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Monte Carlo Calculations with the MCNP Code for Investigations of Neutron and Photon Transport at the ASDEX Upgrade Tokamak

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Abstract

The Los Alamos MCNP Monte Carlo code has been applied to model the ASDEX Upgrade tokamak at the Max-Planck-Institute at Garching for a variety of different plasma diagnostic methods. In addition to this the neutron activation of some structural materials of the tokamak machine has been investigated. Furthermore the transport of photon radiation and resulting dose rates at some strategic points has been studied by applying the photon portion of MCNP. This report describes the neutron activation and photon transport calculations and resulting gamma dose levels at some strategic points near the tokamak.

Monte Carlo Rechnungen mit dem MCNP Code zum Neutronen- und Photonentransport im ASDEX-Upgrade Tokamak

Zusammenfassung

Der Los Alamos Monte Carlo Code MCNP wurde verwendet, um den ASDEX-Upgrade Tokamak am Max-Planck-Institut für Plasmaphysik in Garching für verschiedene Methoden von Plasma-Diagnostiken zu modellieren. Weiterhin wurde die Neutronenaktivierung einiger Strukturmaterialien untersucht und mit Hilfe von MCNP Photonentransportrechnungen die Strahlungsdosen an einigen strategischen Orten ermittelt. Dieser Bericht beschreibt die Untersuchungen zur Neutronenaktivierung und Photontransportrechnungen sowie die daraus resultierenden Gammastrahlungs-Dosen.

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1.Introduction

At the Max-Planck-Institute for Plasmaphysics at Garching a new tokamak, ASDEX Upgrade, has recently been constructed with the main object to study plasma-wall interaction phenomena. Compared to the former ASDEX machine the maximum plasma current will be 2 MA,that is four times higher at ASDEX Upgrade /1/. The plasma discharges can be kept up to 10 seconds. Experiments will be performed with light hydrogen,mixtures of deuterium and light hydrogen and with deuterium plasmas. In addition to the ohmic heating phase the neutral beam injection and ion cyclotron resonance heating (ICRH) up to 15 MW are foreseen for discharges up to 10 seconds.
The maximum neutron production in deuterium plasmas with additional ICRH-heating can amount 10^{18} neutrons per hour in the average. The majority of these neutrons is in the 2.5 MeV energy region due to d-d-reactions, but also a certain amount of 14.7 MeV neutrons will be emitted due to the burnup of tritons which are produced in the d(d,t)p reaction branch. This neutron emission leads to activation of the tokamak machine structures and also of the argon content in the air inside the experimental hall. Activation in the structures is predominantly due to radiative capture. In some cases,especially with high energy d-t neutrons also (n,p)-reactions in the different structure materials will lead to radioactive isotopes of relatively long half times.
To assess radiation levels in the tokamak surrounding due to neutron activation the transport of photon radiation has also to be investigated in addition to neutron transport. The MCNP Monte Carlo code /2/ incorporates a portion for photon transport, which has been used for this purpose.

2. The MCNP Simulation Model

2.1 Topology of the Model

This chapter describes the modeling of the tokamak geometry. Due to symmetry considerations, only one octant needs to be modeled. The two vertical planes which form the borders to the remaining tokamak are reflecting surfaces for both neutron and photon particles. This feature simulates the total 2π geometry, see figs. 1 and 2.This model,from hereone called AUG03, describes the topology including one large and one small port of the tokamak. A toroidal field coil is situated in between the ports and two halfs of toroidal field coils border the reflecting planes. The center structures (column, center poloidal field coil, the inner toroidal field coils, vacuum vessel and carbon tiles are of cylindrical geometry. Inside the vacuum vessel the two passive copper stabilizers are shown. They are needed to calculate the Co-63 (n,γ)-activation. The upper and lower divertor structures are modeled as horizontal plates close to the vacuum vessel.
The outer toroidal structures around the vacuum zone (vacuum vessel, toroidal field coils, shear compression structures ("Kippstruktur"), ports and poloidal field coils together with the steel structure ("Stützstruktur")) are modeled as close as possible to the real geometry using plane, cylindrical and conical surfaces. No surfaces of higher order than two have been applied, such as an elliptical torus which is of fourth order. The reason for that is, that for each collision event of a neutron or a photon in a given cell the distances of this point to all surrounding surfaces have to be calculated. This is a rather long procedure in

the case of fourth order surfaces. Yet, the four conical surfaces do model the outer structures rather realistically. Fig.1 shows a fully 2π ASDEX Upgrade MCNP model in a vertical profile, from which the octant model AUG03 has been deduced. Also shown is the ASDEX Upgrade machine in a vertical profile. Fig.2 shows additionally several cuts of the octant model from different views. In addition to the tokamak machine also the concrete foundation, ceiling and walls are modeled. The wall has the form of a cylindrical shell with an inner radius of 12.0 meters, such that the air volume is identical with the real case.

2.2 Material Compositions, Masses of the Structures and Data Files

In chapter 2.1 the topology of the AUG03 model has been described. The next step is to input materials of different compositions to the single cells. In Tab.I all material data are listed for the tokamak structures. From the cell volumes and the specific densities the total masses of the structures are calculated. MCNP incorporates an elegant feature to calculate volumes of any asymmetric cell by ray tracing particles through a material-voided model. The particles start on a spherical sphere placed outside of the AUG03 model. The particle source is inward directed and cosine biased such that the model is isotropically flooded with particles. This method has been used to calculate the volumes of all cells of interest. In some cases (for example the stainless steel turnover structure ("Kippstruktur")) the densities have to be adjusted to meet the total amount of mass. This way of density "diluting" is a compromise; otherwise even a more detailed structuring of the model would be the consequence.

The MCNP-3A neutron data library consists mainly of ENDF/B-IV evaluations, including the Lawrence Livermore ENDL 85 files.A new data library on the basis of the first version of the European Fusion File EFF-1 has been added in 1989. This new file has been used in these calculations. The photon interaction tables are based on evaluated data from ENDF /2/ for all elements which are present in this AUG03 model.

2.3 Neutron Source Distributions

The toroidal neutron plasma source can be represented by the following analytical expression, see /3/:

$$S(a)=(1-(a/A)^2)^4 \qquad 0 \leq a \leq A$$

with the normalized neutron source strength density S(a). The parameter a defines the flux surface radius and runs from zero to the small plasma radius A. For noncylindrical plasmas the contour lines of constant strength density can be represented by

$$R=R_0 + a*\cos(t+D*\sin(t)) + e*(1-(a/A)^2)$$

$$z=E*a*\sin(t)$$

$$D=D_0*(a/A)$$

with $0 \leq a \leq A$ and the poloidal angle t ($0 \leq t < 2\pi$). Here R_0 and A are the large and the small plasma radii, respectively; E is the elongation, e the excentricity and D_0 the maximum triangularity. R is the radial distance to the tokamak centerline and z the poloidal distance to the midplane. This space dependant neutron source is added to MCNP in form of a Fortran subroutine.

As to the energy dependancy of the plasma neutrons the plasma temperature T and the fusion reaction type (d-d or d-t) are input parameters; the Doppler broadened neutron spectrum is then calculated in MCNP.

For these runs, yet, a neutron source which is distributed uniformly in space has been modeled. This simplification is a rather reasonable choice for the activation calculations of the structures, collimation and some shielding investigations. It may not be advisable to use this source distribution for estimating the response of the fission detector assembly.

2.4 Photon Source Distribution

Neutron activation occurs all over the different tokamak structures, and thus is the photon source distribution. Yet, it would be an inconvenient and uneffective way to model photon sources allover the different structures. A compromise is to combine the distributed photon source together to two sources, one which is located near the very center of the tokamak and one near the outer structures. The inner vacuum chamber wall has been chosen as the first one and represents all photon sources from the center parts (vacuum chamber wall and passive stabilizers). The outer position for the second photon source is located inside the toroidal field coil section, see fig.3. In this figure also the location of the volumetric neutron source is shown. The photon energy spectra differ for the isotopes under study. An average energy distribution should be formed combining all these isotope sources together. Here,for simplification a constant average photon energy of 1 MeV has been chosen.

As an example for MCNP input data, Appendix A lists the AUG03 input data file for neutron activation calculations. The input file consists mainly of four parts defining the cells, the surfaces enclosing those cells, the material compositions of cells and, finally the definition of the source and the tallies to be investigated. A tally is defined by the cell in which to calculate the flux. In addition with a multiplier card, defining the reaction path of an isotope and its isotope density,the specific reactions per source particle are tallied.

3. Neutron Activation Calculations

3.1 Structures, Isotopes and Activation Cross Sections

Five dominant tokamak structures and, in addition, the content of argon in the experimental hall have been chosen for activation calculations, see Tab.II. In this table the structures, neutron reactions with different isotopes, half lives of the products and the isotope densities are listed. Both, radiative (n,γ)-capture as well (n,p)-reactions have been investigated. The cross section tables of the isotopes are from different files, which are also included. Furthermore, these cross sections are shown in figs.4 to 8. For the isotope Fe-54 no (n,p)-cross sections have been available, so the (n,p)-cross section of the element Fe has been used. The energy dependant shapes are similar in form, yet the absolute values differ by a factor of about four to six /4/. This difference can be corrected by increasing the Fe-54 density artificially by a factor of five in the calculations. Unfortunately the Lawrence Livermore Dosimetry File LLL DOS is not yet implemented for display and graphics, so the cross section plot of Cu-63 (n,γ) can not be shown here.

3.2 Neutron Spectra from d-d and d-t Plasma Neutrons

Together with the neutron activation calculations also the energy dependant neutron fluxes have been tallied for the structures of interest. The amount of histories has been chosen to produce an statistical error in the group fluxes below 2%.This is achieved with about 10^5 histories per run.

In the following tables and figures relating to the neutron fluxes (n/cm^2*sec) the normalization is always per 10^{16} source neutrons per second in the case of d-d neutrons, and per 10^{13} source neutrons per second in the d-t case. The tables list the group fluxes $\Phi(E)\Delta E$, neutron fluxes $\Phi(E)$ per MeV and the lethargy fluxes $\Phi(u)$ per lethargy interval. The neutron lethargy is defined as u=-ln(E). In the figures the fluxes $\Phi(E)$ and $\Phi(u)$ are plotted.

The neutron spectra in the stainless steel vacuum vessel and the air space of the experiment hall are shown: Figs. 9, 9a, 10 and 10a for the vacuum vessel and figs. 11, 11a, 12 and 12a for the air space of the experimental hall. In addition to these figures, the Tables III and IV list the data for the vacuum vessel, and tables V and VI for the air space, respectively.

The thermal fluxes inside the tokamak structures are rather small compared to the total ones. For example, the thermal flux portion in the vacuum vessel is less than 1.5% for

0.27%, at the turnover structure 0.3-0.9% depending on the location,at the toroidal field coils 5.5% and at the poloidal field coils about 10%. As to the air space the thermal flux amounts to 32% for d-d-neutrons and 26% for d-t-neutrons. From this one can already deduce that the neutron activation inside the tokamak structures will be due both to thermal and fast neutrons.

3.3 Neutron Activation and Activities

In contrary to neutron spectra evaluation, in the case of activation calculations only two energy groups have been tallied, one covering the thermal energy range and a second one from epithermal to MeV energies. The reason is because in the case of activation the energy dependance is of very little interest. AUG03 tallies the amount of activation for a given isotope in a cell per source neutron. Of further interest to this value is the amount of activations after a cycle of single plasma discharges. This cycle is defined as follows: 10 shots per 5 seconds with a constant neutron source strength of 10^{16} n/s; the time interval between the single shots is 10 minutes. The total activation after this specific discharge cycle can be calculated by paying regard to the decay during the cooling intervals. The activities (in Bq) are calculated for the end of the shot cycle. Table VII shows the results of activations. Listed are the activation data per source neutron, the total activation after this specific shot cycle and the resulting activities in Bq. The following row of Table VII lists the portion of activations due to thermal neutrons. Similar calculations have been performed with 14.7 MeV d-t-neutrons. The last row shows the ratios of activation of d-t-plasma neutrons to d-d-plasma neutrons.
The statistical errors of these activation data range in between 1% to 4%. One can see that the amount of activation due to thermal neutrons varies within a rather large range depending on the specific isotope and the location. The activation due to the 14.7 MeV d-t-neutrons, related to the same neutron source strength as the 2.5 MeV d-d-neutrons, is about 3% to 20% higher for radiative capture. Yet, in the case of the (n,p) threshold reactions the difference is rather large with a factor ranging from 35 to 55.

4. Photon Transport Calculations and Dose Rates

The photon portion of MCNP with the Detailed Physics Treatment has been used for photon transport calculations. The real photon source is distributed all over the tokamak machine. In these calculations two photon sources have been investigated as already mentioned in chapter 2.4. At three different locations the resulting photon fluxes are calculated: 1. the area of the vacuum chamber, 2. at a distance of 6 meters from the tokamak center and 3. near the concrete wall inside the experimental hall. The photon fluxes (number of photons/cm^2*sec) are, as in the neutron transport case, tallied per source photon per second. Tab. VIII shows the results of these photon transport calculations. For all three loca-

tion the photon fluxes are listed for the two cases of photon sources. The fluxes at the two positions in the experimental hall differ by a factor of about 2.5 depending on the source location. For the vacuum area this difference amounts up to a factor of 50.
To account for the total photon fluxes after the specific shot cycle one has to sum up the isotope activities for the inner structures and outer structures separately and weigh them with the corresponding fluxes per source photon. This yields the total photon fluxes after the shot cycle. These results are shown in Tab. IX together with the photon dose rates in mSv/hr, by using the conversion factors as shown in Tab. X. The photon flux calculations have been performed energy dependantly and the results show that the average photon energy at all three locations is about a factor of 2 to 3 lower than the 1 MeV input energy which is mainly due to Compton effects. The conversion factor between photon flux and dose rate has been taken at 500 keV photon energy.
The (n,p) threshold reactions in Fe-54 and Ni-58 do not play an important role regarding the dose rates just after one specific shot cycle; yet, due to the long half live times of the products the accumulation of these activities may play some role if one considers long range tokamak operation times of months or years.
The activation of Argon-40, which leads to an unstable isotope of 1.83 hours half live time is mainly due to thermal neutrons. The resulting activity must be considered to assess radiation levels inside the tokamak experimental hall.

5. Summary and Conclusions

The Monte Carlo Code MCNP version 3A has been applied to model ASDEX Upgrade for neutron activation and photon transport problems. This code is versatile to account for both neutron and photon transport within the same topology of the tokamak model. The data libraries for both neutron and photon cross sections which have been used are up to date for both 2.5 MeV d-d-neutron and photon transport calculations. There may still exist some discrepancies for the 14.7 MeV d-t-neutron range. This energy range, however, is only of a marginal interest of range for this present case of activation calculations.

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APPENDIX A

MCNP Input Data File for AUG03 Neutron Activation Calculations

```
3D : ASDEX UPGRADE MODEL AUG03  (ACTIVATION CALCULATIONS)
C
C     CCCCCCCCCCCCCCCCC
C     CELL CARDS       C
C     CCCCCCCCCCCCCCCCC
C
C                  TOKAMAK MODELING
C                ====================
C     CELL 5     CENTRAL COLUMN
5     1 -8.7     340  -490  -5   -607  610 940
C     CELL 10 -  CENTRAL POL. FIELD COIL
10    2 -8.0     340  -490   5   -10  -607  610 940
C     CELL  20   INNER TOR. FIELD COIL
20    2 -5.3     340  -490  10  -20  -607  610
C     CELL  30   INNER VACUUM CHAMBER WALL
30    3 -8.7     360  -470  20  -30  -607  610
C     CELL  40   INNER GRAPHITE LINER
40    4 -1.85    370  -460  30  -40  -607  610
C     CELL  50   UPPER HORIZ. VACUUM CHAMBER WALL INCL. DIVERTOR
50    3 -8.7     460  -470  30  -220 -607  610
C     CELL  60   LOWER                 "
60    3 -8.7     360  -370  30 -270  -607  610
C     CELL  70   UPPER CONICAL VACUUM CHAMBER WALL
70    3 -8.7     -460  210  -220  430   -607  610
C     CELL  80   LOWER           "
80    3 -8.7     370   260 -270  -410   -607  610
C     CELL  90   PORTWINDOW
90    3 -8.7     125 -130 410 -430      -607  610
C     CELL  100  UPPER GRAPHITE LINER
100   4 -1.85    455  -460  40  -210    -607  610
C     CELL  110  LOWER       "
110   4 -1.85    370  -380  40 -260     -607  610
C     CELL  120  VACUUM CHAMBER WALL OUTSIDE
120   3 -8.7     410  -430  80  -90  610  -604  940
C     CELL  130              "
130   3 -8.7     410  -430  80  -90  605  -607  940
C
C                PLASMA REGION
C                ============
C     CELL  150  VACUUM VOLUME WITHOUT SOURCE REGION
150   0     40  380  -455 (-210:-430) -80 (410:-260) -607 610 #151 #152
      #153  #154  #155
C     CELL  151  SOURCE REGION
151   0     700  703  -702  -704  -701  -705  -607 610 940
C
C              PASSIVE STABILIZERS
C              ===================
C     UPPER STABILIZER
152   15 -8.8  1104 -1105 1102 -1103 -607 610
C     GRAPHITE LINER
153   4  -1.85 1104 -1105 1101 -1102 -607 610
C     LOWER STABILIZER
154   15 -8.8  1114 -1115 1112 -1113 -607 610
C     GRAPHITE LINER
155   4  -1.85 1114 -1115 1111 -1112 -607 610
C
C                STUETZSTRUKTUR
C                ==============
C     CELLS  160 TO  164  UPPER HORIZONTAL  STRUCTURE
160   7 -4.85    510  -520  160 -170  -607 610 940
161   7 -4.85    510  -520  20  -160   606  -607   990
162   7 -4.85    510  -520  20  -160   608  -609   940
163   7 -4.85    510  -520  20  -160   610  -611  -990
164   7 -4.85    490  -520 -20  -607 610 940
C     CELLS  170 TO 174   LOWER HORIZONTAL STRUCTURE
170   7 -4.85    310  -320  160 -170  -607 610 940
171   7 -4.85    310  -320  20  -160   606  -607  990
172   7 -4.85    310  -320  20  -160   608  -609  940
```

```
173  7 -4.85    310   -320   20   -160    610   -611   -990
174  7 -4.85    310   -340  -20   -607 610 940
C    CELLS 181 TO  183  VERTICAL  OUTER STRUCTURE
181  7 -4.85    320   -510   160  -170   606   -607    990
182  7 -4.85    320   -510   160  -170   608   -609    940
183  7 -4.85    320   -510   160  -170   610   -611   -990
C
C    AIR SPACE IN BETWEEN  STUETZSTRUKTUR
C    ====================================
C    CELLS  165 -166   UPPER
165  9 -0.0013 510   -520   20   -160    609   -606
166  9 -0.0013 510   -520   20   -160    611   -608
C    CELLS  175 -176   LOWER
175  9 -0.0013 310   -320   20   -160    609   -606
176  9 -0.0013 310   -320   20   -160    611   -608
C    CELLS  184 -185 OUTSIDE
184  9 -0.0013 320   -510   160  -170   609   -606
185  9 -0.0013 320   -510   160  -170   611   -608
C
C           POLOIDAL FIELD COILS
C           ====================
C    CELL  190 UPPER POL. COIL #1
190  8 -6.51    500   -510   50   -60    -607 610 940
C    CELL  200 LOWER POL. COIL #2
200  8 -6.51    320   -330   50   -60    -607 610 940
C    CELL  210 AIR SPACE  AROUND UPPER COIL #1
210  9 -0.0013 490   -510   20   -160   -607 610 940 #190
C    CELL  220 AIR SPACE AROUND LOWER COIL #2
220  9 -0.0013 320   -340   20   -160   -607 610 940 #200
C    CELL  230 POL. COIL #3
230  8 -6.51    480   -490   100  -120  -607 610 940
C    CELL  240 POL. COIL #4
240  8 -6.51    340   -350   100  -120  -607 610 940
C    CELL  250 AIR SPACE AROUND #3
250  9 -0.0013 450   -490   240  -160   -607 610 940 #230
C    CELL  260 AIR SPACE AROUND #4
260  9 -0.0013 340   -390    290  -160   -607 610 940 #240
C
C              TOROIDAL FIELD COILS
C              ====================
C    CELLS  271 TO  273  UPPER HORIZONTAL PARTS
271  10 -5.30  470   -490   20   -240    606   -607    990
272  10 -5.30  470   -490   20   -240    608   -609    940
273  10 -5.30  470   -490   20   -240    610   -611   -990
C    CELLS  281 TO  283  LOWER      "
281  10 -5.30  340   -360   20 -290      606   -607    990
282  10 -5.30  340   -360   20 -290      608   -609    940
283  10 -5.30  340   -360   20 -290      610   -611   -990
C    CELLS  291 TO  293  UPPER CONICAL PARTS
291  10 -5.30  -470 -230   220   -240   606   -607    990   430
292  10 -5.30  -470 -230   220   -240   608   -609    940   430
293  10 -5.30  -470 -230   220   -240   610   -611   -990   430
C    CELLS  301 TO  303  LOWER      "
301  10 -5.30  360 -280    270 -290     606   -607    990 -410
302  10 -5.30  360 -280    270 -290     608   -609    940 -410
303  10 -5.30  360 -280    270 -290     610   -611   -990 -410
C    CELLS  311 TO  313  OUTER CYLINDR. "
311  10 -5.30    410 -430   90   -125    606   -607    990
312  10 -5.30    410 -430   90   -125    608   -609    940
313  10 -5.30    410 -430   90   -125    610   -611   -990
C
C               KIPPSTRUKTUR
C               ============
C    CELLS  274  TO  275  BETWEEN UPPER HORIZ. FIELD COILS
274  12 -4.8  470   -490   20   -240    609   -606    940
275  12 -4.8  470   -490   20   -240    611   -608    940
C    CELLS  284  TO  285  BETWEEN LOWER     "
284  12 -4.8  340   -360   20 -290      609   -606    940
```

```
285  12 -4.8  340  -360  20 -290    611  -608   940
C    CELLS  294  TO  295  BETWEEN UPPER CONICAL FIELD COILS
294  12 -4.8  -470 -230  220  -240  609  -606   940  430 #296
295  12 -4.8  -470 -230  220  -240  611  -608   940  430 #297
C    CELLS  304  TO  305  BETWEEN LOWER    "
304  12 -4.8  360  -280  270 -290   609  -606   940  -410 #306
305  12 -4.8  360  -280  270 -290   611  -608   940  -410 #307
C
C       CYLINDERS IN KIPPSTRUKTUR ABOVE AND BELOW BOTH PORTS
C       ====================================================
C    LARGE PORT WINDOW
C    CELL  296  UPPER CYLINDER
296  0   -1230  220 -241 940
C    CELL  297  LOWER CYLINDER
306  0   -1240  270 -291 940
C    SMALL PORT WINDOW
C    CELL  306  UPPER CYLINDER
297  0   -1210  220 -241 940
C    CELL  306  LOWER CYLINDER
307  0   -1220  270 -291 940
C
C             PORTS
C             =====
C    CELLS  314 AND 315 ARE THE SMALL AND LARGE PORT AREA
C    LARGE PORT
314  0       410 -430  80  -125  604  -605  940
C    KIPPSTRUKTUR AROUND LARGE PORT
315  12 -4.8 410 -430  90  -125  605  -606  940
316  12 -4.8 410 -430  90  -125  609  -604  940
C    SMALL PORT
317  0                 90  -125   -1200     940
C    KIPPSTRUKTUR AROUND SMALL PORT
318  12 -4.8 410 -430  90  -125  611  -608    #317
C
C           POLOIDAL FIELD COILS #5 AND #6
C           ==============================
C    CELL  320 POLOIDAL  COIL #5
320  8 -6.51   440  -450  140  -150  -607 610 940
C    CELL  330 POLOIDAL  COIL #6
330  8 -6.51   390  -400  140  -150  -607 610 940
C    CELL  325 AIR SPACE AROUND #5
325  9 -0.0013 430  -450  230  -160  -607 610 940 #320
C    CELL  335 AIR SPACE AROUND #6
335  9 -0.0013 390  -410  280  -160  -607 610 940 #330
C    CELL  340 AIR SPACE BEFORE THE PORTS
340  9 -0.0013 410  -430  130  -160  -607 610 940
C
C             REGION UNDER THE TOKAMAK
C             ========================
C    CELL  350 SUPPORTING PILLARS (HOMOGENIZED)
350  7 -2.10   300  -310  170  -180  -607 610 940
C    CELL  360 AIR SPACE
360  9 -0.0013 300  -310  -170  -607 610 940
C
C          TOKAMAKHALL AND WALLS
C          =====================
C    CELL  400 TOTAL AIR SPACE IN EXP. HALL
400  9 -0.0013 300  -810  -190 (170:520) -607 610 940
     #350 #360
C    CELL  410 CONCRETE FLOOR
410  11 -2.25  800  -300  -195 -607 610 940
C    CELL  420 CONCRETE CEILING
420  11 -2.25  810  -820  -195 -607 610 940
C    CELL  430 CONCRETE WALL
430  11 -2.25  300  -810  190  -195 -607 610 940
C
C
C         OUTSIDE WORLD
```

```
C          =============
5000 0     -800:195:607:-610:820:-940
C

C     CCCCCCCCCCCCCCCCCC
C     SURFACE CARDS      C
C     CCCCCCCCCCCCCCCCCC
C
C
C         TOKAMAKSTRUCTURES
C         ==========
C     PLANES  VERTICAL TO Z-AXIS
300   PZ  -540
310   PZ  -308
320   PZ  -260
330   PZ  -214
340   PZ  -190
350   PZ  -145.5
360   PZ  -145
370   PZ  -137.8
380   PZ  -135.6
390   PZ  -83.033089
400   PZ  -54
410   PZ  -40
C     420  PZ  0 NOT USED
430   PZ  40
440   PZ  54
450   PZ  83.033089
455   PZ  135.6
460   PZ  137.8
470   PZ  145
480   PZ  145.5
490   PZ  190
500   PZ  214
510   PZ  260
520   PZ  308
300   PZ  -680
310   PZ  1180
820   PZ  1380
C
C     PLANE VERTICAL TO Y-AXIS
C     PLANE 940 IS AMBUIGITY SURFACE TO DEFINE THE OCTANT
940   PY   0
C
C     PLANE VERTICAL TO X-AXIS
C     PLANE 990 IS AMBUIGITY SURFACE TO DEFINE THE OCTANT
990   PX 0
C
C     OTHER PLANES
604   P    9.8963  -1  0  0
605   P    3.3268  -1  0  0
606   P    2.4142  -1  0 -47.036
C     PLANES 607 AND 610 ARE REFLECTING PLANES
*607 P    2.4142  -1  0  0
608   PX -18
609   PX  18
*610 P    2.4142   1  0  0
611   P    2.4142   1  0  47.036
C
C     CYLINDERS PARALLEL TO Z-AXIS
5     CZ  25
10    CZ  51
20    CZ  92.4
30    CZ  96
40    CZ  96.5
50    CZ  126
60    CZ  206
80    CZ  272
```

```
90    CZ  276
100   CZ  292
120   CZ  337
125   CZ  335
130   CZ  337
140   CZ  346
150   CZ  374
160   CZ  381
170   CZ  425
180   CZ  480
190   CZ  1198
195   CZ  1300
C
C     COMMON  CYLINDER FOR SMALL PORT
1200  GQ 0.962  0.03806  1 0.38268 0 0 0 0 0 -200
C
C     CONI PARALLEL TO Z-AXIS
210   KZ   326.57 .8763   -1
220   KZ   330    .8763   -1
230   KZ   951.7  .1366   -1
240   KZ   426    .8763   -1
260   KZ  -326.57 .8763    1
270   KZ  -330    .8763    1
280   KZ  -951.7  .1366    1
290   KZ  -426    .8763    1
C
C          SURFACES FOR SOURCE CELL
700   CZ   100.0
701   CZ   150
702   PZ   60
703   PZ   -60
704   KZ   188    .8763  -1
705   KZ   -188   .8763   1
C
C
C          SURFACES FOR STABILIZERS AND GRAPHITE
1114  PZ -89
1115  PZ -54
1104  PZ  54
1105  PZ  89
1101  KZ   365.9  .4473  -1
1102  KZ   368.5  .4473  -1
1103  KZ   382.7  .4473  -1
1111  KZ  -365.9  .4473   1
1112  KZ  -368.5  .4473   1
1113  KZ  -382.7  .4473   1
C
C
C          CYLINDERS FOR TUBES ABOVE AND BELOW THE PORTS
C
1210  GQ  0.962  0.03806  1  0.38268  0 0 0 0 -202  10032.
1220  GQ  0.962  0.03806  1  0.38268  0 0 0 0  202  10032.
1230  GQ  0.962  0.03806  1 -0.38268  0 0 0 0 -202  10032.
1240  GQ  0.962  0.03806  1 -0.38268  0 0 0 0  202  10032.
241   KZ  424.0  0.8763  -1
291   KZ -424.0  0.8763   1
C
C

C     CCCCCCCCCCCCCCCCCC
C     MATERIAL CARDS    C
C     CCCCCCCCCCCCCCCCCC
C     ------------------------------------------------------------------
C     FE                    CR                    MN
M1    26000.89C -0.6495     24000.89C -0.1750     25055.89C -0.018
C     NI                    CU                    MO
      28000.89C -0.1225     29000.89C -0.01       42000.89C -0.025
C     ------------------------------------------------------------------
```

```
C     CU                  SI                    C
M2    29000.89C -0.961 14000.89C -0.0028   6000.89C  -0.0207
C     H                     O
      1001.89C -0.0021    8016.89C -0.0134
C     ------------------------------------------------------------------
C     FE                  CR                  MN                  NI
M3    26000.89C -0.705 24000.89C -0.183  25055.89C -0.012 28000.89C -.10
C     ------------------------------------------------------------------
C     C
M4    6000.89C 1.0
C     ------------------------------------------------------------------
C     FE                  CR                  NI
M7    26000.89C -.716     24000.89C  -.181    28000.89C  -.091
C     MN
      25055.89C -.012
C     ------------------------------------------------------------------
C     CU                H                 O                 SI
M8    29000.89C -.937 1001.89C -0.004 8016.89C -0.032 14000.89C -.027
C     ------------------------------------------------------------------
C     O                 N
M9    8016.89C -0.22  7014.89C -0.78
C     ------------------------------------------------------------------
C     CU                  SI                    C
M10   29000.89C -0.961 14000.89C -.0028    6000.89C -.0207
C     H                     O
      1001.89C -0.0021    8016.89C -0.0134
C     ------------------------------------------------------------------
C     H                   O                   NA                  MG
M11   1001.89C -0.0045 8016.89C -0.51 11023.89C -0.011 12000.89C -.004
C     AL                  SI                  K                   CA
      13027.89C -0.035 14000.89C -.36 19000.89C -.014 20000.89C -.0455
C     FE
      26000.89C -.016
C     ------------------------------------------------------------------
C     FE                  CR                  MN
M12   26000.89C -0.663 24000.89C -0.184 25055.89C -0.0816
C     NI
      28000.89C -0.0714
C     ---------------------------------------------------------------
C     CU
M15   29000.89C 1.0
C     ---------------------------------------------------------------
C
C
C
C
C     MATERIALS FOR TALLY-MULTIPLIERS:
C     ++++++++++++++++++++++++++++++++++
C
C     ARGON
M999  18000.01C 1.0
C
C     MANGAN 55
M998  25055.89C 1.0
C
C     CHROMIUM  50
M997  24050.30Y 1.0
C
C     COPPER 63
M996  29063.30Y 1.0
C
C     NICKEL 58
M994  28058.35C 1.0
C
C     IRON  58 (HERE:ELEMENT IRON !)
M995  26000.89C 1.0
C
C
```

```
C     ===================================================================
C
C
MODE  N
C     SOURCE IN CELL  151
SDEF  POS=0  0  0 CEL=151 RAD=D2 ERG=D1
      EXT=D3 AXS= 0  0  1
SI2   100 150
SI3   60
SP1   -4  -0.001 -1
C     D-D NEUTRON SOURCE IN CELL 151 T=1 KEV
C
IMP:N  1  89R 0
C
C     CCCCCCCCCCCCCCCCCC
C     TALLY CARDS        C
C     CCCCCCCCCCCCCCCCCC
C     VOLUMES SET TO ONE
VOL     1  89R 0
C
C     ENERGY GROUPS
C
E0    1.E-11 4.1399E-07 3.9279E-6 3.7267E-05 3.5358E-04 3.3546E-03
      3.1828E-02 1.6573E-01 3.0197E-01 5.5023E-01 6.7206E-01
      8.2085E-01 1.0026 1.2246 1.6530 2.2313 2.7253 3.6788 4.9659
      6.7032 8.1873 10 11.052 12.214 13.499 14.918
C
C                CELL FLUXES
C                ===========
C                (ACTIVATION)
C
C
F4:N  165 184 325 340 360 400
FC4   ARGONACTIVATION IN THE HALL
C     MULTIPLIER CARD
C     ATOMDENSITY        MATERIAL      REAKTIONSPATH
FM4    1.385E-07       999            102
C
F14:N 30 50 70  120 130
FC14 MANGANACTIVATION VACUUM CHAMBER WALL
C     MULTIPLIER CARD
FM14   1.14E-03        998             102
C
F24:N 30 50 70 120 130
FC24 CHROMIUMACTIVATION VACUUM CHAMBER WALL
C     MULTIPLIER CARD
FM24   8.30E-04        997           102
C
F34:N 190 230 320
FC34 KOPPER 63 ACTIVATION POL. COILS
C     MULTIPLIER CARD
FM34    3.08E-02       996           102
C
F44:N 152
FC44 COPPER 63 ACTIVATION OF THE PASSIVE STABILIZERS
C     MULTIPLIER CARD
FM44   5.790E-02         996           102
C
F54:N 272 292 312
FC54 COPPER 63 ACTIVATION  TF-COIL  OUTSIDE
C      MULTIPLIER CARD
FM54   3.230E-02       996             102
C
F64:N 20
FC64 COPPER 63 ACTIVATION  TF-COIL INSIDE
C      MULTIPLIER CARD
FM64    3.230E-02      996              102
C
```

```
FC74 MANGANACTIVATION KIPPSTRUKTUR
C     MULTIPLIER CARD
FM74  4.27E-03         998              102
C
F84:N 274 294
FC84  CHROMIUMACTIVATION KIPPSTRUKTUR
FM84  4.61E-04         997              102
C
C         REACTION FE(N,P)
C
F164:N 30 50 70 120 130
FC164 FE(N,P) IN THE VACUUM CHAMBER WALL
C    MULTIPLIER CARD
FM164  6.52E-02        995              103
C
F174:N 274 294
FC174 FE(N,P) IN THE KIPPSTRUKTUR
C    MULTIPLIER CARD
FM174 3.41E-02        995               103
C
C         REACTION NI-58 (N,P)
C
F184:N 30 50 70  120 130
FC184 NI-58 (N,P) REAKTION IN THE VACUUM CHAMBER WALL
C    MULTIPLIER CARD
FM184 6.12E-03        994               103
C
F194:N 274 294
FC194 NI-58 (N,P) REACTION IN THE KIPPSTRUKTUR
C    MULTIPLIERCARD
FM194 2.41E-03        994               103
C
C    CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C    CUT NEUTRON ENERGY RANGE
CUT:N 1J 1.0E-11 0.0 0.0
PRINT
CTME 0.30
NPS   1000000
```

Tab.I Composition of Materials and Masses

		(Weight %)		
1.	Vacuum Vessel:	Fe	70.6	
		Cr	18.2	
		Ni	10.0	
		Mn	1.2	Total Mass: 29600 kg
2.	Passive Stabilizers:	Cu	100.0	Total Mass: 7500 kg
3.	Toroidal Field Coils:	Cu	96.1	
		Si	0.28	
		C	2.07	
		H	0.21	
		O	1.34	Total Mass: 9375 kg (one Coil)
4.	Turnover Structure: "Kippstruktur"	Fe	66.3	
		Cr	18.4	
		Mn	8.16	
		Ni	7.14	Total Mass: 130000 kg
5.	Poloidal Field Coils:	Cu	93.33	
		C	3.09	
		H	0.43	
		O	2.54	
		Si	0.60	Total Mass: 125000 kg
6.	PF-Structure "Stützstruktur"	Fe	71.6	
		Cr	18.1	
		Ni	9.1	
		Mn	1.2	Total Mass: 195000 kg
7:	Graphite:	C	100	
				Inner Wall: 150 kg
				Divertors : 566 kg
				Stabilizers: 290 kg
				Total Mass: 1006 kg
8.	Concrete:	H	0.45	
		O	51.0	
		Na	1.1	
		Mg	0.4	
		Al	3.5	
		Si	36.0	
		K	1.4	
		Ca	4.5	
		Fe	1.6	

Tab. II ASDEX-Upgrade Structures and Neutron Reaction Paths which have been investigated in these Calculations

Isotopes	Reaction Path	Half Live $T_{1/2}$	Isotope Density (atom/barn*cm)
Vacuum Chamber Wall			
Cr-50	(n,Gamma)	27.7 d	7.95E-04
Fe-54	(n,p)	312.2 d	3.80E-03
Mn-55	(n,Gamma)	2.58 h	1.14E-03
Ni-58	(n,p)	70.8 d	6.05E-03
Passive Stabilizers			
Cu-63	(n,Gamma)	12.7 h	5.74E-02
Toroidal Field Coils			
Cu-63	(n,Gamma)	12.7 h	3.33E-02
Poloidal Field Coils			
Cu-63	(n,Gamma)	12.7 h	3.98E-02
"Kippstruktur"			
Cr-50	(n,Gamma)	27.7 d	4.43E-04
Fe-54	(n,p)	312.2 d	1.98E-03
Mn-55	(n,Gamma)	2.58 h	4.28E-03
Ni-58	(n,p)	70.8 d	2.38E-03
Air Space of Exp. Hall			
Ar-40	(n,Gamma)	1.83 h	1.38E-07

Tab.III Spectral Neutron Fluxes at the Vacuum Vessel for 2.45 MeV d-d-Source Neutrons at ASDEX-Upgrade
Normalization is per 1.0E+16 Neutrons per Second

Energies (MeV)		Spectral Neutron Fluxes		
Lower	Upper	(n/cm^2*s)	(n/cm^2*s*MeV)	per Lethargy Interval
1.000E-11	4.140E-07	3.995E+08	9.651E+14	3.758E+07
4.140E-07	3.930E-06	1.803E+09	5.127E+14	8.010E+08
3.930E-06	3.730E-05	4.033E+09	1.209E+14	1.792E+09
3.730E-05	3.540E-04	5.414E+09	1.710E+13	2.406E+09
3.540E-04	3.350E-03	8.292E+09	2.768E+12	3.690E+09
3.350E-03	3.180E-02	1.121E+10	3.940E+11	4.980E+09
3.180E-02	1.660E-01	1.670E+10	1.244E+11	1.010E+10
1.660E-01	3.020E-01	9.510E+09	6.993E+10	1.589E+10
3.020E-01	5.500E-01	1.208E+10	4.871E+10	2.015E+10
5.500E-01	6.720E-01	4.895E+09	4.012E+10	2.443E+10
6.720E-01	8.210E-01	3.909E+09	2.623E+10	1.952E+10
8.210E-01	1.003E+00	4.201E+09	2.313E+10	2.102E+10
1.003E+00	1.225E+00	3.518E+09	1.582E+10	1.756E+10
1.225E+00	1.653E+00	6.815E+09	1.592E+10	2.274E+10
1.653E+00	2.231E+00	3.828E+09	6.623E+09	1.277E+10
2.231E+00	2.725E+00	1.213E+10	2.456E+10	6.065E+10
		Total=1.087E+11		

Tab.IV Spectral Neutron Fluxes at the Vacuum Vessel for 14.7 MeV d-t-Source Neutrons at ASDEX-Upgrade
Normalization is per 1.0E+13 Neutrons per Second

Energies(MeV)		Spectral Neutron Fluxes		
Lower	Upper	(n/cm^2*s)	(n/cm^2*s*MeV)	per Lethargy Interval
1.000E-11	4.140E-07	7.66E+05	1.85E+12	7.21E+04
4.140E-07	3.930E-06	3.62E+06	1.03E+12	1.61E+06
3.930E-06	3.730E-05	8.79E+06	2.63E+11	3.91E+06
3.730E-05	3.540E-04	1.20E+07	3.80E+10	5.35E+06
3.540E-04	3.350E-03	1.88E+07	6.28E+09	8.37E+06
3.350E-03	3.180E-02	2.56E+07	9.00E+08	1.14E+07
3.180E-02	1.660E-01	3.88E+07	2.89E+08	2.35E+07
1.660E-01	3.020E-01	2.26E+07	1.66E+08	3.77E+07
3.020E-01	5.500E-01	2.74E+07	1.10E+08	4.56E+07
5.500E-01	6.720E-01	1.02E+07	8.38E+07	5.11E+07
6.720E-01	8.210E-01	8.23E+06	5.52E+07	4.11E+07
8.210E-01	1.003E+00	7.19E+06	3.96E+07	3.60E+07
1.003E+00	1.225E+00	6.55E+06	2.94E+07	3.27E+07
1.225E+00	1.653E+00	6.89E+06	1.61E+07	2.30E+07
1.653E+00	2.231E+00	5.00E+06	8.64E+06	1.67E+07
2.231E+00	2.725E+00	2.52E+06	5.10E+06	1.26E+07
2.725E+00	3.679E+00	2.60E+06	2.73E+06	8.67E+06
3.679E+00	4.966E+00	1.59E+06	1.24E+06	5.31E+06
4.966E+00	6.703E+00	1.29E+06	7.44E+05	4.31E+06
6.703E+00	8.187E+00	1.01E+06	6.81E+05	5.05E+06
8.187E+00	1.000E+01	1.22E+06	6.73E+05	6.10E+06
1.000E+01	1.105E+01	4.91E+05	4.67E+05	4.91E+06
1.105E+01	1.221E+01	4.23E+05	3.64E+05	4.24E+06
1.221E+01	1.350E+01	1.52E+06	1.18E+06	1.52E+07
1.350E+01	1.492E+01	1.47E+07	1.04E+07	1.47E+08
		Total=2.30E+08		

Tab.V Spectral Neutron Fluxes in the Tokamak Hall for 2.45 MeV d-d-Source Neutrons at ASDEX-Upgrade
Normalization is per 1.0E+16 Neutrons per Second
Fluxes are averaged over the whole Hall Volume

Energies (MeV)		Spectral Neutron Fluxes		
Lower	Upper	(n/cm^2*s)	(n/cm^2*s*MeV)	per Lethargy Interval
1.000E-11	4.140E-07	1.498E+08	3.619E+14	1.409E+07
4.140E-07	3.930E-06	3.471E+07	9.872E+12	1.542E+07
3.930E-06	3.730E-05	4.291E+07	1.286E+12	1.907E+07
3.730E-05	3.540E-04	4.834E+07	1.526E+11	2.148E+07
3.540E-04	3.350E-03	4.983E+07	1.663E+10	2.217E+07
3.350E-03	3.180E-02	5.967E+07	2.097E+09	2.651E+07
3.180E-02	1.660E-01	7.169E+07	5.342E+08	4.338E+07
1.660E-01	3.020E-01	3.388E+07	2.491E+08	5.661E+07
3.020E-01	5.500E-01	2.755E+07	1.111E+08	4.595E+07
5.500E-01	6.720E-01	1.040E+07	8.527E+07	5.193E+07
6.720E-01	8.210E-01	8.436E+06	5.662E+07	4.213E+07
8.210E-01	1.003E+00	6.422E+06	3.537E+07	3.214E+07
1.003E+00	1.225E+00	5.586E+06	2.512E+07	2.788E+07
1.225E+00	1.653E+00	8.517E+06	1.990E+07	2.842E+07
1.653E+00	2.231E+00	7.906E+06	1.368E+07	2.637E+07
2.231E+00	2.725E+00	1.568E+07	3.173E+07	7.837E+07

Total=5.81E+08

Tab.VI Spectral Neutron Fluxes in the Tokamak Hall for 14.7 MeV d-t-Source Neutrons at ASDEX-Upgrade
Normalization is per 1.0E+13 Neutrons per Second
Fluxes are averaged over the whole Hall Volume

Energies (MeV)		Spectral Neutron Fluxes		
Lower	Upper	(n/cm^2*s)	(n/cm^2*s*MeV)	per Lethargy Interval
1.000E-11	4.140E-07	1.65E+05	3.98E+11	1.55E+04
4.140E-07	3.930E-06	4.14E+04	1.18E+10	1.84E+04
3.930E-06	3.730E-05	4.59E+04	1.37E+09	2.04E+04
3.730E-05	3.540E-04	5.15E+04	1.62E+08	2.29E+04
3.540E-04	3.350E-03	5.84E+04	1.95E+07	2.60E+04
3.350E-03	3.180E-02	7.41E+04	2.61E+06	3.29E+04
3.180E-02	1.660E-01	8.28E+04	6.17E+05	5.01E+04
1.660E-01	3.020E-01	4.13E+04	3.03E+05	6.89E+04
3.020E-01	5.500E-01	3.37E+04	1.36E+05	5.62E+04
5.500E-01	6.720E-01	1.21E+04	9.93E+04	6.05E+04
6.720E-01	8.210E-01	8.60E+03	5.77E+04	4.29E+04
8.210E-01	1.003E+00	6.83E+03	3.76E+04	3.42E+04
1.003E+00	1.225E+00	5.03E+03	2.26E+04	2.51E+04
1.225E+00	1.653E+00	4.65E+03	1.09E+04	1.55E+04
1.653E+00	2.231E+00	3.96E+03	6.85E+03	1.32E+04
2.231E+00	2.725E+00	2.53E+03	5.13E+03	1.27E+04
2.725E+00	3.679E+00	1.93E+03	2.02E+03	6.41E+03
3.679E+00	4.966E+00	1.57E+03	1.22E+03	5.22E+03
4.966E+00	6.703E+00	1.50E+03	8.61E+02	4.99E+03
6.703E+00	8.187E+00	5.40E+02	3.64E+02	2.70E+03
8.187E+00	1.000E+01	6.72E+02	3.71E+02	3.36E+03
1.000E+01	1.105E+01	6.51E+02	6.19E+02	6.51E+03
1.105E+01	1.221E+01	5.76E+02	4.96E+02	5.76E+03
1.221E+01	1.350E+01	8.46E+02	6.59E+02	8.46E+03
1.350E+01	1.492E+01	1.65E+04	1.16E+04	1.65E+05
		Total=6.62E+05		

Tab. VII Neutron Activation of the Isotopes in the Different Structures

Isotope	Activation per Source Neutron	Total Activation after Shot Cycle	Activity (Bq)	Thermal Activation (%)	(d,t) to (d,d) Activation *)
Vacuum Chamber Wall					
Cr-50	3.23E-03	1.62E+15	4.68E+08	23-35	1.08
Fe-54	2.37E-04	1.18E+14	3.05E+06	0	35.2
Mn-55	8.25E-03	4.04E+15	1.26E+10	10-15	1.13
Ni-58	2.61E-03	1.31E+15	1.47E+08	0	45.0
Passive Stabilizers					
Cu-63	6.12E-02	3.06E+16	4.65E+11	2.7	1.09
Toroidal Field Coils					
Cu-63	6.93E-01	3.47E+17	5.27E+12	30-35	1.17
Poloidal Field Coils					
Cu-63	3.16E-02	1.58E+16	2.40E+11	50-60	1.21
"Kippstruktur"					
Cr-50	4.55E-03	2.28E+15	6.60E+08	13-20	1.03
Fe-54	9.05E-05	4.53E+13	1.16E+06	0	43.7
Mn-55	6.16E-02	3.02E+16	9.39E+10	10-18	1.06
Ni-58	8.68E-04	4.34E+14	4.90E+07	0	55.0
Air Space of Exp. Hall					
Ar-40	8.47E-06	4.12E+12	4.33E+08	93	1.05

*) Related to the same neutron source strength

Tab. VIII Calculated Photon Fluxes at the Three Positions for both Inner and Outer Photon Sources.

Position of Tally	Flux per Inner Source Photon (1/cm^2*s)	Flux per Outer Source Photon (1/cm^2*s)
Plasmavolume	1.03E-06	3.32E-08
6m from Tokamak Center	1.39E-09	3.77E-09
12m from Tokamak Center	6.35E-10	1.50E-09

Tab. IX Dose Rates due to Photon Fluxes at the three Positions

Position	Total Photon Flux after Shot Cycle (1/cm^2*s)	Dose (mSv/hr)
Plasmavolume	5.68E+06	52.0
6m from Tokamak-Center	1.53E+05	1.39
12m from Tokamak-Center	6.12E+04	0.56

Tab. X Photon Flux-to-Dose Rate Conversion Factors /2/ (ICRP-21)

Photon Energy MeV	DF(E) (rem/hr)(photons/cm^2*s)
0.01	2.78E-06
0.015	1.11E-06
0.02	5.88E-07
0.03	2.56E-07
0.04	1.56E-07
0.05	1.20E-07
0.06	1.11E-07
0.08	1.20E-07
0.1	1.47E-07
0.15	2.38E-07
0.2	3.34E-07
0.3	5.56E-07
0.4	7.69E-07
0.5	9.09E-07
0.6	1.14E-06
0.8	1.47E-06
1.	1.79E-06
1.5	2.44E-06
2.	3.03E-06
3.	4.00E-06
4.	4.76E-06
5.	5.56E-06
6.	6.25E-06
8.	7.69E-06
10.	9.09E-06

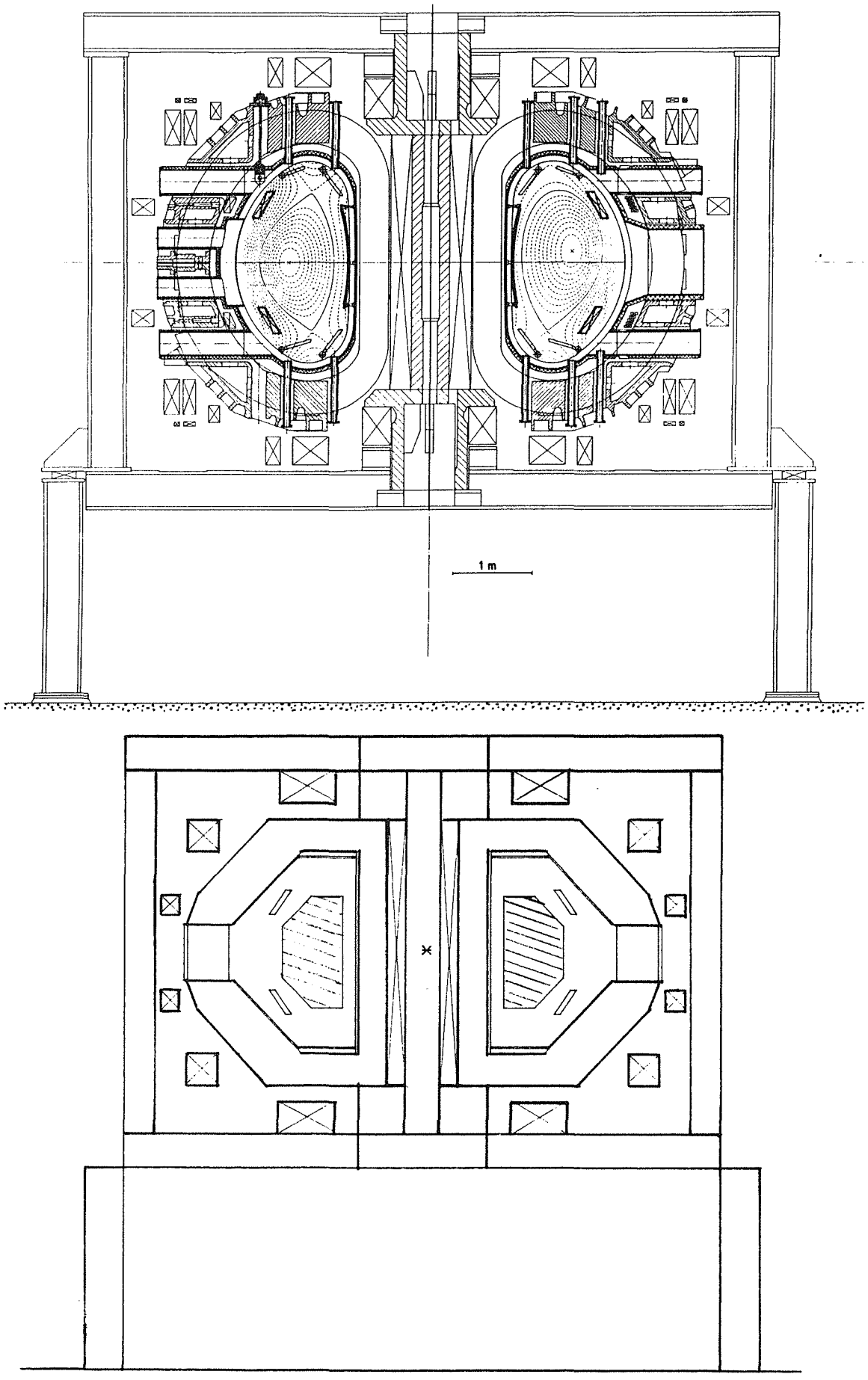
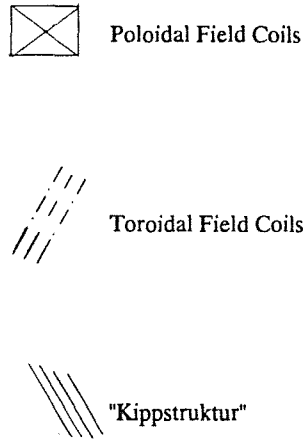
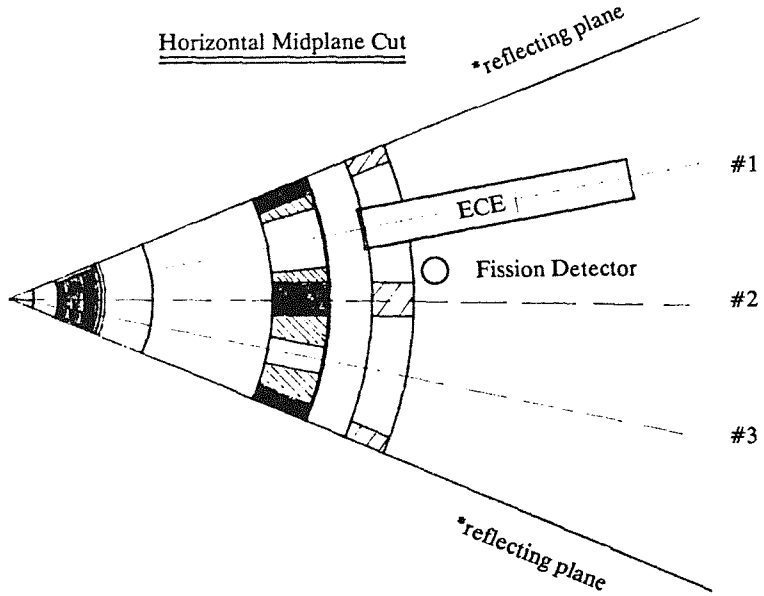
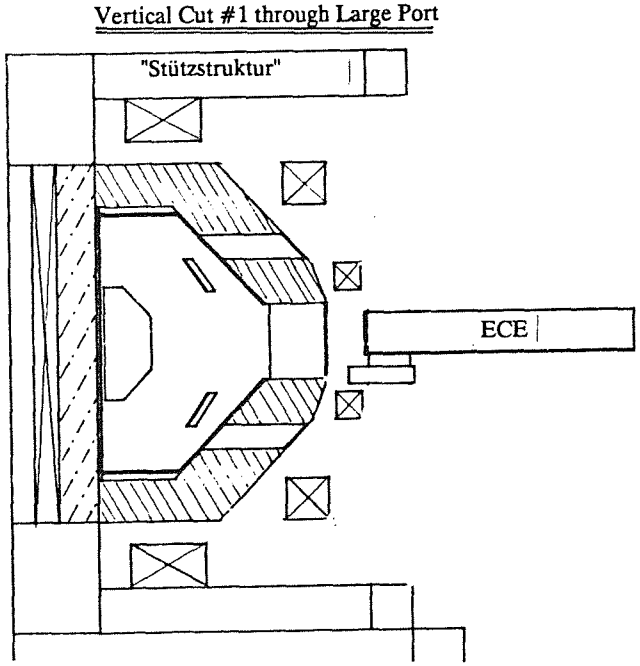


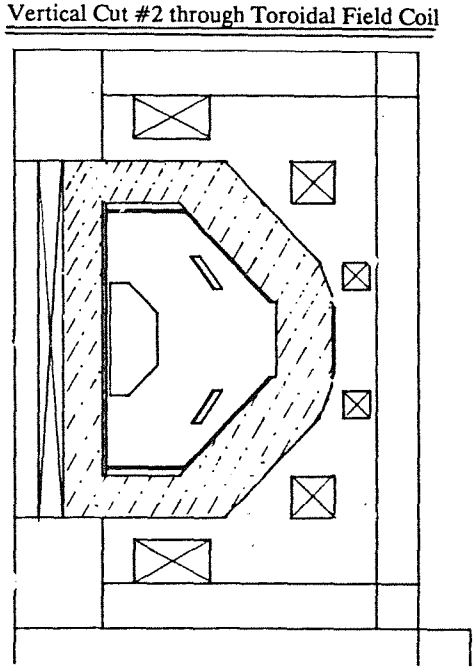
Fig.1 Vertical Cuts of the ASDEX-Upgrade Tokamak

and the Homogenized MCNP Model AUG01









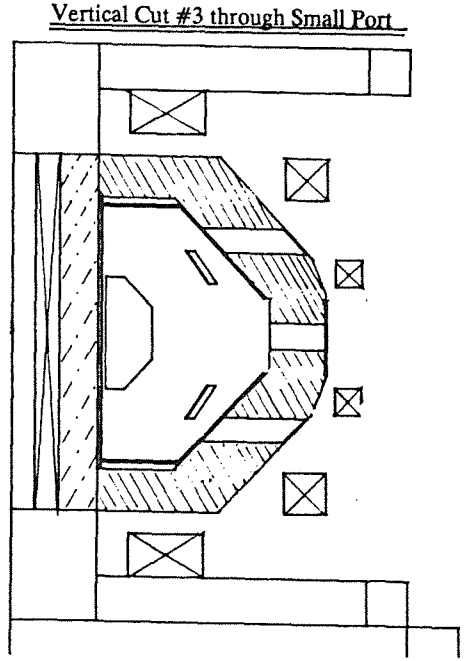


Fig.2 Graphs of the AUG03 Octant Model from Different Views

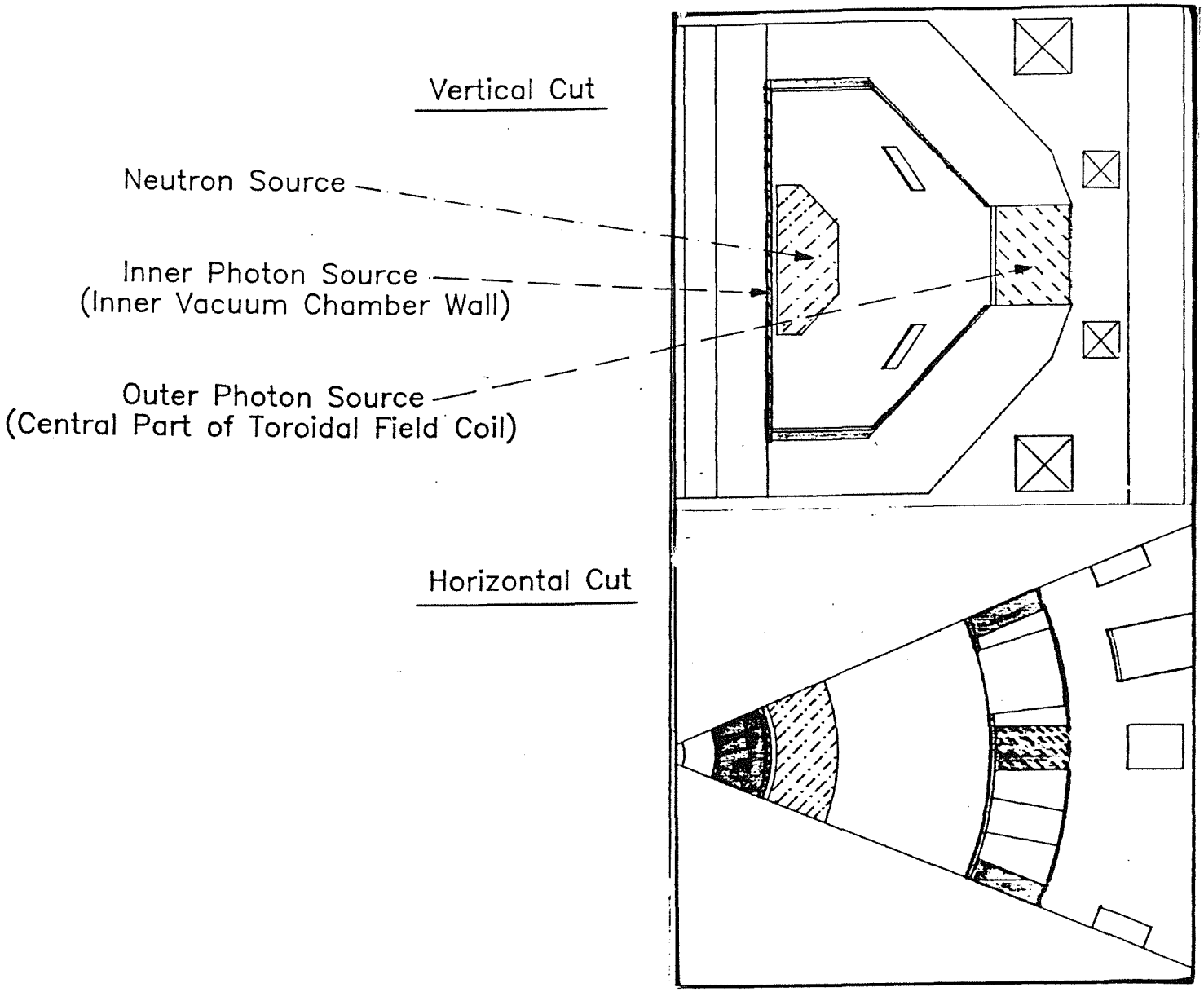


Fig.3 Locations of Volumetric Neutron and Photon Sources

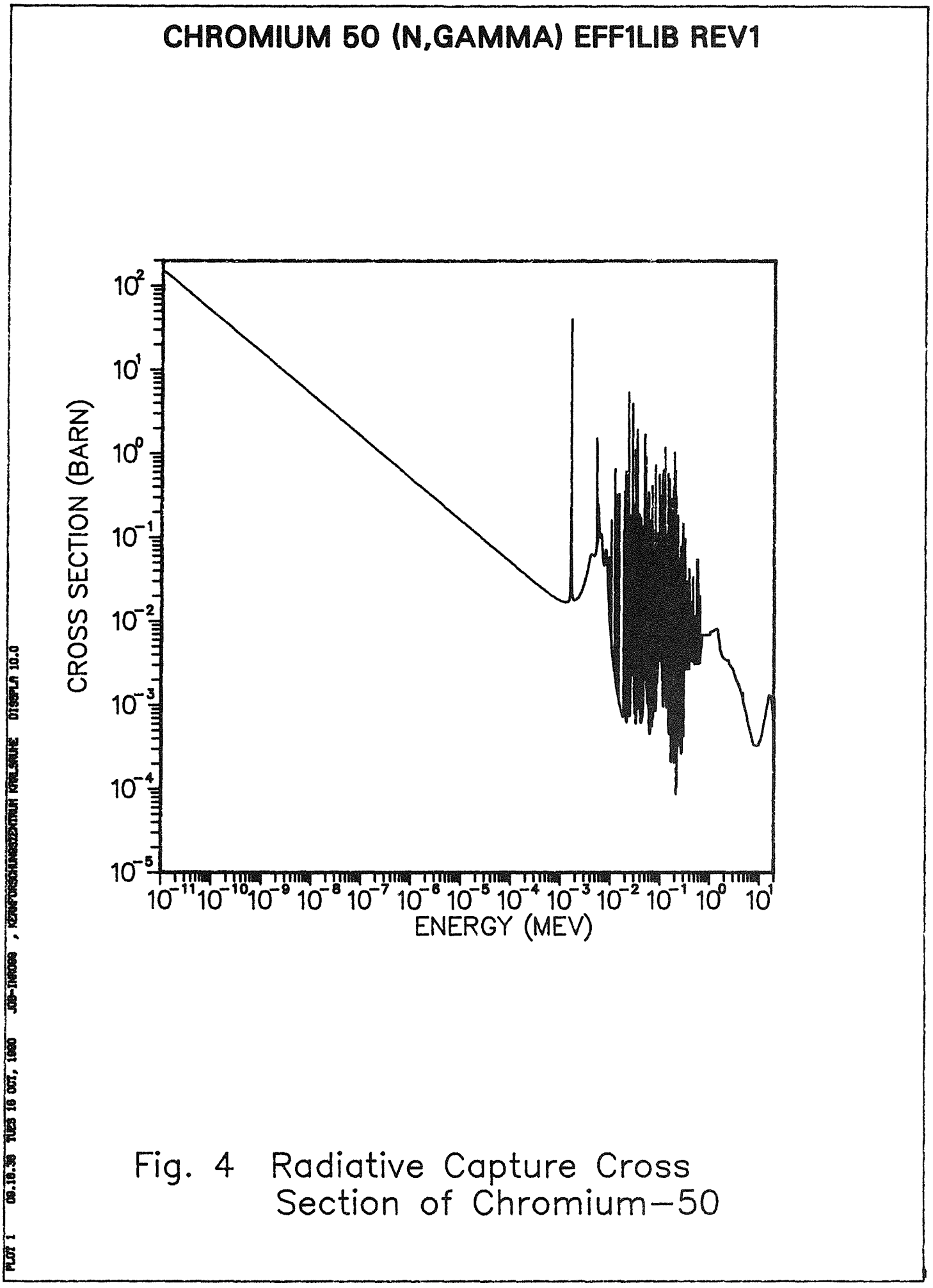


Fig. 4 Radiative Capture Cross Section of Chromium–50

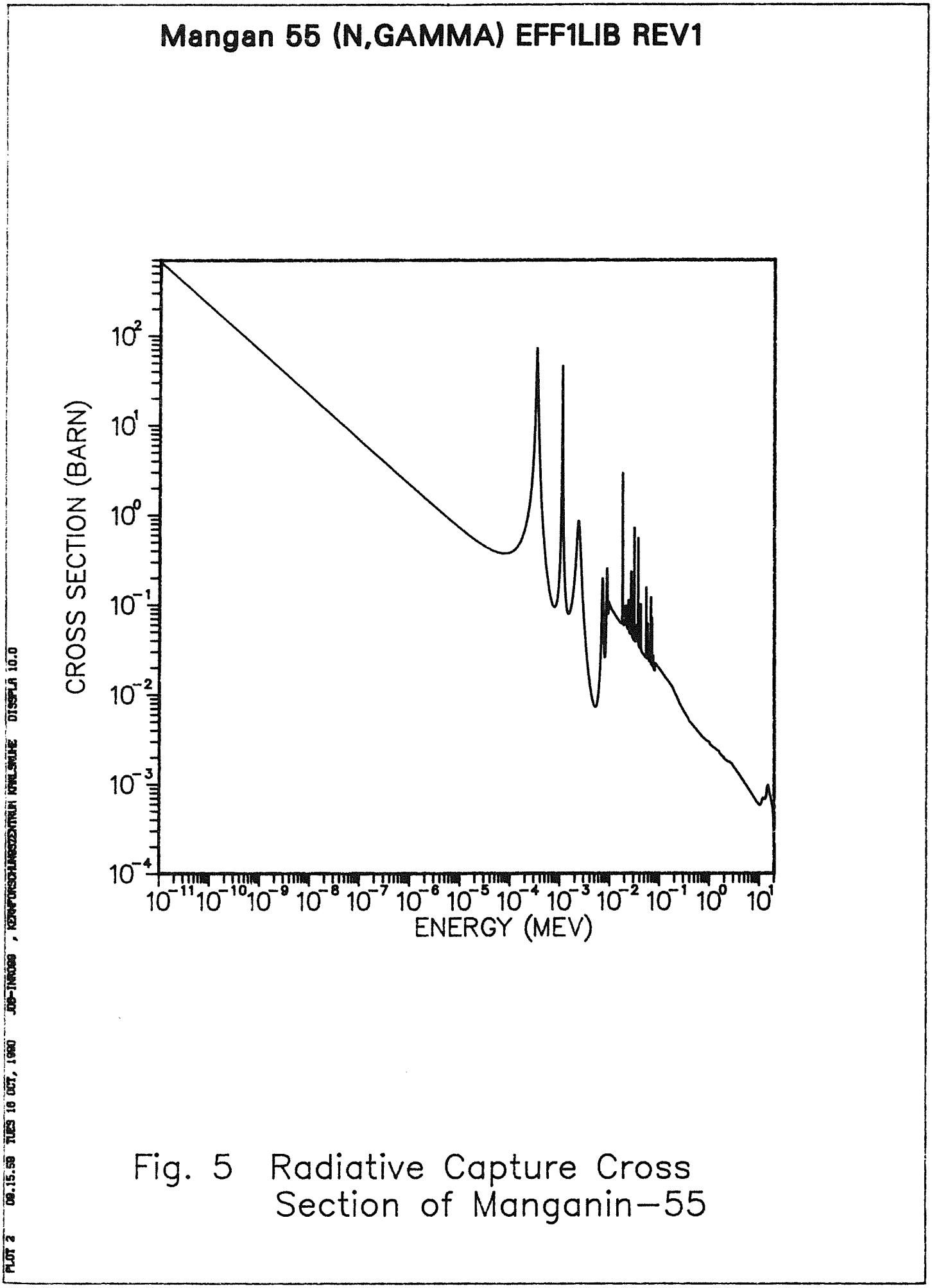


Fig. 5 Radiative Capture Cross Section of Manganin–55

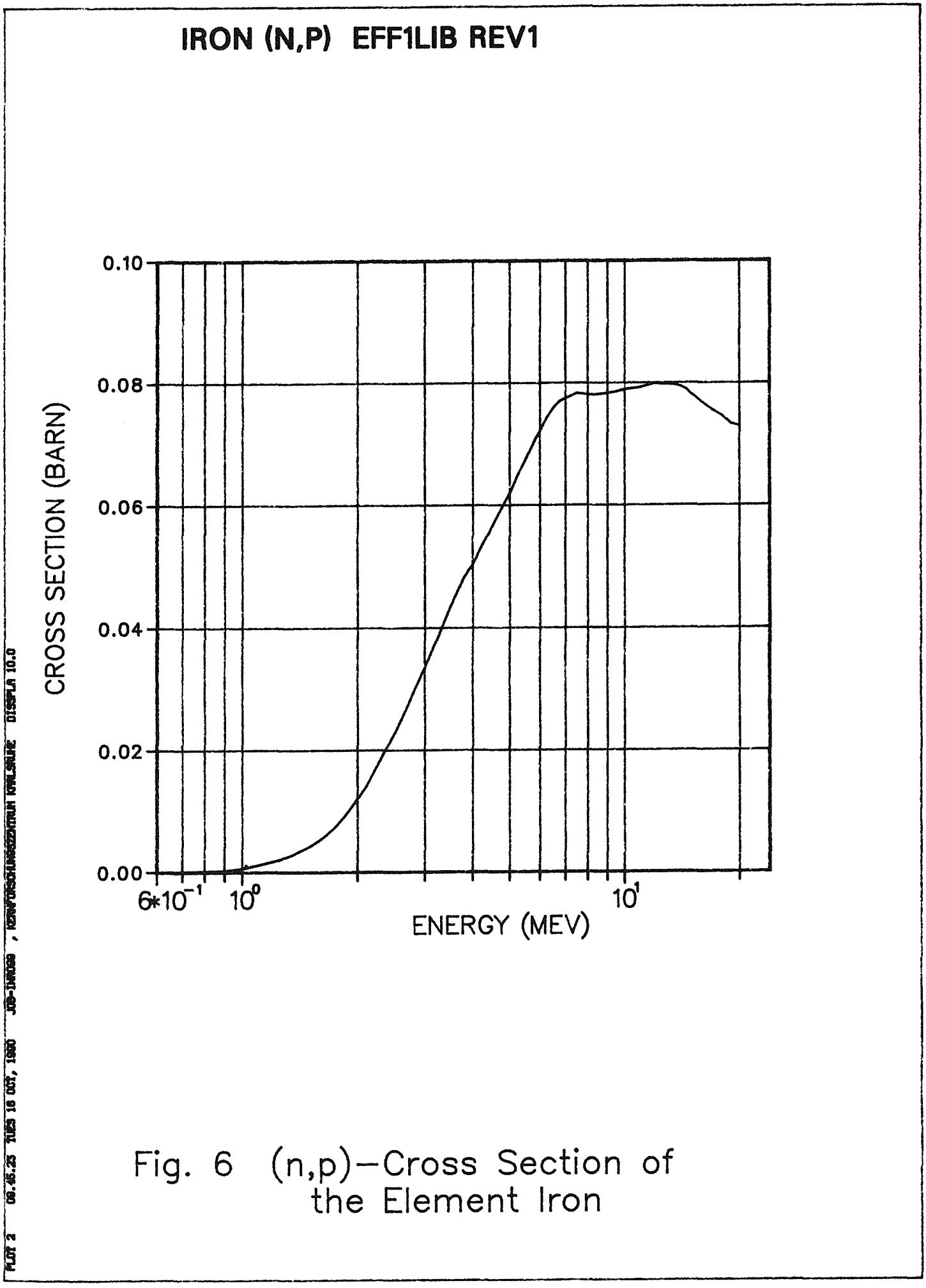


Fig. 6 (n,p)–Cross Section of the Element Iron

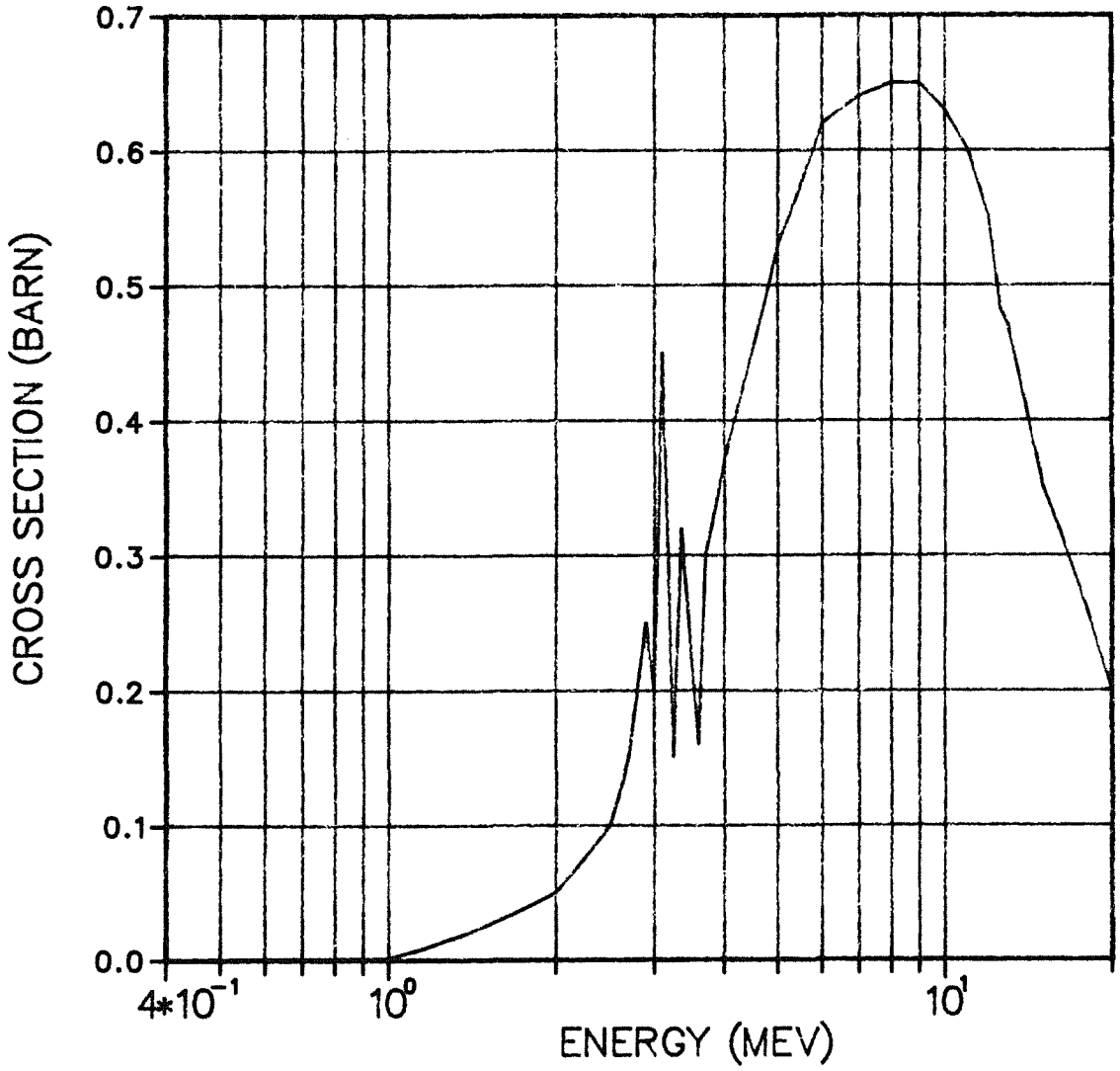


Fig. 7 (n,p)–Cross Section of the Isotope Nickel–58

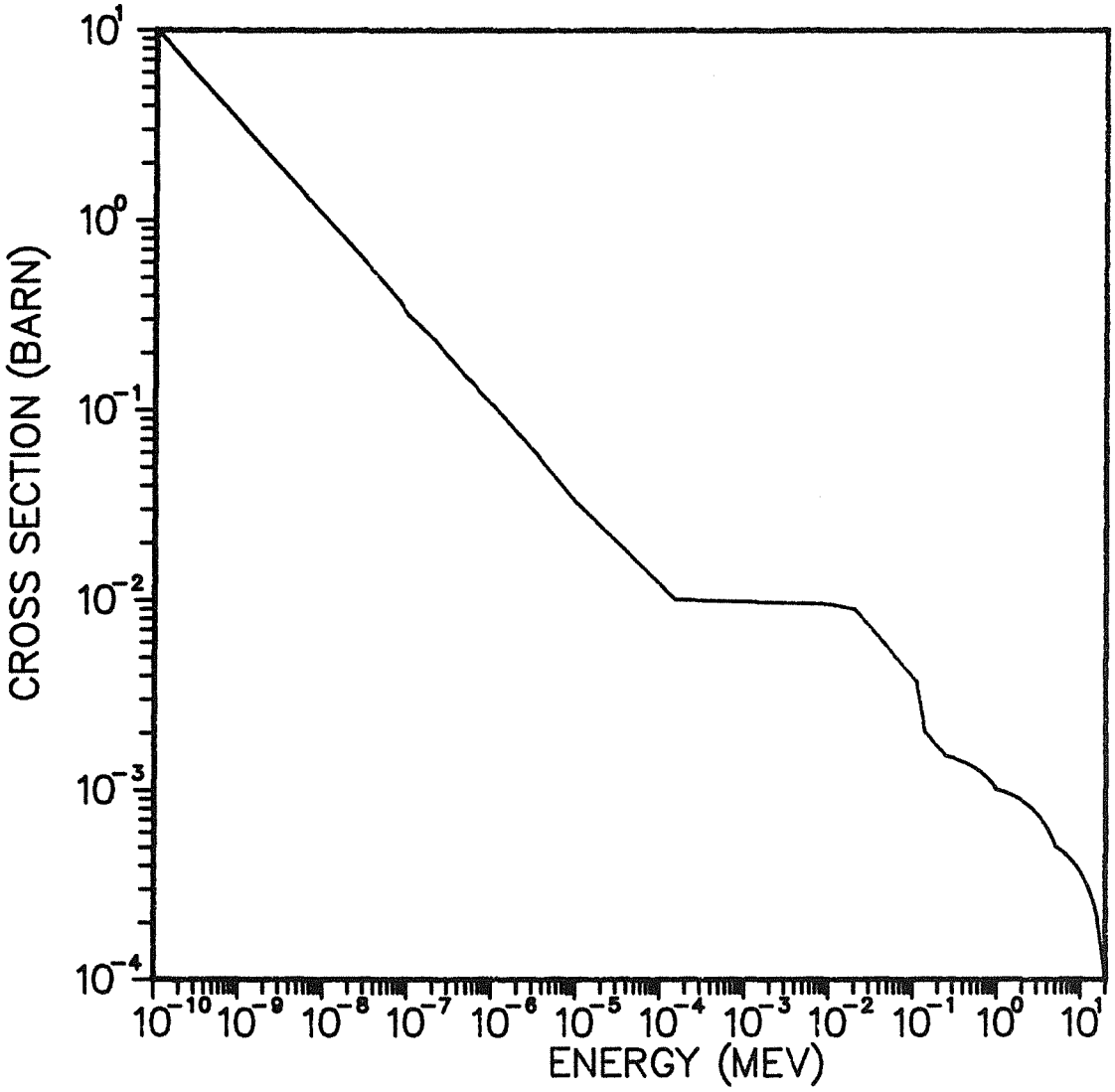


Fig. 8 Radiative Capture Cross Section of Argon—40

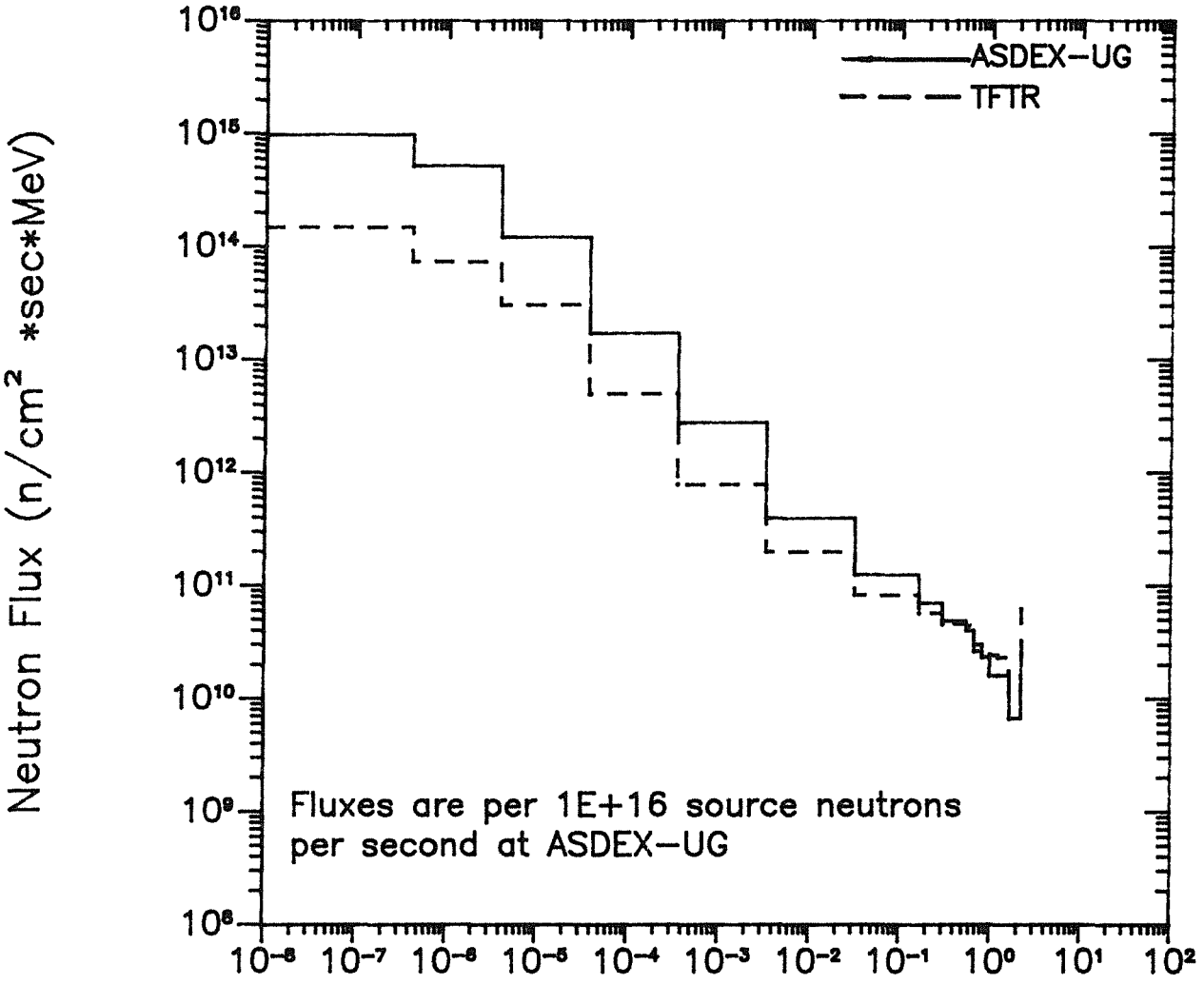


Fig.9 Neutron Flux at the Vacuum Vessel for 2.45 MeV d–d–Neutrons (for Comparison the TFTR Data /5/ are shown, normalized to the ASDEX–UG Data)

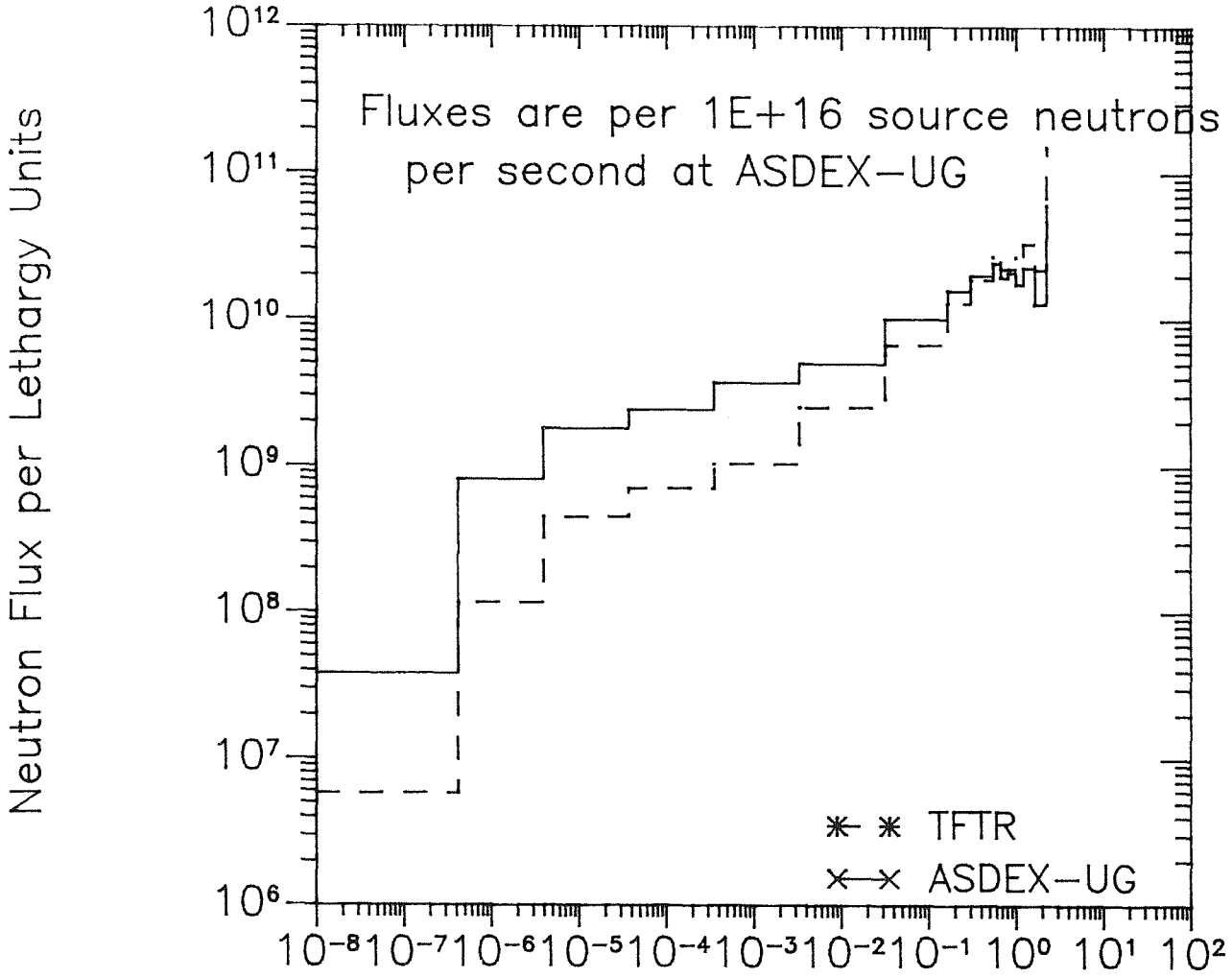


Fig.9a Neutron Flux per Lethargy Units at the Vacuum Vessel for d–d–Neutrons (for Comparison the TFTR Data /5/ are shown, normalized to the ASDEX–UG Data)

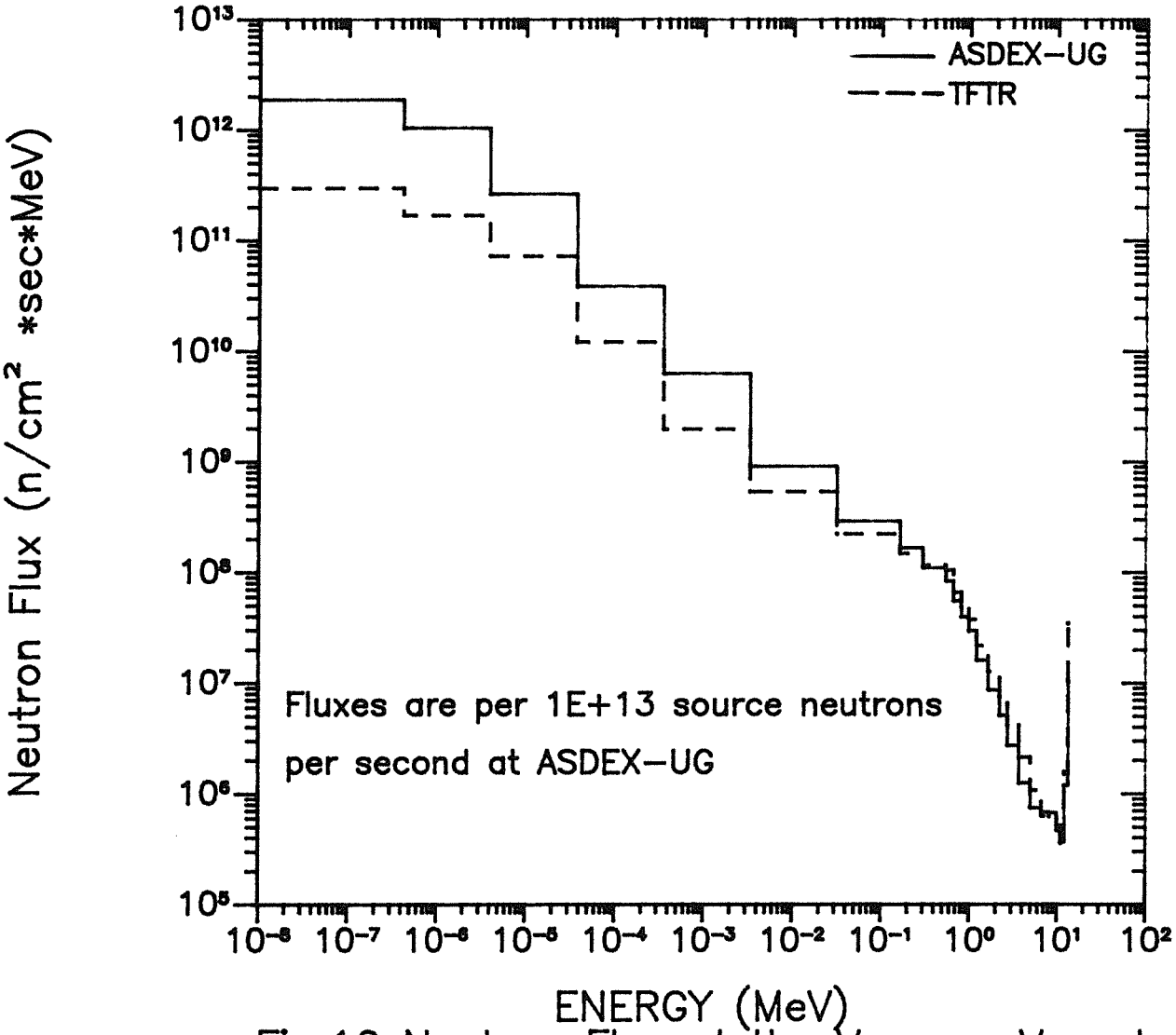


Fig.10 Neutron Flux at the Vacuum Vessel for 14.7 MeV d–t–Neutrons (for Comparison the TFTR Data /5/ are shown, normalized to the ASDEX–UG Data)

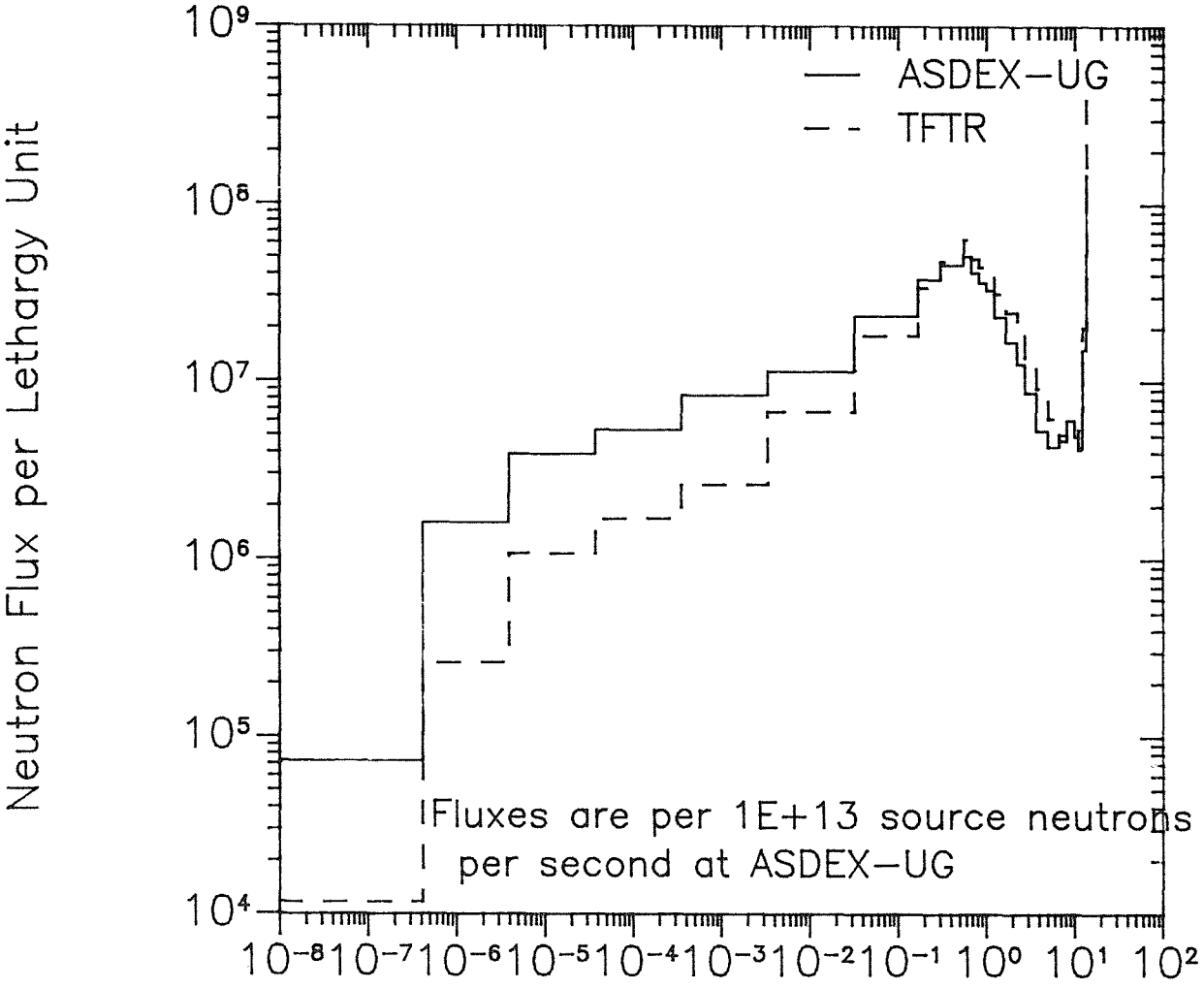


Fig.10a Neutron Flux per Lethargy Units at the Vacuum Vessel for d–t–Source Neutrons [for Comparison the TFTR Data /5/ are shown, normalized to the ASDEX–UG Data]

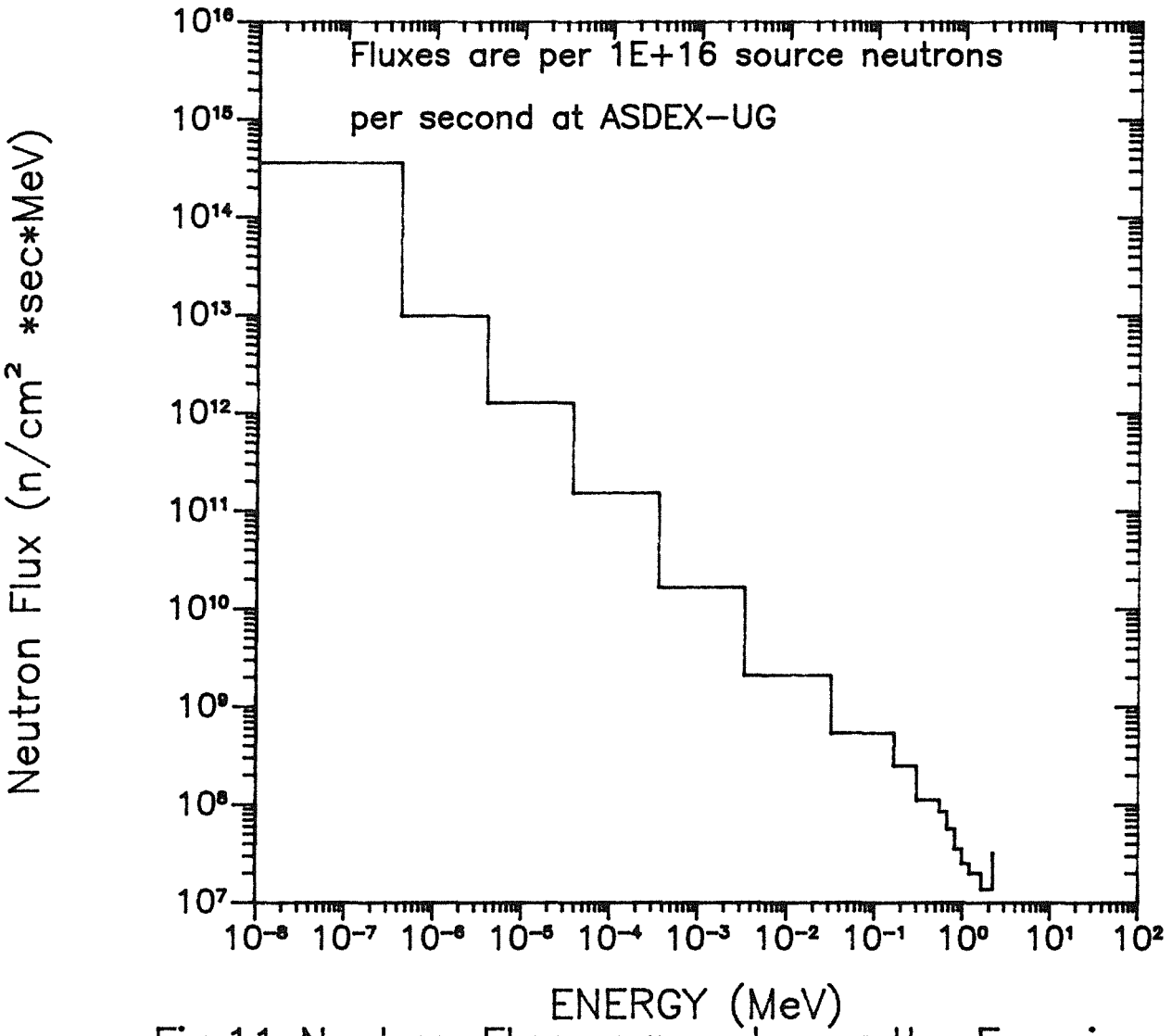


Fig.11 Neutron Flux,averaged over the Experimental Hall for 2.45 MeV d–d–Source Neutrons

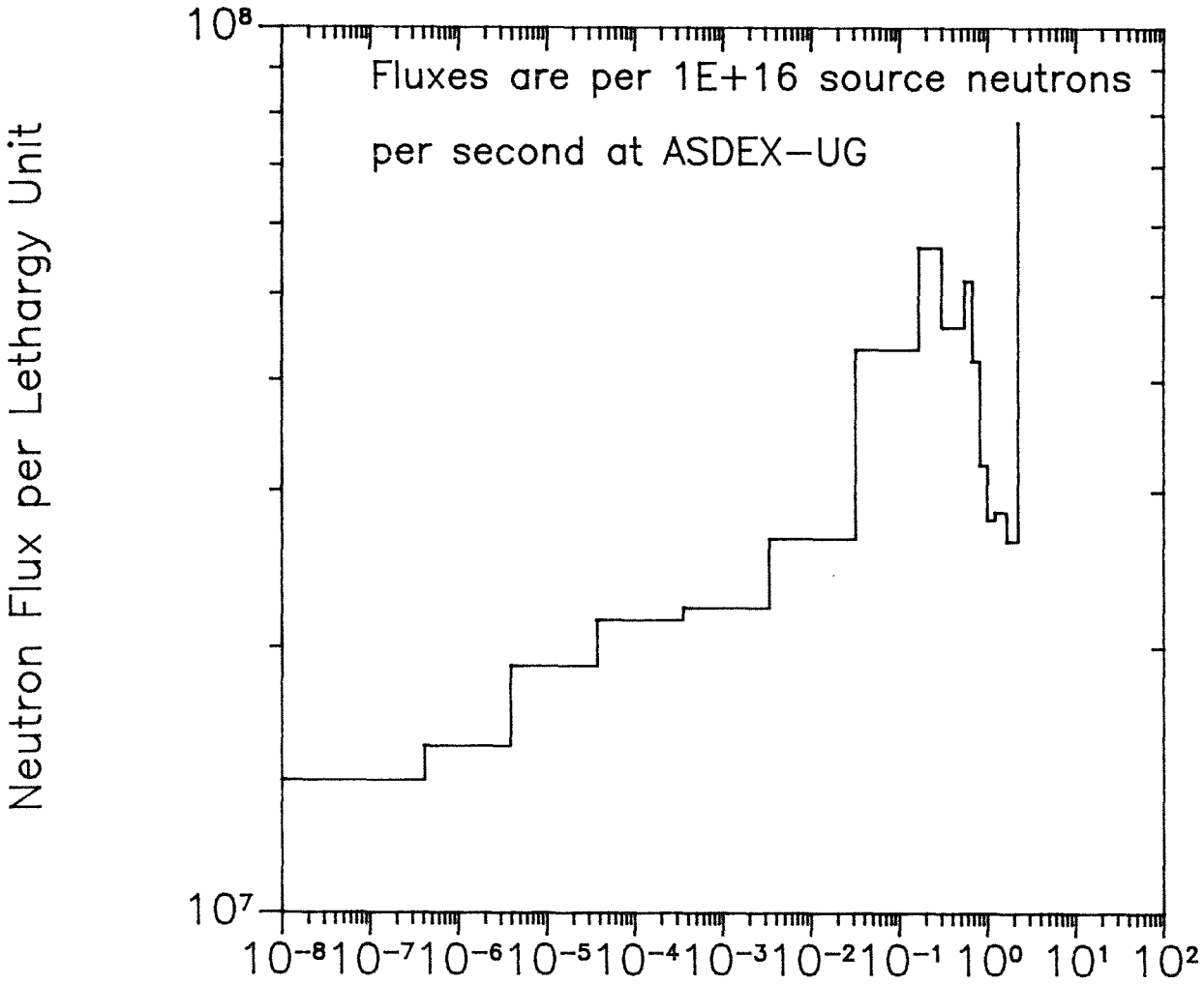


Fig.11a Neutron Flux per Lethargy Units in the Experiment Hall for d–d–Source Neutrons

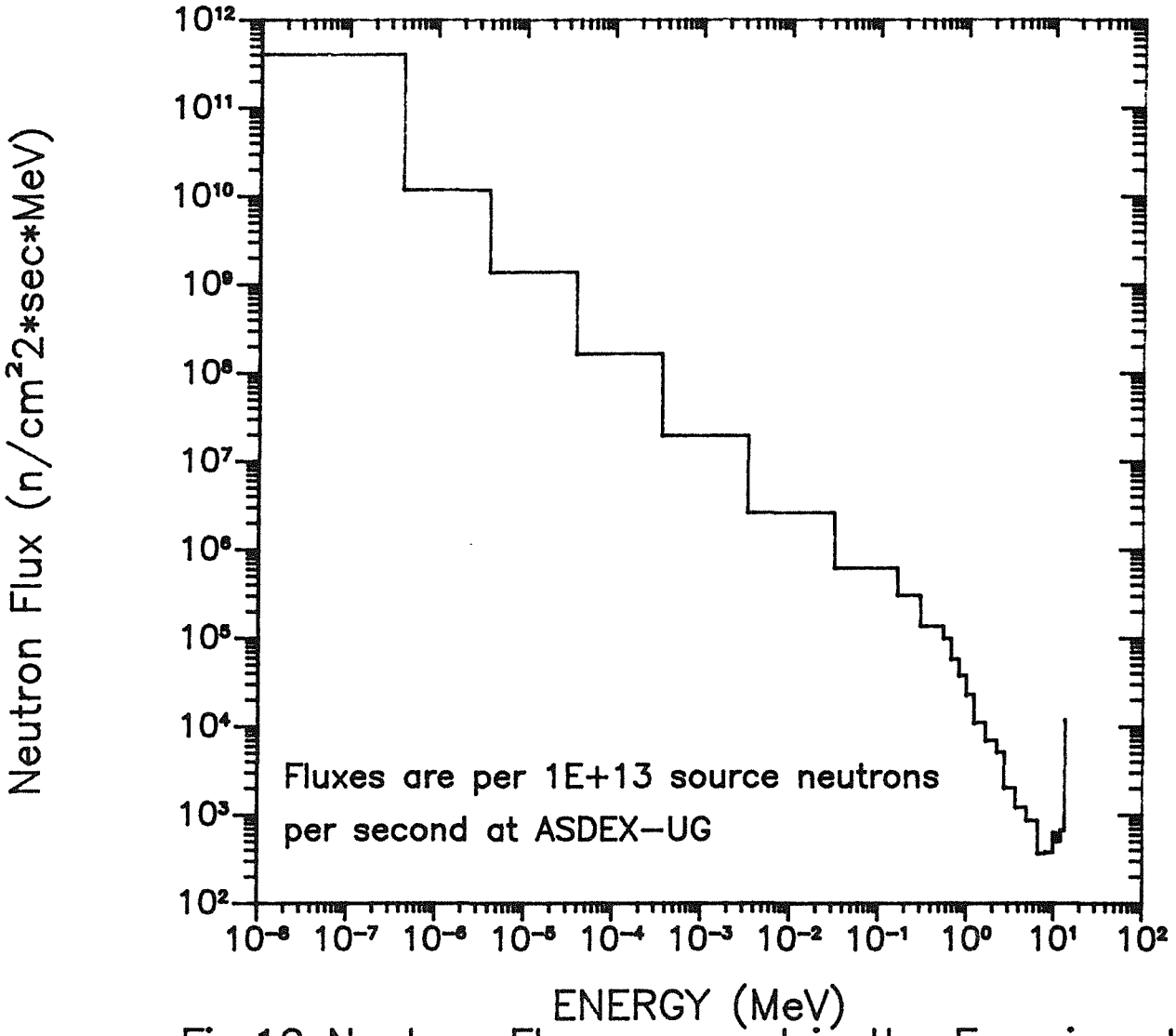


Fig.12 Neutron Flux,averaged in the Experimental Hall for 14.7 MeV d–t–Source Neutrons

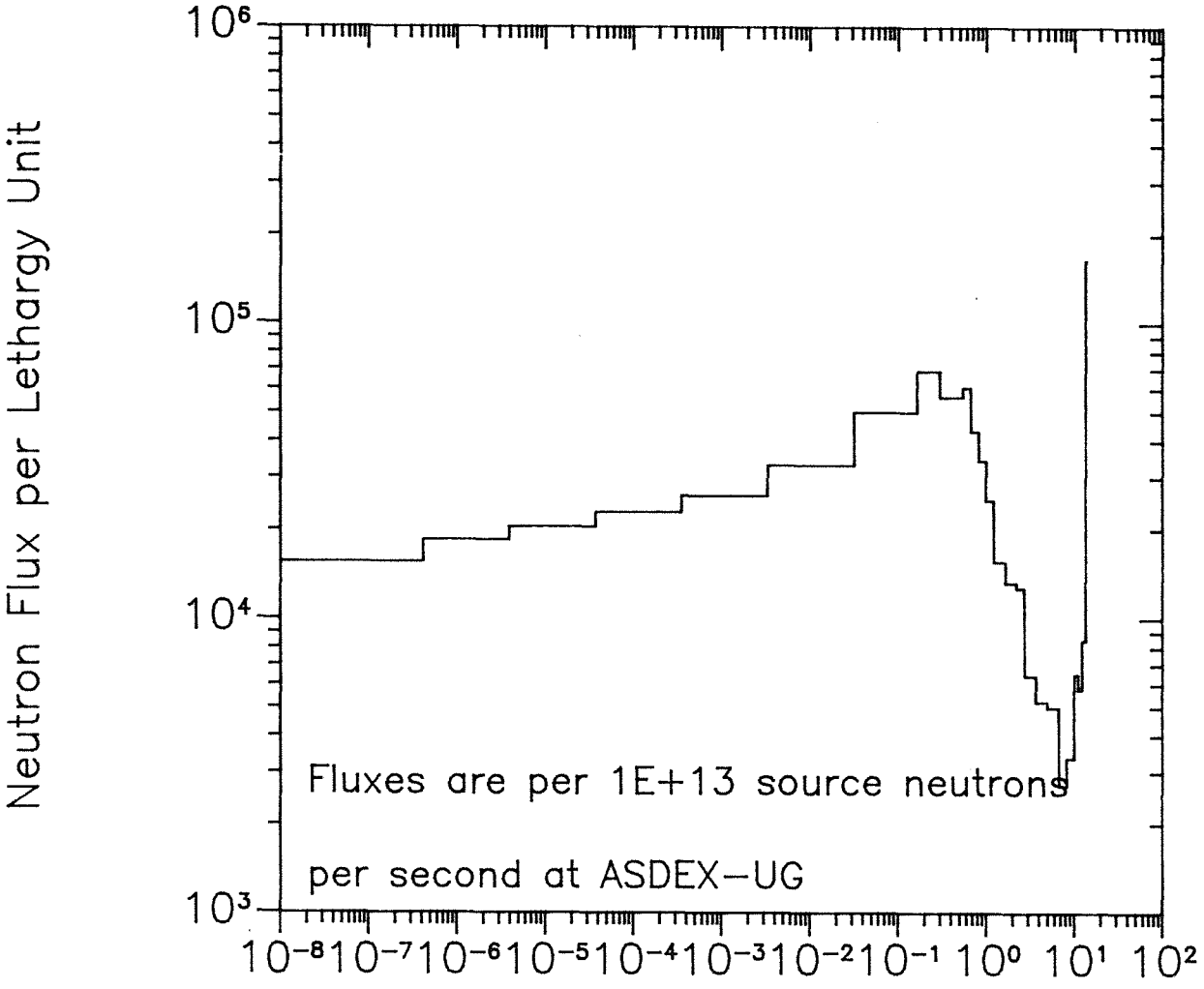


Fig.12a Neutron Flux per Lethargy Units in the Experiment Hall for d–t–Source Neutrons