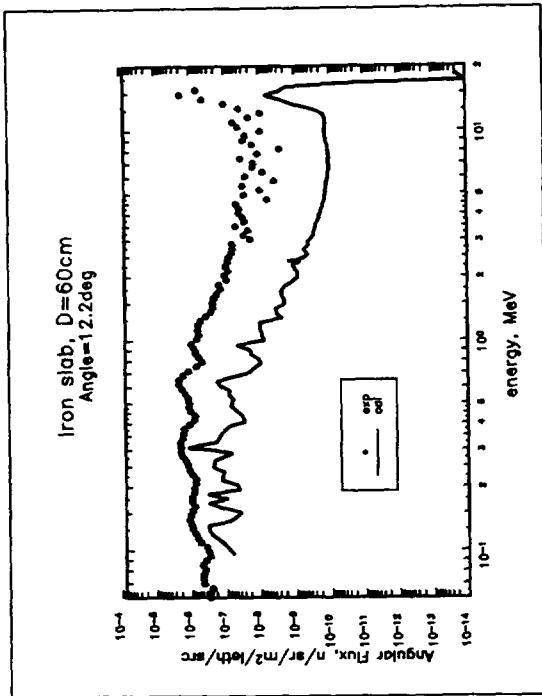
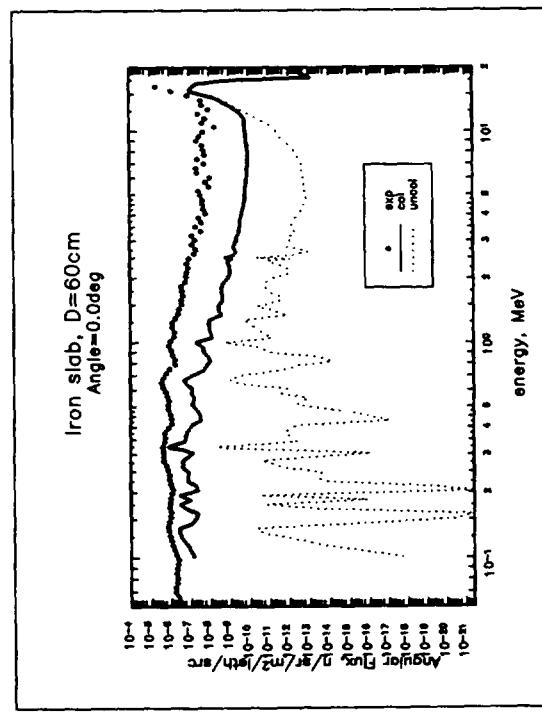


Fig. 17



## IRON

### FNS slab TOF - experiment

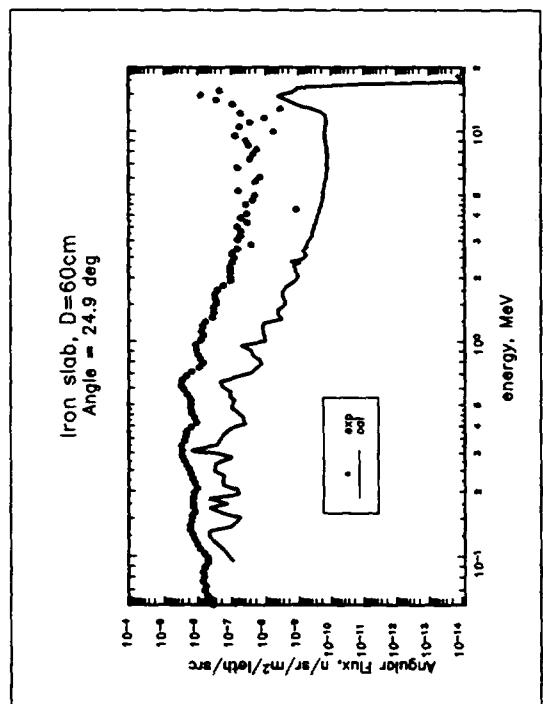


Fig. 19

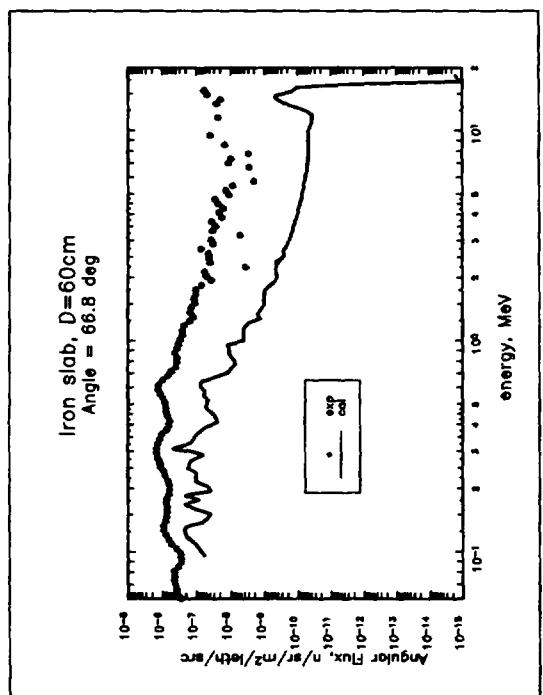


Fig. 20

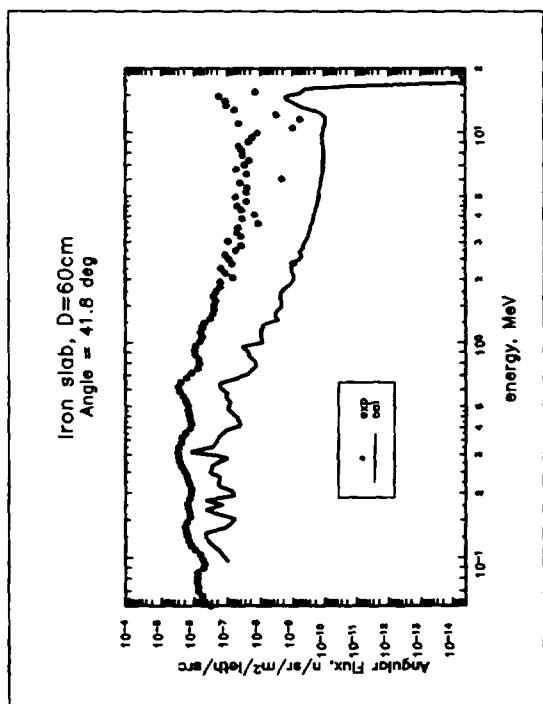


Fig. 21

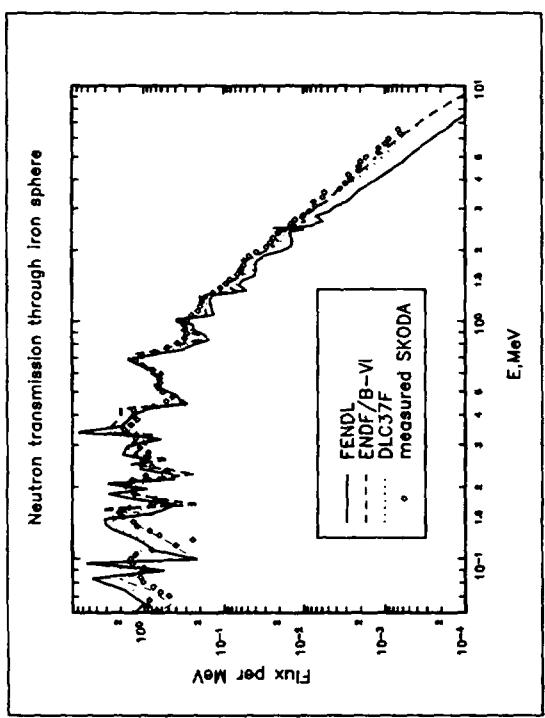


Fig. 22

## BERYLLIUM

### IPPE, Obninsk - sphere experiment

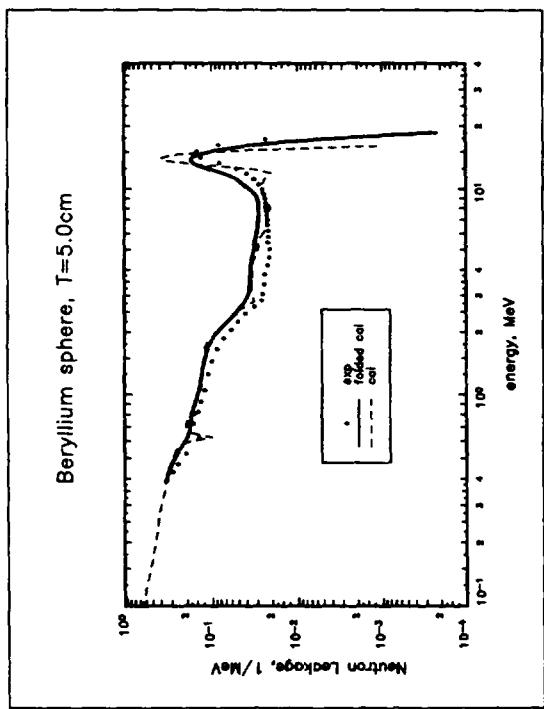


Fig. 23

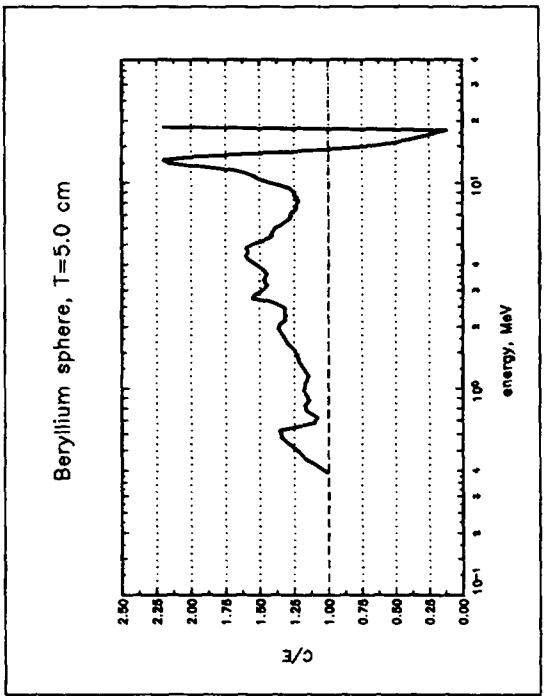


Fig. 24

## BERYLLIUM

### FNS slab TOF - experiment

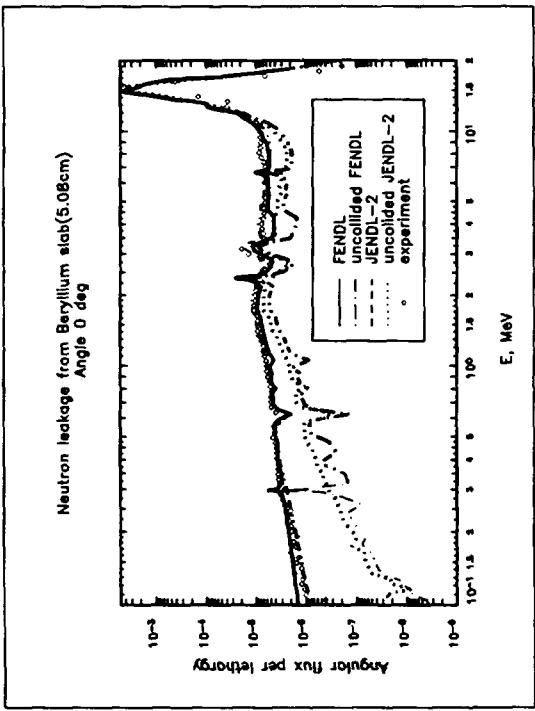


Fig. 25

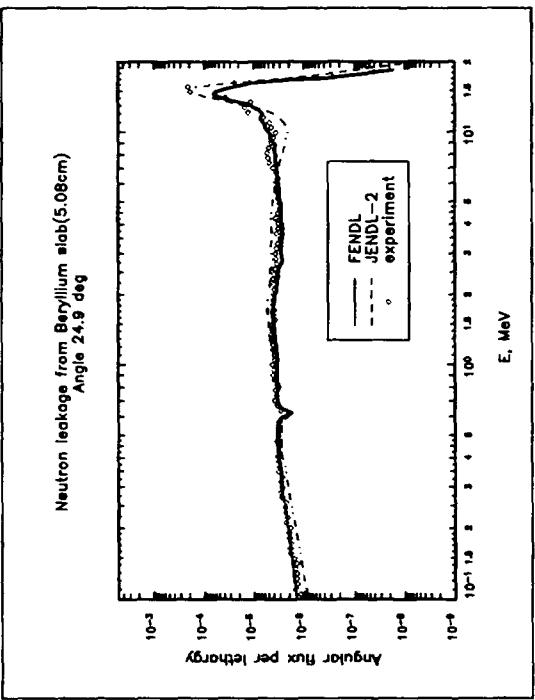


Fig. 26

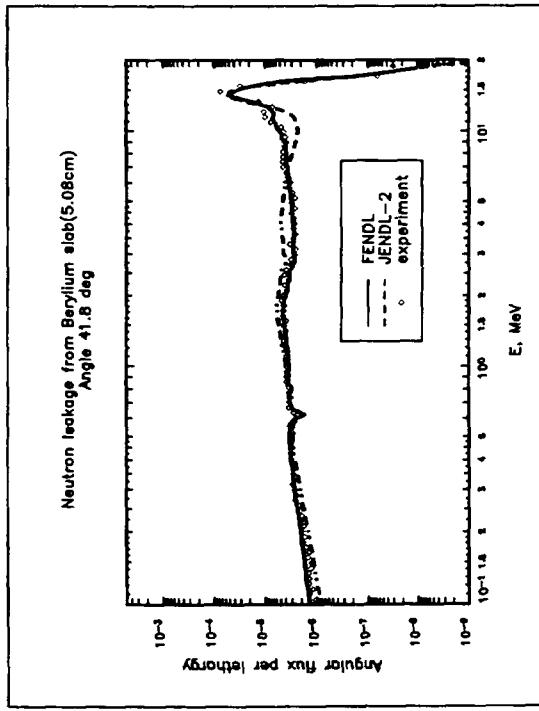


Fig. 27

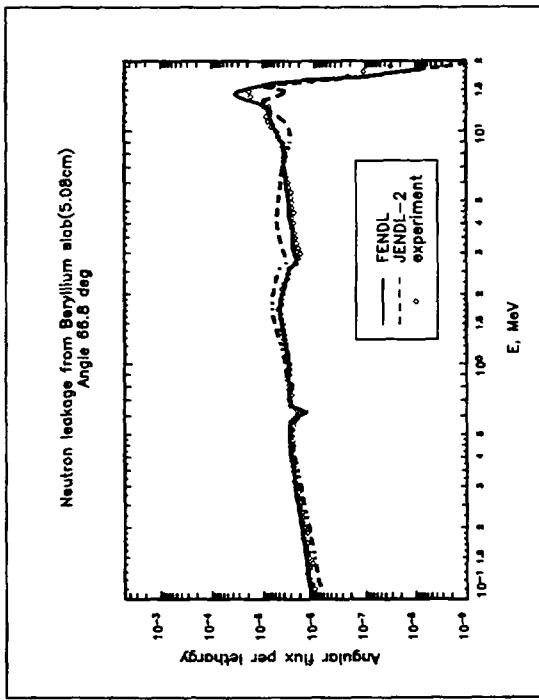


Fig. 28

## BERILLIUM

### FNS slab TOF - experiment

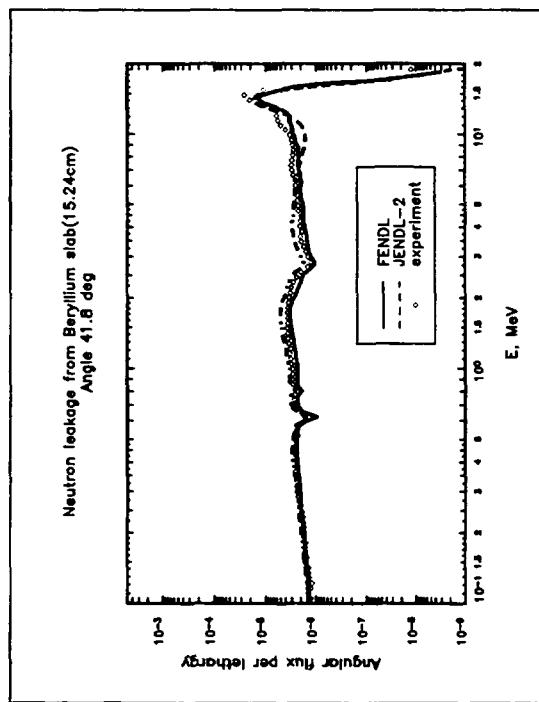
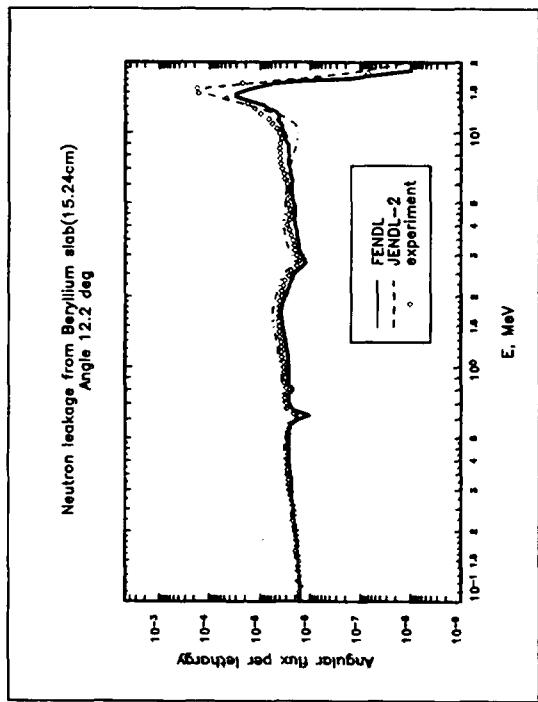
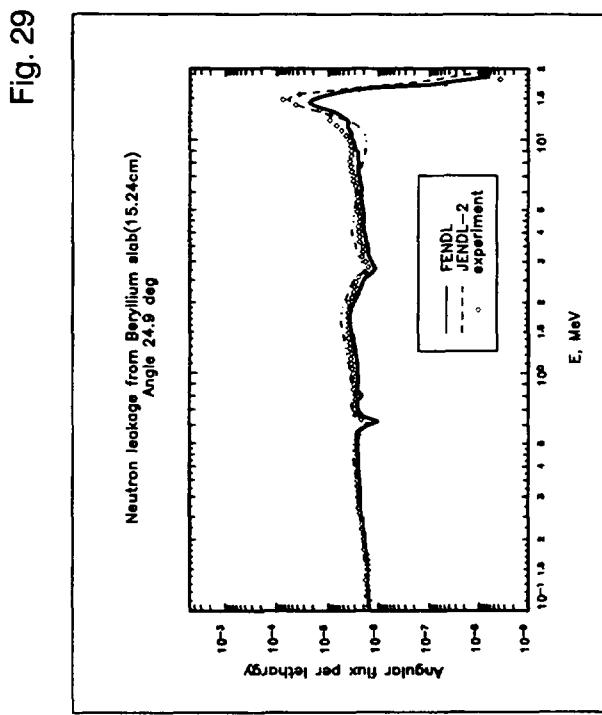
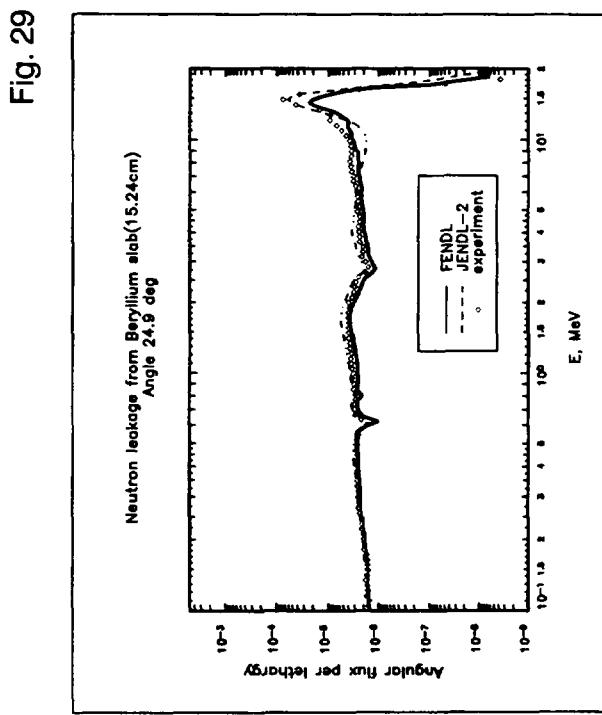
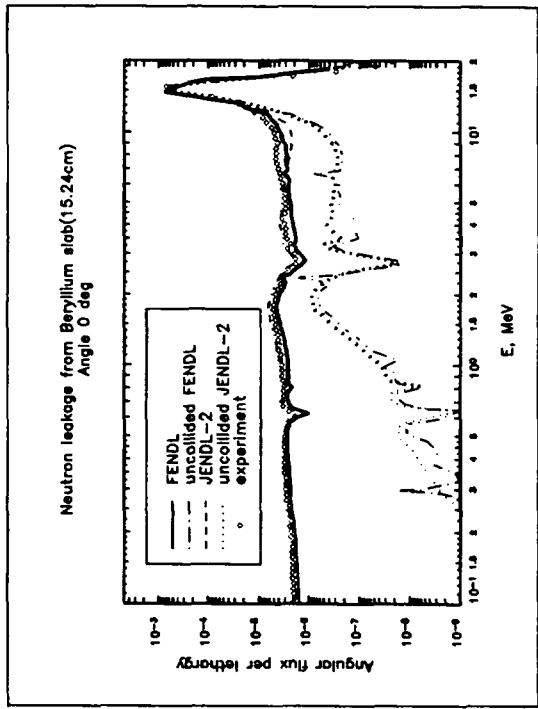


Fig. 30

Fig. 31

Fig. 32

## BERYLLIUM

### FNS slab TOF - experiment

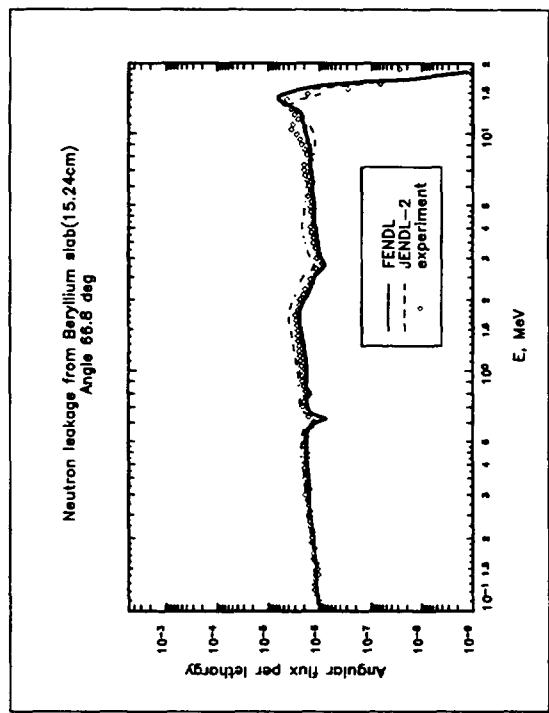


Fig. 33

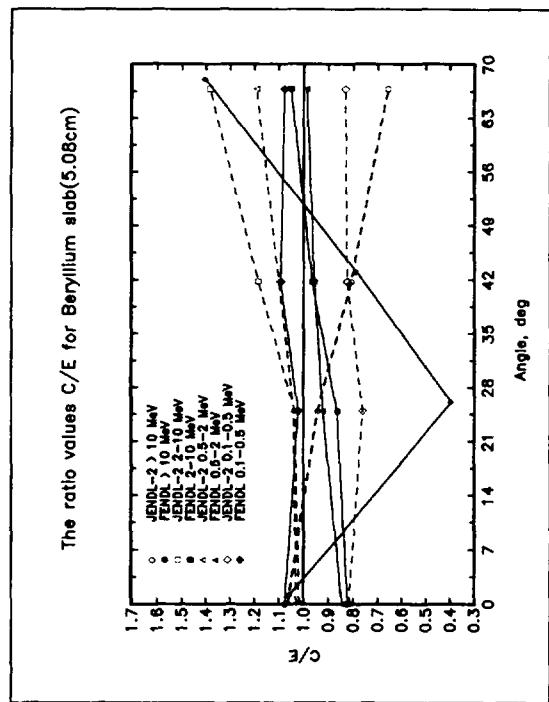


Fig. 34

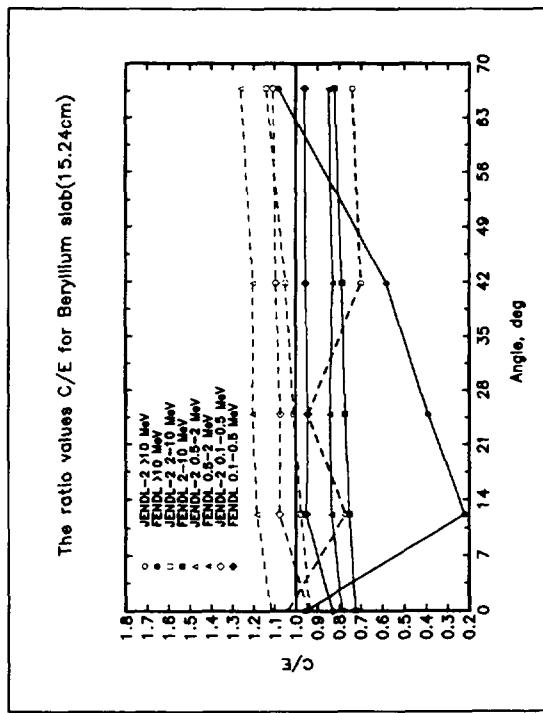


Fig. 35

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username: ANONYMOUS for FTP file transfer  
For users with Web-browsers: <http://www-nds.iaea.or.at>

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