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MEASUREMENT OF DOUBLE DIFFERENTIAL NEUTRON EMISSION CROSS SECTIONS AT 14.1 MEV FOR TI, MO AND SN

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Measurement of Double Differential Neutron Emission Cross Sections at 14.1 MeV for Ti, Mo and Sn

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To provide accurate experimental data of double differential neutron emission cross sections at 14.1 MeV which are required for the fusion reactor technology, measurements using the neutron TOF spectrometer at OKTAVIAN have been carried out in these three years under the Research-in-Trust of JAERI. This report describes the results in the third year, for Ti, Mo and Sn.

Data were obtained at 15-16 angle-points in the LAB system for each element and angle-integrated neutron emission spectra were deduced. Angle-differential cross sections were also deduced for elastic and resolved discrete inelastic scatterings. Graphs are given for double differential neutron emission cross sections. Graphs and tables are given for angle-integrated neutron emission spectra and angle-differential cross sections.

Results for Ti and Mo are comparewd with the JENDL-3 data, and disagreements in the 7-13 MeV region are pointed out. Results for Sn are compared with the ENDL-75 data.

This report is written by summarizing the study implemented under the Research-in-Trust in 1989 fiscal year from the Japan Atomic Energy Research Institute.

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Keywords : Double Differential Neutron Emission Cross Section, 14.1 MeV, TOF Measurement, Ti, Mo, Sn, JENDL-3

Ti, Mo, Snの 14.1 MeVにおける中性子放出二重微分断面積の測定

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（1990年11月16日受理）

核融合炉研究開発に必要な中性子生成の二重微分断面積の14.1MeVにおける精度良いデータをうるために，オクタビアンのＴＯＦスペクトロメータを用いて，ここ３年間測定を行なってきた。この報告は，最終年度に行なったTi，Mo，Sn の結果について述べる。ＤＤＸデータは，実験室系の15－16角度点について測定し，角度積分して中性子放出スペクトルが求められた。また，弾性散乱と分離非弾性散乱について角度微分断面積もえられた。

ＴｉとMoの結果は，ＪＥＮＤＬ－３のデータと比較され，７－13MeVの領域で不一致があることがわかった。Ｓｎの結果は，ＥＮＤＬ－75のデータと比較された。

本報告書は，日本原子力研究所から平成元年度委託研究で行なわれた成果をまとめたものである。
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1. Introduction

The data base of double differential neutron emission cross sections is useful to assess theoretical nuclear models currently being used in evaluation works of fusion nuclear data, which are required for the nuclear design of Tokamak devices like ITER. Ti and Sn are constituents of super conductors like NbTi and Nb_3Sn. Mo is considered to be used as coating material of diverters. Double differential neutron emission data at 14.1 MeV for these elements are of interest for the estimation of the displacement damages and the kerma factors.

Using the high resolution neutron TOF spectrometer at OKTAVIAN, double differential neutron emission cross sections at 14.1 MeV have been measured for many elements[1-3] since 1983. Under the support of JAERI, the autors have carried out experiments for B-10, B-11, Bi-209, Ca, Mn, Co and W[2,3]. In the present report, results are given for Ti, Mo and Sn.

2. Experimental

The experimental method is described in detail elsewhere[4]. A brief description is given in the following.

The D-T neutron source facility (OKTAVIAN) was operated in pulse mode. The pulse width was 1.8 ns at FWHM and the repetition frequency was 1 MHz. The neutron TOF spectrometer was set along the 85 degree line to the OKTAVIAN beam line and had 8.3 m long flight path. An NE213 detector of 25 cm diameter and 10 cm thickness was set inside a heavy shield at the end of the flight path. The double gain n-gamma discrimination circuit was applied to cover a recoil proton dynamic range of 0.5 MeV to 15 MeV.

The scattering sample (Ti, Mo or Sn) was set along the arc, radially distant by 17 cm from the tritium target. To change the scattering angle, we moved the sample along the arc. Variation of incident neutron energy according to the change of scattering angle was so small that the source energy was regarded as monochromatic (14.1±0.2 MeV). Samples were made of cylindrical metal rods (3 cm in diameter and 7 cm long).

To obtain absolute values of double differential cross sections, a polyethylene sample of 1.5 cm diameter and 5 cm length was used as a reference

scatterer to measure elastically scattered neutron peaks by the H(n,n) reaction at 5 angles from 20 to 50 degree. Absolute efiiciency of the NE213 detector was calibrated using these polyethylene data and the differential H(n,n) cross sections of ENDF/B-V. The low energy part (less than 7 MeV) of the efficiency curve was obtained by the TOF experiment using Cf-252 neutron source. Two efficiency curves were normalized in the 5-7 MeV region.

The method of data processing is described in detail elsewhere[4].To make corrections for multiple scatterings and attenuations, the MUSCC3 code[5] was used by adopting JENDL-3 data[6] for Ti and Mo, and ENDL-75 data for Sn[7].

3. Results

3.1 DDX (double differential cross section)

Obtained double differential neutron emission cross sections for Ti are shown in Fig.T-1 through Fig.T-15, compared with JENDL-3 data. Data for Mo are shown in Fig.M-1 through Fig.M-16, compared with JENDL-3 data. Data for Sn are shown in Fig.S-1 through Fig.S-16, compared with ENDL-75 data.

Numerical data tables of these data will be published in OKTAVIAN Report.

3.2 EDX (angle-integrated neutron emission spectrum)

Measured DDX data at the laboratory angles were converted to those at the center-of-mass system, which were integrated over the CMS angle to deduce EDX data. EDX data in the LAB system were also derived.

Results for Ti are shown in Figs.T-16 and T-17, and in Table 4. Results for Mo are shown in Figs.M-17 and M-18, and in Table 5. Results for Sn are shown in Figs.S-17 and S-18, and in Table 6.

3.3 ADX (angle-differential cross section)

Nemerical data sre presented for elastic and some resolved angular distributions in Table 1,2 and 3. Resolved data for Ti are for elastic scattering (Fig.T-18), discrete inelastic scattering within a level bin of 0.16-1.794 MeV (Fig.T-19, upper), discrete inelastic scattering of 2.01-2.793 MeV level (Fig.T-19, lower) and discrete inelastic scattering of 3.508-4.16 MeV level

(Fig.T-20).

ADX data for Mo are obtained for elastic scattering (Fig.M-19), discrete inelastic scattering of 1.4-3.4 MeV level (Fig.M-20, upper) and (n,2n) reaction (Fig.M-20, lower).

ADX data for Sn are obtained for elastic scattering (Fig.S-19) and discrete inelastic scattering of 1.9-3.1 MeV level (Fig.S-20).

4. Discussions

From comparisons of DDX data for Ti between the present measurements and the JENDL-3 data, we can say that disagreements are seen in the 3-15 MeV region. In the 1-6 MeV region of Ex (excitation energy), the experiment shows structures probably due to the direct processes and the JENDL-3 data do not reproduce the DDX spectra. Discussions should be similar to the case of Mo.

Comparing all the data of DDX, EDX and ADX for Mo, between the present measurement and the JENDL-3 data, we can say the following;

1) The JENDL-3 evaluation is good in the secondary energy region less than 3 MeV. Almost complete agreements are seen in EDX.
2) JENDL-3 overestimates differential elastic scattering cross sections in the scattering angle region larger than 40 degree, while good agreements are obtained in forward angles less than 40 degree.
3) Though the evaluation is made for the discrete inelastic scattering cross sections of Ex = 3-4 MeV, JENDL-3 gives several orders of magnitude smaller values.
4) Neutron emission cross sections of JENDL-3 in the 4-13 MeV region are very underestimated. Choice of calculational parameters for the pre-equilibrium process should be reconsidered, and the use of DWUCK-4 code[8] for many discrete levels of direct processes is needed. The combinational use of EGNASH[9], DWUCK-4 code and the Kalbach-Mann systematics[10] is desired to reproduce the measured DDX spectra.
5) Measured angle-differential cross sections of (n,2n) reaction show slight forward enhancement. Probably due to this fact, the JENDL-3 data slightly overestimate the measured data in the backward angles.

No evaluations are given for Sn, in JENDL-3. The presently measured data are compared with the ENDL-75 data, which show overall fairly good agreement except the energy region where the measured data show "structures".
In future evaluation works for JENDL-upgrade, the combinational use of DWUCK4, EGNASH and the Kalbach-Mann systematics is recommended.

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Table 1 Partial differential cross sections for titanium at 14.1 MeV

θ_{LAB} (deg)	elastic		Q=-0.16～-1.8MeV		Q=-2.0～-2.1MeV		Q=-3.5～-4.2MeV	
	dσ/dΩ (b/sr)	error	dσ/dΩ (b/sr)	error	dσ/dΩ (b/sr)	error	dσ/dΩ (b/sr)	error
15	3.62E-3	1.1E-4	——	——	——	——	7.99E-4	1.4E-4
20	2.13E-3	6.4E-5	——	——	——	——	5.05E-4	9.1E-5
30	9.57E-4	2.9E-5	——	——	——	——	3.04E-4	5.5E-5
40	4.37E-4	1.3E-5	1.89-E4	4.7E-5	1.49E-4	4.5E-5	2.00E-4	3.6E-5
50	3.83E-4	1.5E-5	1.83E-4	4.6E-5	1.39E-4	4.2E-5	2.00E-4	3.6E-5
70	3.28E-4	1.3E-5	1.63E-4	4.1E-5	1.21E-4	4.2E-5	1.83E-4	3.3E-5
80	2.11E-4	6.3E-6	1.10E-4	2.8E-5	8.00E-5	2.4E-5	1.20E-4	2.4E-5
90	3.60E-4	1.1E-5	1.79E-4	4.5E-5	1.38E-4	4.8E-5	1.93E-4	3.5E-5
100	1.44E-4	4.3E-6	8.29E-5	2.1E-4	6.10E-5	1.8E-5	9.01E-5	1.8E-5
110	2.12E-4	6.4E-6	1.26E-4	3.3E-5	1.15E-4	4.0E-5	1.65E-4	3.0E-5
120	2.18E-4	6.5E-6	1.54E-4	3.9E-5	1.26E-4	4.4E-5	1.83E-4	3.3E-5
130	1.85E-4	5.6E-6	1.19E-4	3.0E-5	1.07E-4	3.7E-5	1.62E-4	2.9E-5
140	1.93E-4	5.8E-6	1.23E-4	3.2E-5	1.15E-4	4.0E-5	1.74E-4	3.1E-5
150	2.39E-4	7.2E-6	1.56E-4	4.4E-5	1.44E-4	5.0E-5	2.34E-4	5.6E-5
160	4.12E-4	1.2E-5	2.83E-4	8.0E-5	3.00E-4	1.2E-4	4.72E-4	1.1E-4
σ_{Total}(b)	9.01E-1	4.5E-2	7.09E-2	2.1E-2	2.55E-2	9.7E-3	7.22E-2	1.8E-2

Table 2 Partial differential cross sections for molybdenum at 14.1 MeV

θ_{LAB} (deg)	elastic		Q =-1.4～-3.4MeV		(n , 2n)	
	dσ/dΩ (b/sr)	error	dσ/dΩ (b/sr)	error	dσ/dΩ (b/sr)	error
15	3.95E+0	1.2E-1	——	—	1.95E-1	1.2E-2
20	1.74E+0	5.2E-2	——	—	1.78E-1	1.1E-2
30	4.59E-1	1.4E-2	——	—	1.85E-1	1.1E-2
40	2.20E-2	6.6E-3	9.84E-3	3.0E-3	1.82E-1	1.1E-2
50	3.15E-2	9.5E-4	9.61E-3	2.4E-3	1.68E-1	1.0E-2
60	3.03E-2	9.1E-4	9.07E-3	1.8E-3	1.79E-1	1.1E-2
70	3.04E-2	1.2E-3	7.64E-3	1.5E-3	1.55E-1	1.2E-2
80	1.26E-2	3.8E-4	6.00E-3	1.2E-3	1.58E-1	9.5E-3
90	7.98E-3	2.4E-4	5.31E-3	1.1E-3	1.49E-1	9.0E-3
100	1.33E-2	4.0E-4	4.95E-3	9.9E-4	1.52E-1	9.1E-3
110	1.49E-2	4.5E-4	3.88E-3	7.8E-4	1.39E-1	8.4E-3
120	6.92E-3	2.1E-4	3.56E-3	8.9E-4	1.33E-1	8.0E-3
130	7.90E-3	2.4E-4	4.15E-3	8.3E-4	1.38E-1	8.3E-3
140	7.90E-3	2.4E-4	3.60E-3	1.1E-3	1.63E-1	9.8E-3
150	7.64E-3	3.1E-4	4.54E-3	1.4E-3	1.47E-1	1.0E-2
160	1.47E-2	5.9E-4	4.45E-3	1.3E-3	1.47E-1	1.0E-2
σ_{Total}(b)	2.51E+0	2.5E-1	8.00E-2	1.6E-2	1.95E+0	1.4E-1

Table 3 Partial differential cross sections for tin at En=14.1 MeV

θ_{LAB} (deg)	elastic		Q =-1.4～-3.4MeV	
	dσ/dΩ (b/sr)	error	dσ/dΩ (b/sr)	error
15	3.37E+0	1.0E-1	——	—
20	1.68E+0	5.0E-2	——	—
30	3.44E-1	1.0E-2	1.22E-2	2.4E-3
40	6.20E-2	1.9E-3	9.63E-3	1.9E-3
50	8.01E-2	2.4E-3	8.56E-3	1.7E-3
60	3.63E-2	1.1E-3	5.71E-3	1.1E-3
70	1.93E-2	5.8E-4	5.98E-3	1.2E-3
80	1.37E-2	4.1E-4	4.88E-3	9.8E-4
90	1.36E-2	6.8E-4	4.55E-3	9.1E-4
100	1.71E-2	5.1E-4	3.54E-3	7.1E-4
110	1.05E-2	3.2E-4	2.94E-3	5.9E-4
120	5.19E-3	1.6E-4	2.55E-3	5.1E-4
130	5.43E-3	1.6E-4	3.00E-3	6.0E-4
140	9.84E-3	3.0E-4	2.19E-3	5.5E-4
150	7.96E-3	2.4E-4	2.21E-3	6.6E-4
160	8.11E-3	2.4E-4	4.04E-3	1.2E-3
σ_{Total}(b)	——	——	6.73E-2	1.7E-2

Table 4 Angle-integrated neutron emission spectra for Ti

```
SUBENTRY        00025003      900201                                          00025003     1
BIB                    2           8                                          00025003     2
COMMENT      TWO DATA SETS ARE GIVEN.                                         00025003     3
             DATA OBTAINED FROM RAW DDX DATA , IN LEFT HAND SIDE.             00025003     4
             DATA OBTAINED FROM CORRECTED DDX DATA WITH MUSCC3 CODE           00025003     5
             IN RIGHT HAND SIDE.                                              00025003     6
REACTION     (22-TI-0(N,SCT),,,DE) SECONDARY NEUTRON SPECTRUM                 00025003     7
             IN THE CENTER-OF-MASS SYSTEM                                     00025003     8
ENDBIB                 8                                                      00025003     9
COMMON                 1           5                                          00025003    10
EN                                                                            00025003    11
MEV                                                                           00025003    12
   14.10000                                                                   00025003    13
ENDCOMMON              5                                                      00025003    14
DATA                   6          69                                          00025003    15
E-MAX        E-MIN        DATA        DATA-ERR    DATA        DATA-ERR        00025003    16
MEV          MEV          B/MEV       B/MEV       B/MEV       B/MEV           00025003    17
   14.60000   14.40000   5.35E-02    4.59E-03    6.39E-02    4.77E-0300025003    18
   14.40000   14.20000   1.49E-01    3.51E-03    1.68E-01    3.73E-0300025003    19
   14.20000   14.00000   4.06E-01    2.30E-03    4.63E-01    2.39E-0300025003    20
   14.00000   13.80000   8.06E-01    2.69E-03    9.21E-01    2.88E-0300025003    21
   13.80000   13.60000   1.03E+00    2.81E-03    1.17E+00    3.06E-0300025003    22
   13.60000   13.40000   9.03E-01    2.63E-03    1.03E+00    2.89E-0300025003    23
   13.40000   13.20000   6.08E-01    2.24E-03    6.88E-01    2.46E-0300025003    24
   13.20000   13.00000   3.61E-01    1.82E-03    4.07E-01    1.98E-0300025003    25
   13.00000   12.80000   2.13E-01    1.51E-03    2.40E-01    1.66E-0300025003    26
   12.80000   12.60000   1.52E-01    1.36E-03    1.71E-01    1.50E-0300025003    27
   12.60000   12.40000   1.17E-01    1.26E-03    1.32E-01    1.40E-0300025003    28
   12.40000   12.20000   8.38E-02    1.14E-03    9.39E-02    1.26E-0300025003    29
   12.20000   12.00000   5.90E-02    1.05E-03    6.56E-02    1.15E-0300025003    30
   12.00000   11.80000   4.27E-02    9.84E-04    4.76E-02    1.07E-0300025003    31
   11.80000   11.60000   3.47E-02    9.31E-04    3.86E-02    1.00E-0300025003    32
   11.60000   11.40000   3.37E-02    9.00E-04    3.75E-02    9.78E-0400025003    33
   11.40000   11.20000   3.41E-02    8.83E-04    3.79E-02    9.67E-0400025003    34
   11.20000   11.00000   3.18E-02    8.52E-04    3.53E-02    9.37E-0400025003    35
   11.00000   10.80000   2.89E-02    8.23E-04    3.22E-02    9.06E-0400025003    36
   10.80000   10.60000   3.00E-02    8.25E-04    3.35E-02    9.12E-0400025003    37
   10.60000   10.40000   3.62E-02    8.49E-04    4.03E-02    9.41E-0400025003    38
   10.40000   10.20000   4.23E-02    8.76E-04    4.72E-02    9.74E-0400025003    39
   10.20000   10.00000   4.28E-02    8.74E-04    4.76E-02    9.71E-0400025003    40
   10.00000    9.80000   3.84E-02    8.51E-04    4.27E-02    9.45E-0400025003    41
    9.80000    9.60000   3.46E-02    8.44E-04    3.85E-02    9.36E-0400025003    42
    9.60000    9.40000   3.23E-02    8.34E-04    3.59E-02    9.26E-0400025003    43
    9.40000    9.20000   3.15E-02    8.40E-04    3.46E-02    9.24E-0400025003    44
    9.20000    9.00000   3.01E-02    8.37E-04    2.99E-02    8.45E-0400025003    45
    9.00000    8.80000   3.05E-02    8.45E-04    2.95E-02    8.41E-0400025003    46
    8.80000    8.60000   2.97E-02    8.51E-04    2.86E-02    8.49E-0400025003    47
    8.60000    8.40000   2.83E-02    8.45E-04    2.79E-02    8.55E-0400025003    48
    8.40000    8.20000   2.98E-02    8.60E-04    2.98E-02    8.70E-0400025003    49
    8.20000    8.00000   3.11E-02    8.64E-04    3.14E-02    8.80E-0400025003    50
    8.00000    7.80000   3.49E-02    8.74E-04    3.53E-02    8.91E-0400025003    51
    7.80000    7.60000   3.61E-02    8.86E-04    3.69E-02    9.10E-0400025003    52
    7.60000    7.40000   3.87E-02    8.96E-04    3.98E-02    9.23E-0400025003    53
    7.40000    7.20000   4.15E-02    9.03E-04    4.28E-02    9.31E-0400025003    54
    7.20000    7.00000   4.41E-02    9.05E-04    4.58E-02    9.36E-0400025003    55
    7.00000    6.80000   4.45E-02    9.09E-04    4.67E-02    9.43E-0400025003    56
    6.80000    6.60000   4.58E-02    9.09E-04    4.76E-02    9.42E-0400025003    57
    6.60000    6.40000   4.75E-02    9.02E-04    4.95E-02    9.38E-0400025003    58
    6.40000    6.20000   5.00E-02    9.05E-04    5.19E-02    9.43E-0400025003    59
    6.20000    6.00000   5.31E-02    9.18E-04    5.53E-02    9.59E-0400025003    60
    6.00000    5.80000   5.62E-02    9.27E-04    5.88E-02    9.70E-0400025003    61
    5.80000    5.60000   6.06E-02    9.38E-04    6.36E-02    9.85E-0400025003    62
    5.60000    5.40000   6.42E-02    9.43E-04    6.75E-02    9.92E-0400025003    63
    5.40000    5.20000   6.82E-02    9.63E-04    7.17E-02    1.01E-0300025003    64
    5.20000    5.00000   7.48E-02    9.84E-04    7.89E-02    1.04E-0300025003    65
    5.00000    4.80000   8.01E-02    9.98E-04    8.44E-02    1.05E-0300025003    66
    4.80000    4.60000   8.80E-02    1.01E-03    9.25E-02    1.06E-0300025003    67
    4.60000    4.40000   9.44E-02    1.03E-03    9.90E-02    1.08E-0300025003    68
    4.40000    4.20000   1.01E-01    1.05E-03    1.06E-01    1.10E-0300025003    69
    4.20000    4.00000   1.11E-01    1.08E-03    1.16E-01    1.13E-0300025003    70
    4.00000    3.80000   1.19E-01    1.10E-03    1.24E-01    1.15E-0300025003    71
    3.80000    3.60000   1.28E-01    1.13E-03    1.34E-01    1.18E-0300025003    72
    3.60000    3.40000   1.38E-01    1.16E-03    1.44E-01    1.21E-0300025003    73
    3.40000    3.20000   1.49E-01    1.19E-03    1.55E-01    1.23E-0300025003    74
    3.20000    3.00000   1.66E-01    1.24E-03    1.71E-01    1.28E-0300025003    75
    3.00000    2.80000   1.80E-01    1.31E-03    1.85E-01    1.35E-0300025003    76
    2.80000    2.60000   1.96E-01    1.37E-03    2.01E-01    1.41E-0300025003    77
    2.60000    2.40000   2.24E-01    1.46E-03    2.28E-01    1.49E-0300025003    78
    2.40000    2.20000   2.56E-01    1.56E-03    2.58E-01    1.57E-0300025003    79
    2.20000    2.00000   2.74E-01    1.64E-03    2.73E-01    1.64E-0300025003    80
    2.00000    1.80000   3.06E-01    1.7[illegible]E-03    3.03E-01    1.70E-0300025003    81
    1.80000    1.60000   3.41E-01    1.8[illegible]E-03    3.33E-01    1.82E-0300025003    82
    1.60000    1.40000   3.89E-01    2.14E-03    3.77E-01    2.07E-0300025003    83
    1.40000    1.20000   4.46E-01    2.75E-03    4.27E-01    2.62E-0300025003    84
    1.20000    1.00000   4.59E-01    4.20E-03    4.32E-01    3.96E-0300025003    85
    1.00000    0.80000   4.09E-01    6.52E-03    3.78E-01    6.04E-0300025003    86
                                                                              00025003    87
ENDDATA               73                                                      0002500399999
ENDSUBENTRY           88                                                      0002599999999
ENDENTRY               3
```

Table 5 Angle-integrated neutron emission spectra for Mo

```
SUBENTRY      00024003     900201                                    00024003     1
BIB                2            8                                    00024003     2
COMMENT     TWO DATA SETS ARE GIVEN.                                  00024003     3
            DATA OBTAINED FROM RAW DDX DATA , IN LEFT HAND SIDE.      00024003     4
            DATA OBTAINED FROM CORRECTED DDX DATA WITH MUSCC3 CODE    00024003     5
            IN RIGHT HAND SIDE.                                       00024003     6
REACTION    (42-MO-0(N,SCT),,,DE) SECONDARY NEUTRON SPECTRUM          00024003     7
            IN THE CENTER-OF-MASS SYSTEM                              00024003     8
ENDBIB                8                                               00024003     9
COMMON                1            5                                  00024003    10
EN                                                                    00024003    11
MEV                                                                   00024003    12
   14.10000                                                           00024003    13
ENDCOMMON             5                                               00024003    14
DATA                  6           68                                  00024003    15
E-MAX       E-MIN       DATA        DATA-ERR    DATA        DATA-ERR  00024003    16
MEV         MEV         B/MEV       B/MEV       B/MEV       B/MEV     00024003    17
   14.80000    14.60000   5.62E-02    3.09E-03    5.60E-02    3.52E-0300024003    18
   14.60000    14.40000   3.17E-01    4.19E-03    3.56E-01    4.85E-0300024003    19
   14.40000    14.20000   7.94E-01    2.60E-03    1.03E+00    3.05E-0300024003    20
   14.20000    14.00000   1.85E+00    3.30E-03    2.40E+00    3.97E-0300024003    21
   14.00000    13.80000   2.52E+00    3.56E-03    3.26E+00    4.35E-0300024003    22
   13.80000    13.60000   2.11E+00    3.15E-03    2.70E+00    3.81E-0300024003    23
   13.60000    13.40000   1.18E+00    2.37E-03    1.50E+00    2.79E-0300024003    24
   13.40000    13.20000   5.23E-01    1.76E-03    6.47E-01    1.98E-0300024003    25
   13.20000    13.00000   2.51E-01    1.42E-03    3.04E-01    1.55E-0300024003    26
   13.00000    12.80000   1.56E-01    1.24E-03    1.88E-01    1.38E-0300024003    27
   12.80000    12.60000   1.06E-01    1.12E-03    1.30E-01    1.27E-0300024003    28
   12.60000    12.40000   7.68E-02    1.04E-03    9.56E-02    1.19E-0300024003    29
   12.40000    12.20000   6.34E-02    1.00E-03    7.84E-02    1.16E-0300024003    30
   12.20000    12.00000   5.89E-02    9.83E-04    7.14E-02    1.13E-0300024003    31
   12.00000    11.80000   6.32E-02    9.76E-04    7.45E-02    1.11E-0300024003    32
   11.80000    11.60000   6.40E-02    9.64E-04    7.46E-02    1.11E-0300024003    33
   11.60000    11.40000   5.96E-02    9.37E-04    6.97E-02    1.08E-0300024003    34
   11.40000    11.20000   5.41E-02    8.99E-04    6.35E-02    1.05E-0300024003    35
   11.20000    11.00000   5.03E-02    8.71E-04    5.99E-02    1.03E-0300024003    36
   11.00000    10.80000   4.41E-02    8.39E-04    5.26E-02    9.97E-0400024003    37
   10.80000    10.60000   3.70E-02    8.15E-04    4.46E-02    9.72E-0400024003    38
   10.60000    10.40000   3.02E-02    7.94E-04    3.65E-02    9.50E-0400024003    39
   10.40000    10.20000   2.87E-02    7.86E-04    3.47E-02    9.41E-0400024003    40
   10.20000    10.00000   2.94E-02    7.82E-04    3.59E-02    9.42E-0400024003    41
   10.00000     9.80000   2.91E-02    7.94E-04    3.55E-02    9.55E-0400024003    42
    9.80000     9.60000   2.78E-02    7.84E-04    3.36E-02    9.42E-0400024003    43
    9.60000     9.40000   2.81E-02    7.86E-04    3.32E-02    9.25E-0400024003    44
    9.40000     9.20000   2.77E-02    7.91E-04    2.42E-02    7.69E-0400024003    45
    9.20000     9.00000   2.76E-02    7.95E-04    2.23E-02    7.64E-0400024003    46
    9.00000     8.80000   2.85E-02    8.03E-04    2.44E-02    7.78E-0400024003    47
    8.80000     8.60000   2.74E-02    8.12E-04    2.45E-02    7.95E-0400024003    48
    8.60000     8.40000   2.81E-02    8.17E-04    2.53E-02    8.05E-0400024003    49
    8.40000     8.20000   2.81E-02    8.30E-04    2.60E-02    8.30E-0400024003    50
    8.20000     8.00000   3.12E-02    8.46E-04    2.93E-02    8.53E-0400024003    51
    8.00000     7.80000   3.07E-02    8.50E-04    2.96E-02    8.64E-0400024003    52
    7.80000     7.60000   2.98E-02    8.56E-04    2.93E-02    8.73E-0400024003    53
    7.60000     7.40000   3.32E-02    8.65E-04    3.29E-02    8.83E-0400024003    54
    7.40000     7.20000   3.53E-02    8.65E-04    3.47E-02    8.87E-0400024003    55
    7.20000     7.00000   3.65E-02    8.66E-04    3.70E-02    8.87E-0400024003    56
    7.00000     6.80000   3.70E-02    8.65E-04    3.77E-02    8.90E-0400024003    57
    6.80000     6.60000   3.93E-02    8.68E-04    4.02E-02    9.01E-0400024003    58
    6.60000     6.40000   4.25E-02    8.64E-04    4.31E-02    9.03E-0400024003    59
    6.40000     6.20000   4.47E-02    8.67E-04    4.59E-02    9.07E-0400024003    60
    6.20000     6.00000   4.58E-02    8.72E-04    4.76E-02    9.23E-0400024003    61
    6.00000     5.80000   4.84E-02    8.76E-04    5.11E-02    9.32E-0400024003    62
    5.80000     5.60000   4.94E-02    8.87E-04    5.26E-02    9.52E-0400024003    63
    5.60000     5.40000   5.22E-02    8.94E-04    5.63E-02    9.64E-0400024003    64
    5.40000     5.20000   5.83E-02    9.03E-04    6.33E-02    9.78E-0400024003    65
    5.20000     5.00000   6.28E-02    9.04E-04    6.83E-02    9.85E-0400024003    66
    5.00000     4.80000   6.85E-02    9.19E-04    7.50E-02    1.01E-0300024003    67
    4.80000     4.60000   7.61E-02    9.31E-04    8.39E-02    1.03E-0300024003    68
    4.60000     4.40000   8.33E-02    9.44E-04    9.31E-02    1.05E-0300024003    69
    4.40000     4.20000   9.44E-02    9.63E-04    1.06E-01    1.08E-0300024003    70
    4.20000     4.00000   1.04E-01    9.84E-04    1.18E-01    1.11E-0300024003    71
    4.00000     3.80000   1.16E-01    9.99E-04    1.32E-01    1.14E-0300024003    72
    3.80000     3.60000   1.28E-01    1.03E-03    1.47E-01    1.18E-0300024003    73
    3.60000     3.40000   1.45E-01    1.05E-03    1.67E-01    1.21E-0300024003    74
    3.40000     3.20000   1.67E-01    1.10E-03    1.93E-01    1.27E-0300024003    75
    3.20000     3.00000   1.95E-01    1.15E-03    2.25E-01    1.33E-0300024003    76
    3.00000     2.80000   2.22E-01    1.21E-03    2.57E-01    1.41E-0300024003    77
    2.80000     2.60000   2.60E-01    1.30E-03    2.99E-01    1.51E-0300024003    78
    2.60000     2.40000   3.09E-01    1.45E-03    3.54E-01    1.68E-0300024003    79
    2.40000     2.20000   3.64E-01    1.53E-03    4.18E-01    1.77E-0300024003    80
    2.20000     2.00000   4.21E-01    1.67E-03    4.85E-01    1.93E-0300024003    81
    2.00000     1.80000   4.83E-01    1.88E-03    5.56E-01    2.18E-0300024003    82
    1.80000     1.60000   5.60E-01    2.33E-03    6.43E-01    2.69E-0300024003    83
    1.60000     1.40000   6.99E-01    3.64E-03    8.00E-01    4.20E-0300024003    84
    1.40000     1.20000   7.26E-01    6.86E-03    8.30E-01    7.91E-0300024003    85
ENDDATA              72                                                 00024003    86
ENDSUBENTRY          87                                                 0002400399999
ENDENTRY              3                                                 0002499999999
```

Table 6 Angle-integrated neutron emission spectra for Sn

```
SUBENTRY        00026003      900401                                          00026003     1
BIB                    2           8                                          00026003     2
COMMENT      TWO DATA SETS ARE GIVEN.                                         00026003     3
             DATA OBTAINED FROM RAW DDX DATA , IN LEFT HAND SIDE.             00026003     4
             DATA OBTAINED FROM CORRECTED DDX DATA WITH MUSCC3 CODE           00026003     5
             IN RIGHT HAND SIDE.                                              00026003     6
REACTION     (50-SN-0(N,SCT)...DE) SECONDARY NEUTRON SPECTRUM                 00026003     7
             IN THE CENTER-OF-MASS SYSTEM                                     00026003     8
ENDBIB                 8                                                      00026003     9
COMMON                 1           5                                          00026003    10
EN                                                                            00026003    11
MEV                                                                           00026003    12
   14.10000                                                                   00026003    13
ENDCOMMON              5                                                      00026003    14
DATA                   6          70                                          00026003    15
E-MAX        E-MIN       DATA       DATA-ERR    DATA        DATA-ERR          00026003    16
MEV          MEV        B/MEV       B/MEV       B/MEV       B/MEV             00026003    17
   14.80000   14.60000   9.97E-02   3.34E-03   1.11E-01   3.58E-0300026003    18
   14.60000   14.40000   3.69E-01   4.14E-03   4.11E-01   4.18E-0300026003    19
   14.40000   14.20000   1.07E+00   4.00E-03   1.19E+00   4.20E-0300026003    20
   14.20000   14.00000   1.92E+00   5.02E-03   2.12E+00   5.29E-0300026003    21
   14.00000   13.80000   2.27E+00   5.00E-03   2.50E+00   5.24E-0300026003    22
   13.80000   13.60000   1.92E+00   4.50E-03   2.12E+00   4.72E-0300026003    23
   13.60000   13.40000   1.25E+00   3.67E-03   1.38E+00   3.82E-0300026003    24
   13.40000   13.20000   6.95E-01   2.91E-03   7.71E-01   3.02E-0300026003    25
   13.20000   13.00000   3.85E-01   2.38E-03   4.10E-01   2.40E-0300026003    26
   13.00000   12.80000   2.35E-01   2.08E-03   2.63E-01   2.19E-0300026003    27
   12.80000   12.60000   1.67E-01   1.91E-03   1.87E-01   2.03E-0300026003    28
   12.60000   12.40000   1.24E-01   1.77E-03   1.38E-01   1.88E-0300026003    29
   12.40000   12.20000   9.41E-02   1.64E-03   1.06E-01   1.76E-0300026003    30
   12.20000   12.00000   7.56E-02   1.56E-03   8.47E-02   1.68E-0300026003    31
   12.00000   11.80000   7.45E-02   1.52E-03   8.29E-02   1.64E-0300026003    32
   11.80000   11.60000   8.71E-02   1.52E-03   9.61E-02   1.64E-0300026003    33
   11.60000   11.40000   8.98E-02   1.51E-03   9.87E-02   1.64E-0300026003    34
   11.40000   11.20000   7.76E-02   1.44E-03   8.51E-02   1.57E-0300026003    35
   11.20000   11.00000   6.08E-02   1.35E-03   6.67E-02   1.47E-0300026003    36
   11.00000   10.80000   4.79E-02   1.29E-03   5.27E-02   1.40E-0300026003    37
   10.80000   10.60000   4.20E-02   1.26E-03   4.59E-02   1.36E-0300026003    38
   10.60000   10.40000   3.74E-02   1.24E-03   4.08E-02   1.35E-0300026003    39
   10.40000   10.20000   3.73E-02   1.24E-03   4.06E-02   1.35E-0300026003    40
   10.20000   10.00000   3.45E-02   1.22E-03   3.75E-02   1.33E-0300026003    41
   10.00000    9.80000   3.36E-02   1.21E-03   3.67E-02   1.32E-0300026003    42
    9.80000    9.60000   3.14E-02   1.20E-03   3.46E-02   1.32E-0300026003    43
    9.60000    9.40000   3.42E-02   1.22E-03   3.69E-02   1.32E-0300026003    44
    9.40000    9.20000   3.48E-02   1.23E-03   3.07E-02   1.20E-0300026003    45
    9.20000    9.00000   3.64E-02   1.23E-03   3.16E-02   1.20E-0300026003    46
    9.00000    8.80000   3.86E-02   1.25E-03   3.35E-02   1.22E-0300026003    47
    8.80000    8.60000   3.69E-02   1.27E-03   3.35E-02   1.24E-0300026003    48
    8.60000    8.40000   3.70E-02   1.29E-03   3.43E-02   1.26E-0300026003    49
    8.40000    8.20000   3.50E-02   1.29E-03   3.29E-02   1.27E-0300026003    50
    8.20000    8.00000   3.63E-02   1.30E-03   3.49E-02   1.29E-0300026003    51
    8.00000    7.80000   3.69E-02   1.30E-03   3.55E-02   1.30E-0300026003    52
    7.80000    7.60000   3.74E-02   1.30E-03   3.62E-02   1.30E-0300026003    53
    7.60000    7.40000   4.18E-02   1.31E-03   4.06E-02   1.32E-0300026003    54
    7.40000    7.20000   4.69E-02   1.32E-03   4.65E-02   1.32E-0300026003    55
    7.20000    7.00000   4.64E-02   1.31E-03   4.55E-02   1.31E-0300026003    56
    7.00000    6.80000   4.98E-02   1.30E-03   4.78E-02   1.29E-0300026003    57
    6.80000    6.60000   5.20E-02   1.30E-03   4.96E-02   1.30E-0300026003    58
    6.60000    6.40000   5.21E-02   1.31E-03   4.99E-02   1.30E-0300026003    59
    6.40000    6.20000   5.39E-02   1.32E-03   5.16E-02   1.31E-0300026003    60
    6.20000    6.00000   5.59E-02   1.32E-03   5.35E-02   1.32E-0300026003    61
    6.00000    5.80000   5.46E-02   1.33E-03   5.34E-02   1.34E-0300026003    62
    5.80000    5.60000   5.66E-02   1.35E-03   5.56E-02   1.36E-0300026003    63
    5.60000    5.40000   5.86E-02   1.36E-03   5.83E-02   1.39E-0300026003    64
    5.40000    5.20000   5.99E-02   1.39E-03   5.99E-02   1.42E-0300026003    65
    5.20000    5.00000   6.95E-02   1.41E-03   6.97E-02   1.44E-0300026003    66
    5.00000    4.80000   7.73E-02   1.44E-03   7.76E-02   1.46E-0300026003    67
    4.80000    4.60000   8.70E-02   1.47E-03   8.74E-02   1.51E-0300026003    68
    4.60000    4.40000   9.72E-02   1.51E-03   9.89E-02   1.57E-0300026003    69
    4.40000    4.20000   1.06E-01   1.54E-03   1.09E-01   1.60E-0300026003    70
    4.20000    4.00000   1.20E-01   1.59E-03   1.23E-01   1.66E-0300026003    71
    4.00000    3.80000   1.34E-01   1.64E-03   1.36E-01   1.70E-0300026003    72
    3.80000    3.60000   1.50E-01   1.70E-03   1.53E-01   1.75E-0300026003    73
    3.60000    3.40000   1.75E-01   1.76E-03   1.78E-01   1.82E-0300026003    74
    3.40000    3.20000   2.04E-01   1.85E-03   2.09E-01   1.92E-0300026003    75
    3.20000    3.00000   2.43E-01   1.96E-03   2.47E-01   2.01E-0300026003    76
    3.00000    2.80000   2.93E-01   2.10E-03   2.89E-01   2.09E-0300026003    77
    2.80000    2.60000   3.51E-01   2.28E-03   3.45E-01   2.27E-0300026003    78
    2.60000    2.40000   4.26E-01   2.52E-03   4.19E-01   2.52E-0300026003    79
    2.40000    2.20000   5.21E-01   2.63E-03   5.19E-01   2.64E-0300026003    80
    2.20000    2.00000   6.26E-01   2.83E-03   6.28E-01   2.87E-0300026003    81
    2.00000    1.80000   7.60E-01   3.12E-03   7.56E-01   3.13E-0300026003    82
    1.80000    1.60000   9.19E-01   3.43E-03   9.08E-01   3.43E-0300026003    83
    1.60000    1.40000   1.09E+00   3.91E-03   1.08E+00   3.89E-0300026003    84
    1.40000    1.20000   1.28E+00   4.59E-03   1.25E+00   4.56E-0300026003    85
    1.20000    1.00000   1.57E+00   7.17E-03   1.51E+00   7.13E-0300026003    86
    1.00000    0.80000   1.68E+00   8.41E-03   1.57E+00   7.94E-0300026003    87
                                                                  00026003    88
ENDDATA               74                                          0002600399999
ENDSUBENTRY           89                                          0002699999999
ENDENTRY               3
```

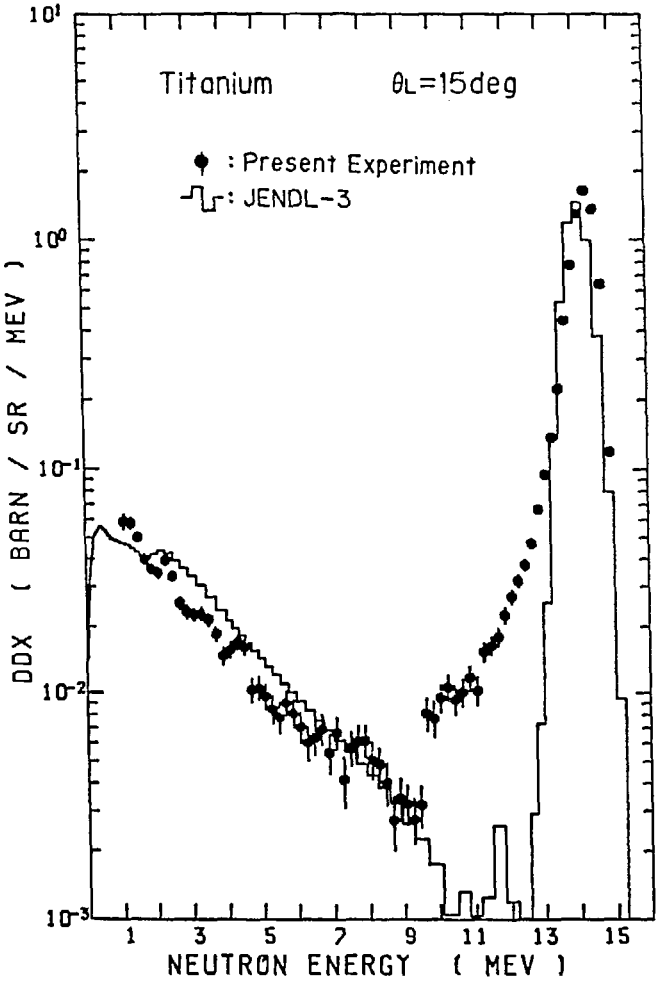

Fig.T-1 Double differential neutron emission cross sections at 15 deg, for Ti

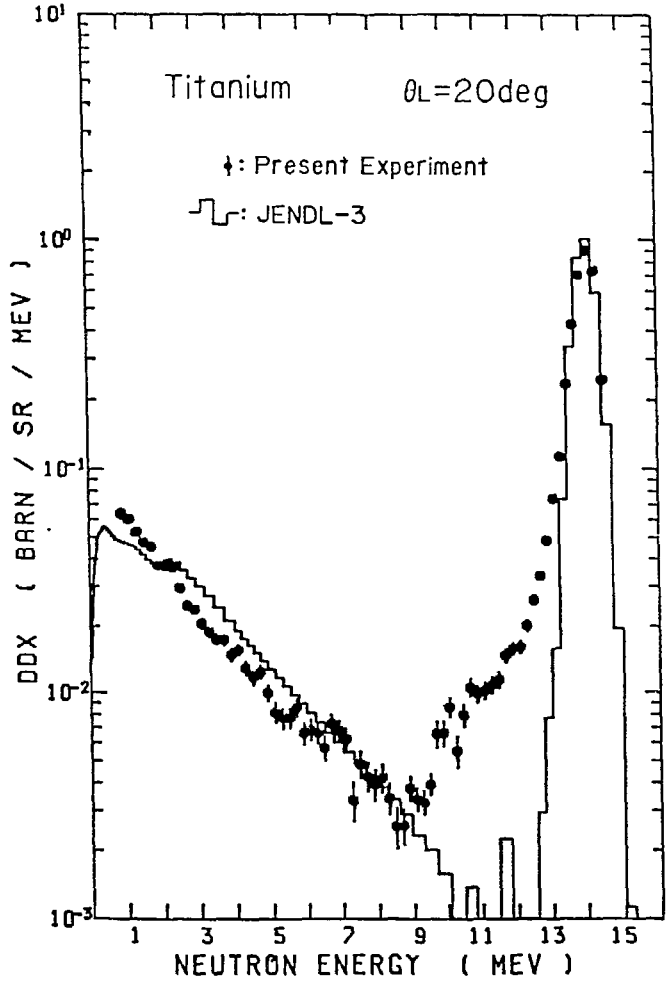

Fig.T-2 Double differential neutron emission cross sections at 20 deg, for Ti

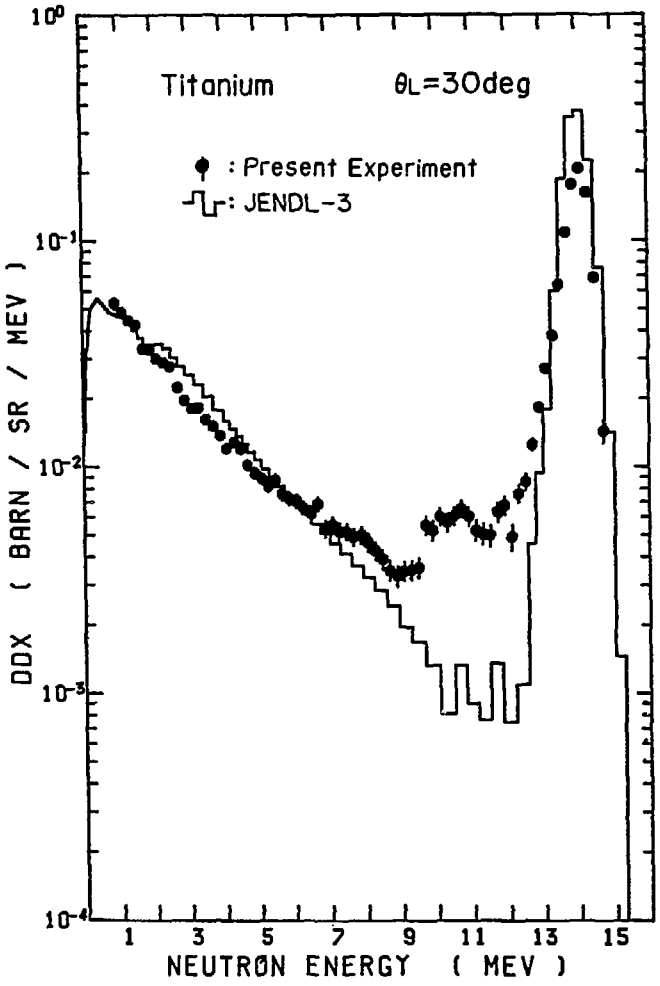

Fig.T-3 Double differential neutron emission cross sections at 30 deg, for Ti

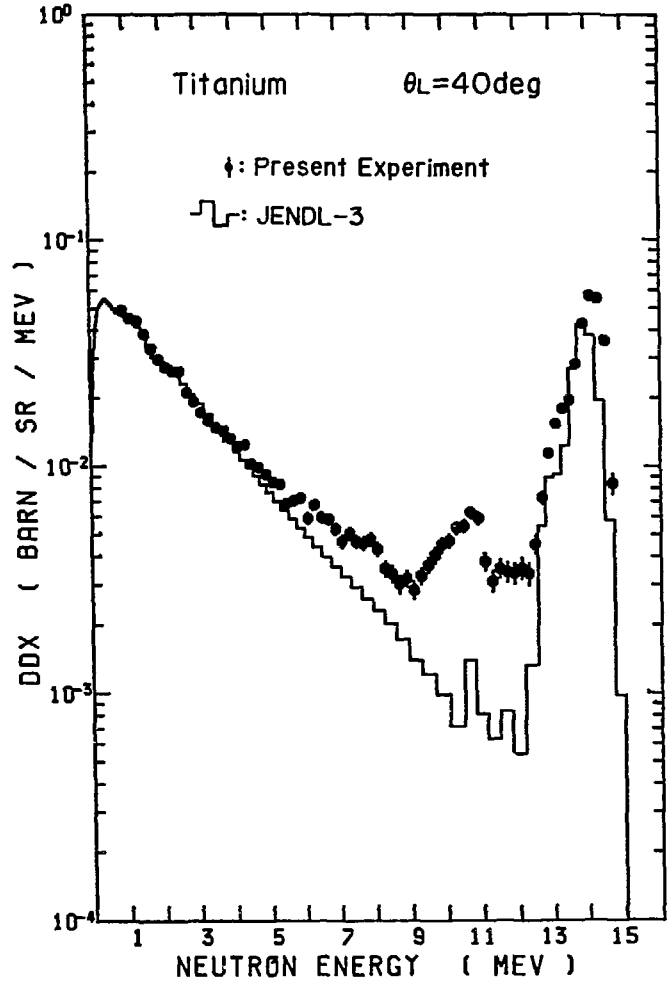

Fig.T-4 Double differential neutron emission cross sections at 40 deg, for Ti

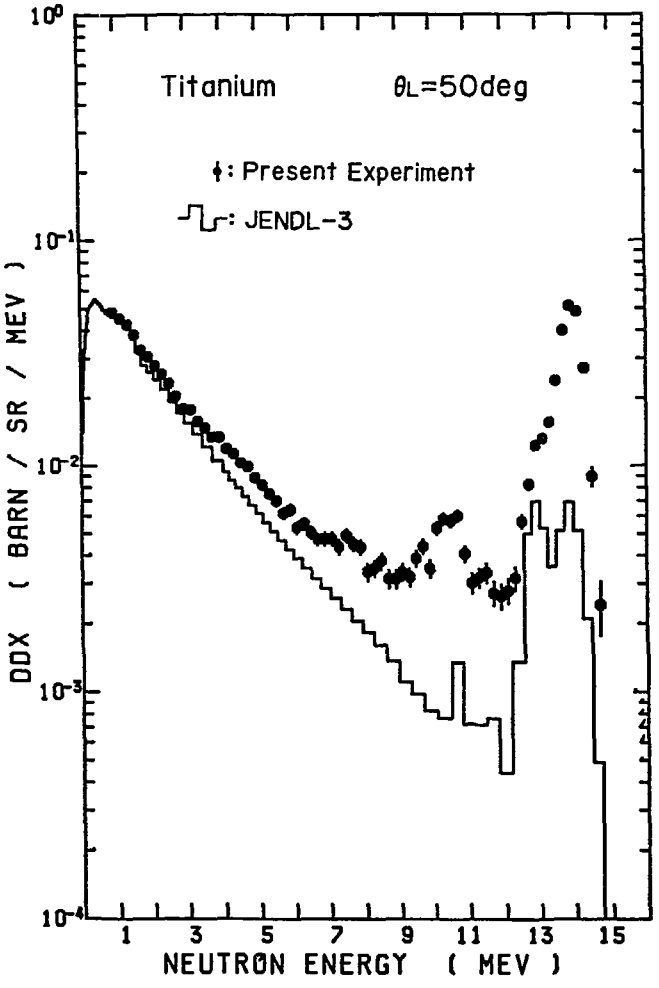

Fig.T-5 Double differential neutron emission cross sections at 50 deg, for Ti

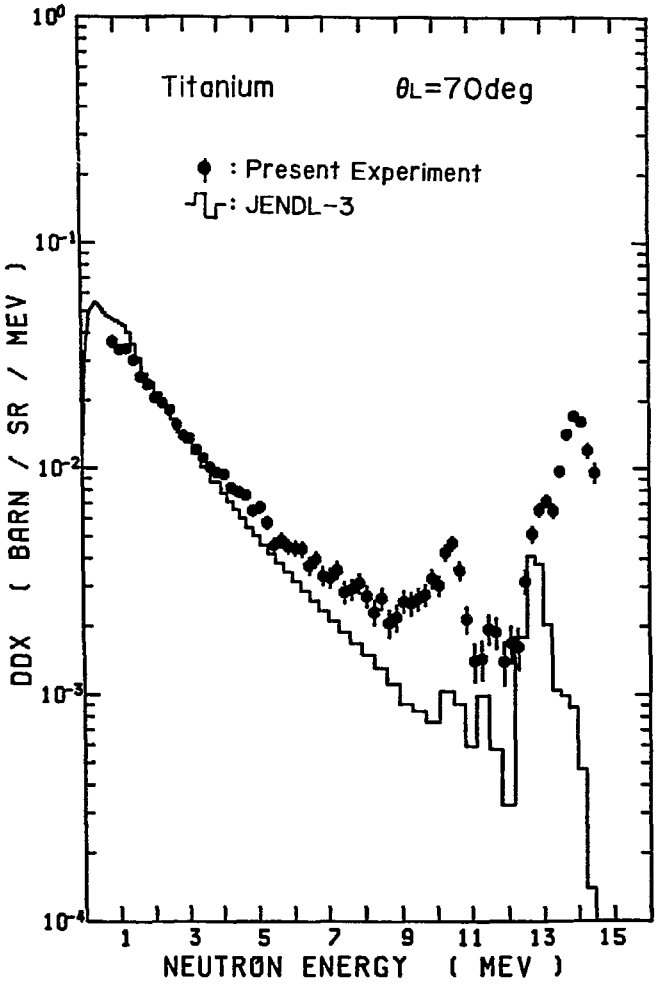

Fig.T-6 Double differential neutron emission cross sections at 70 deg, for Ti

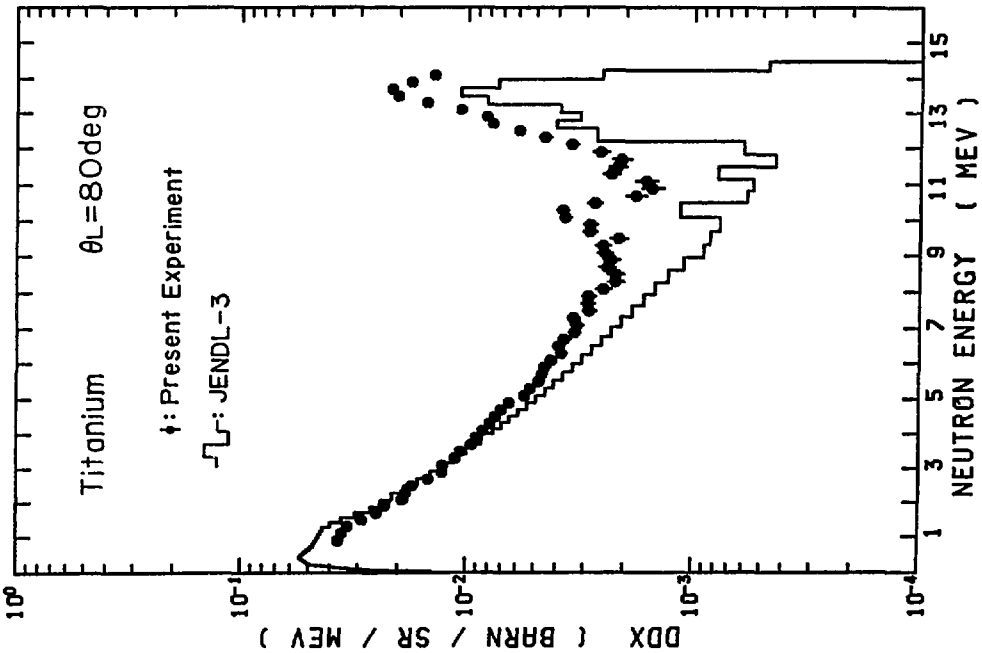

Fig.T-7 Double differential neutron emission cross sections at 80 deg, for Ti

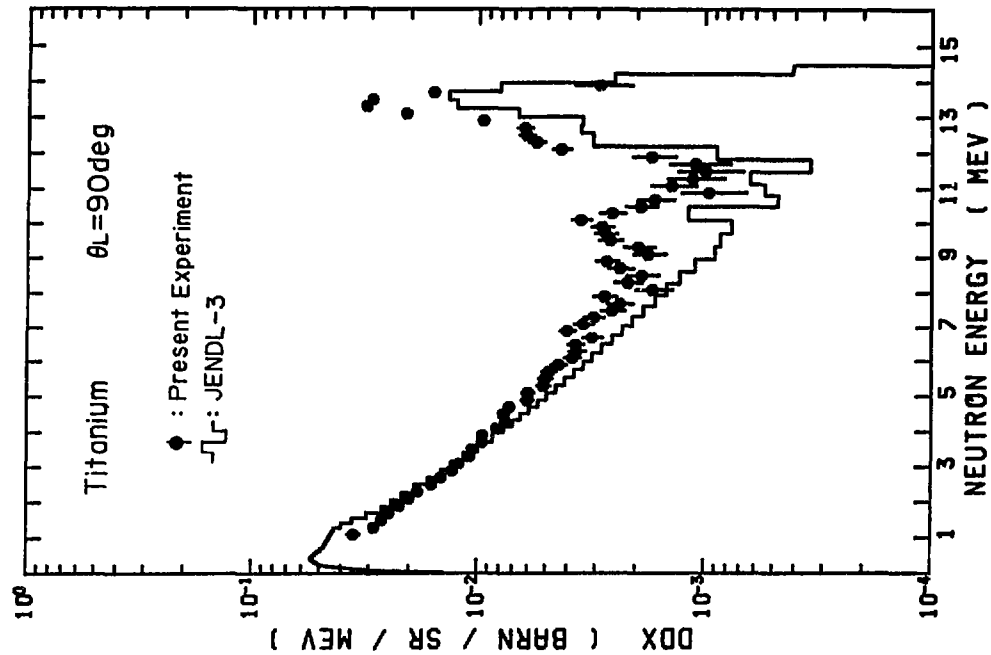

Fig.T-8 Double differential neutron emission cross sections at 90 deg, for Ti

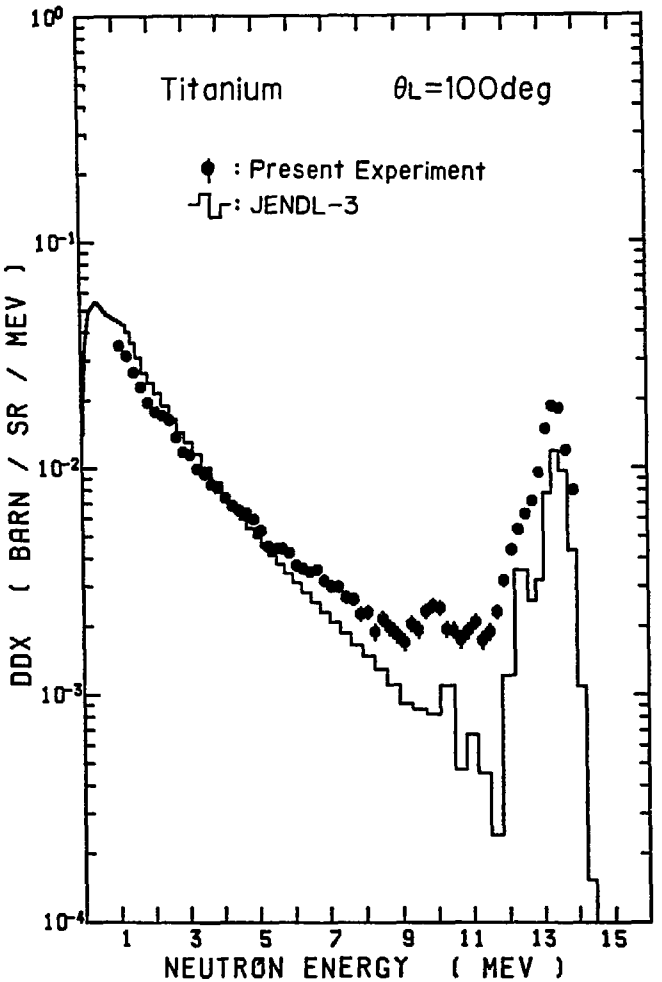

Fig.T-9 Double differential neutron emission cross sections at 100 deg, for Ti

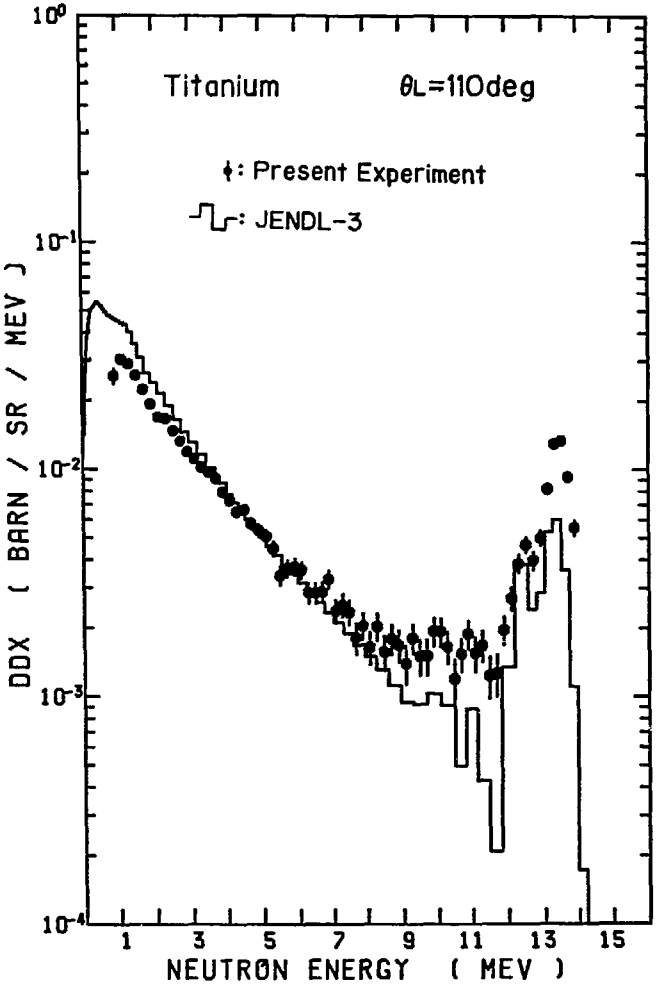

Fig.T-10 Double differential neutron emission cross sections at 110 deg, for Ti

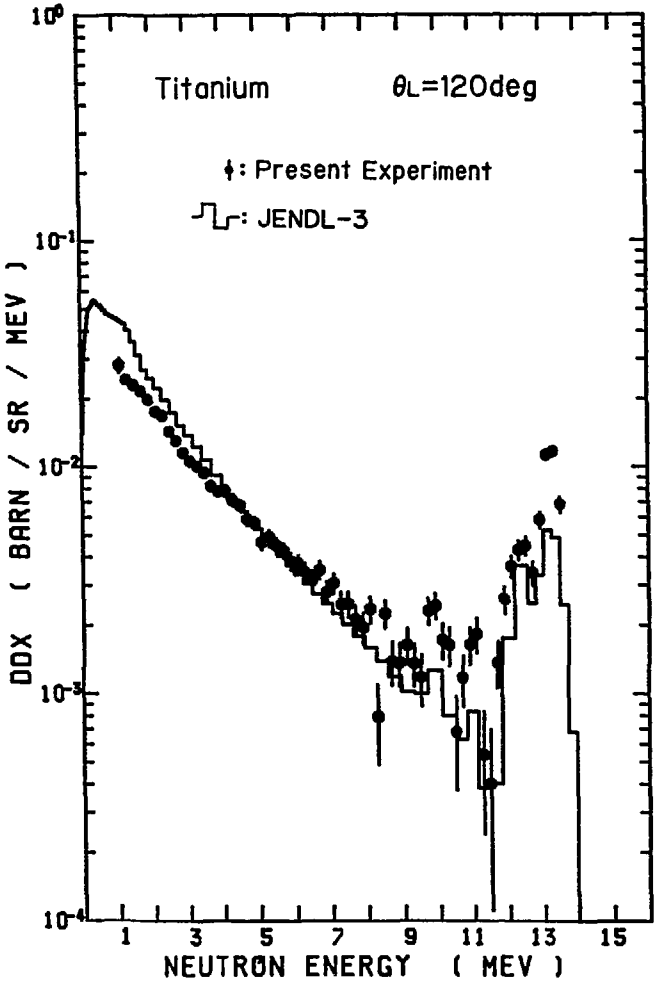

Fig.T-11 Double differential neutron emission cross sections at 120 deg, for Ti

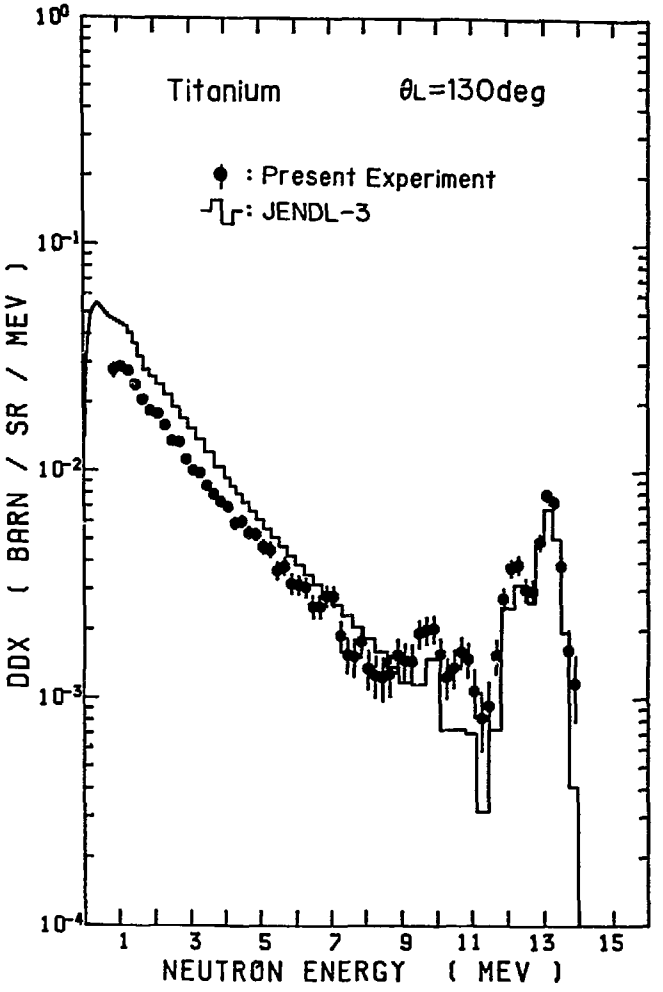

Fig.T-12 Double differential neutron emission cross sections at 130 deg, for Ti

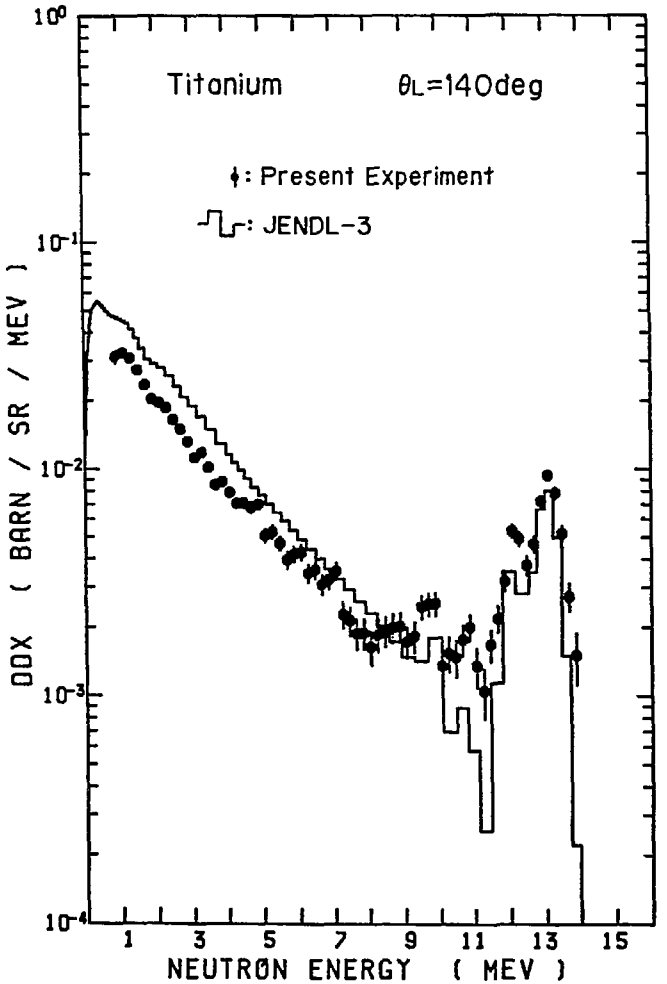

Fig.T-13 Double differential neutron emission cross sections at 140 deg, for Ti

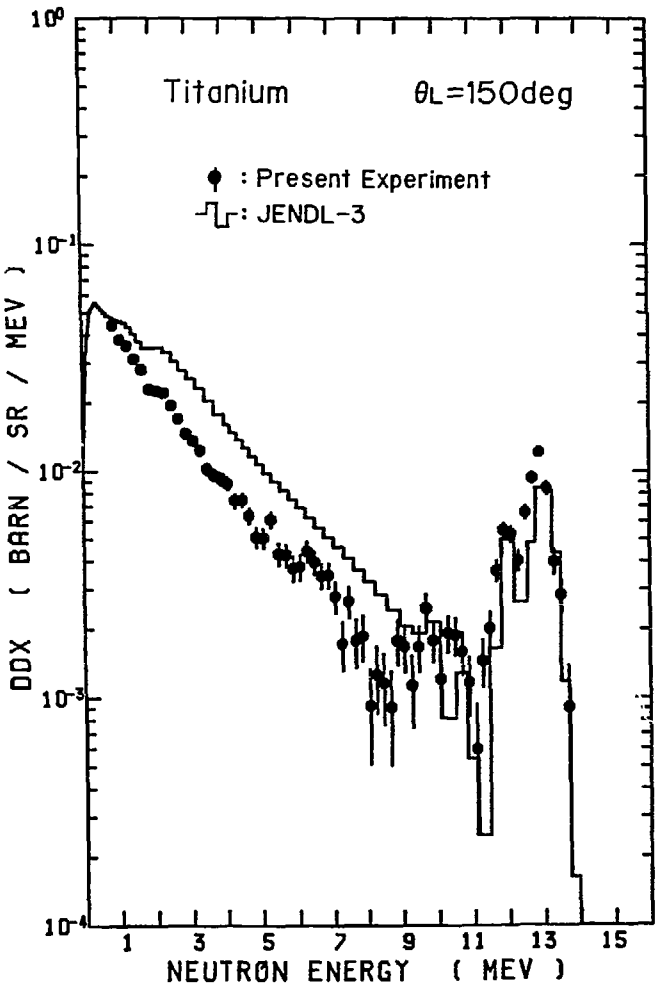

Fig.T-14 Double differential neutron emission cross sections at 150 deg, for Ti

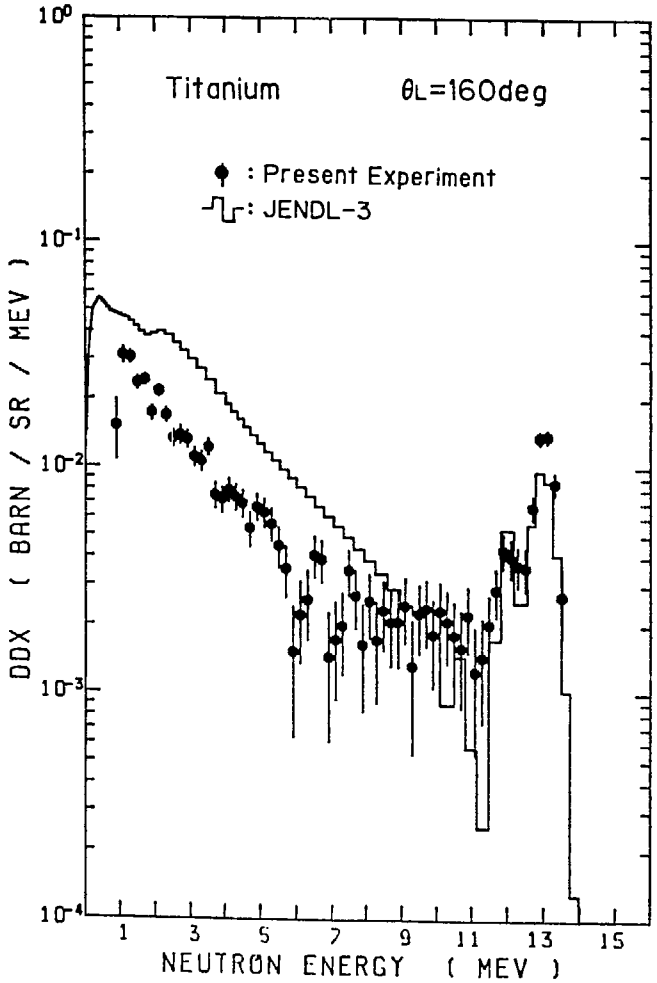

Fig.T-15 Double differential neutron emission cross sections at 160 deg, for Ti

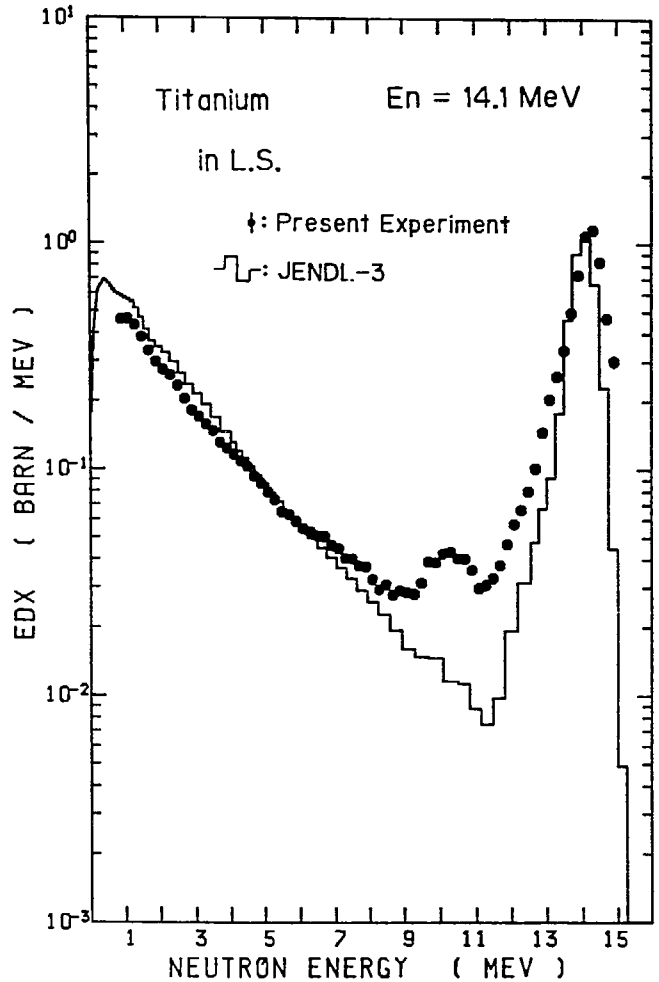

Fig.T-16 Angle-integrated neutron emission spectra in LAB system, for Ti

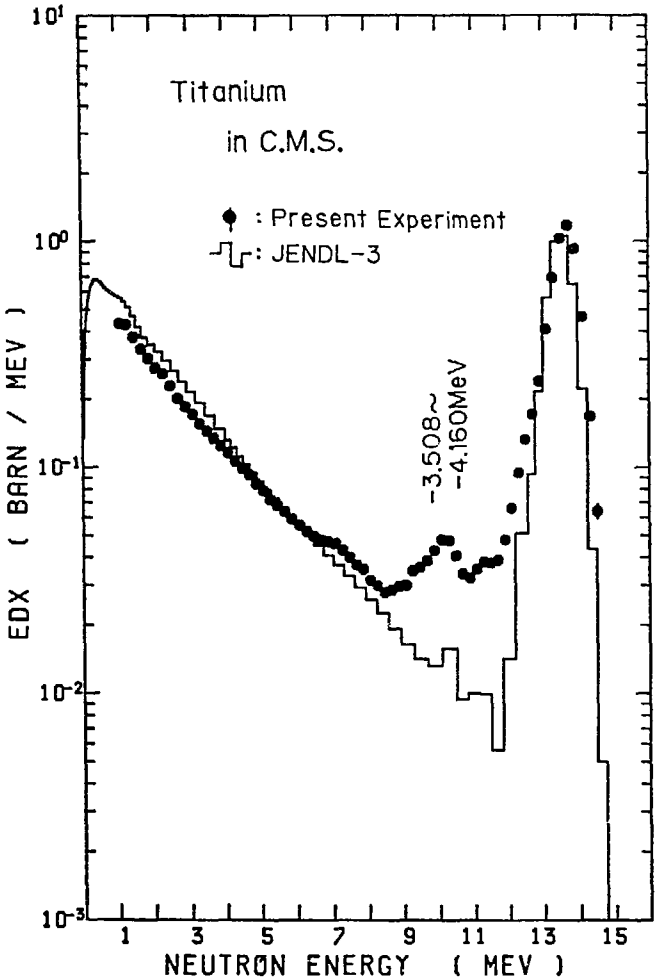

Fig.T-17 Angle-integrated neutron emission spectra in CMS, for Ti

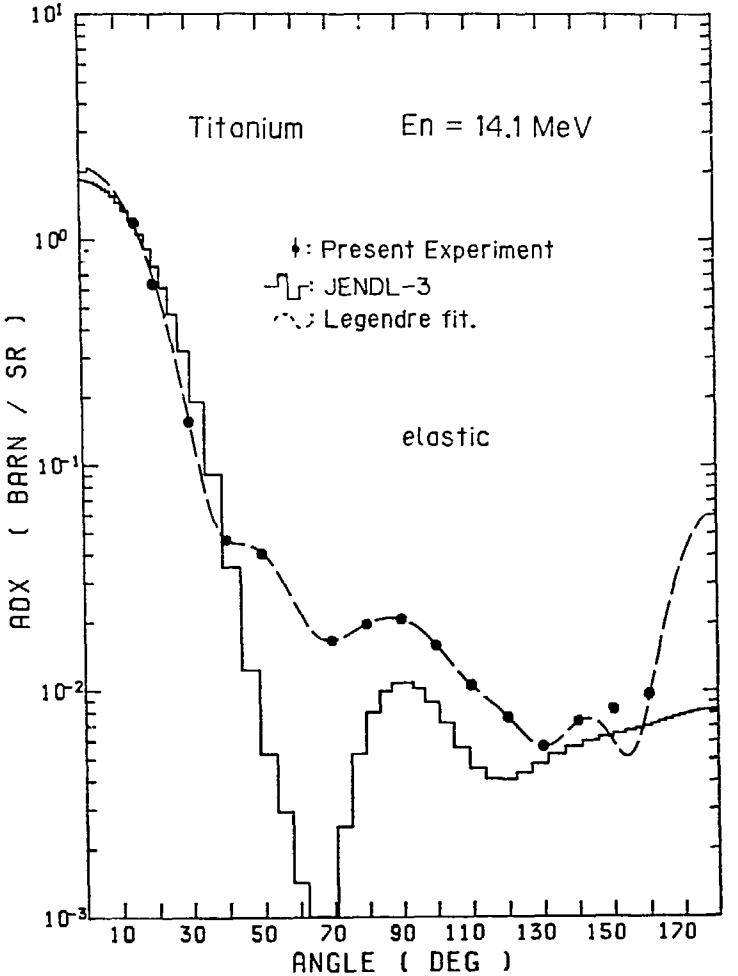

Fig.T-18 Differential elastic scattering cross sections, for Ti

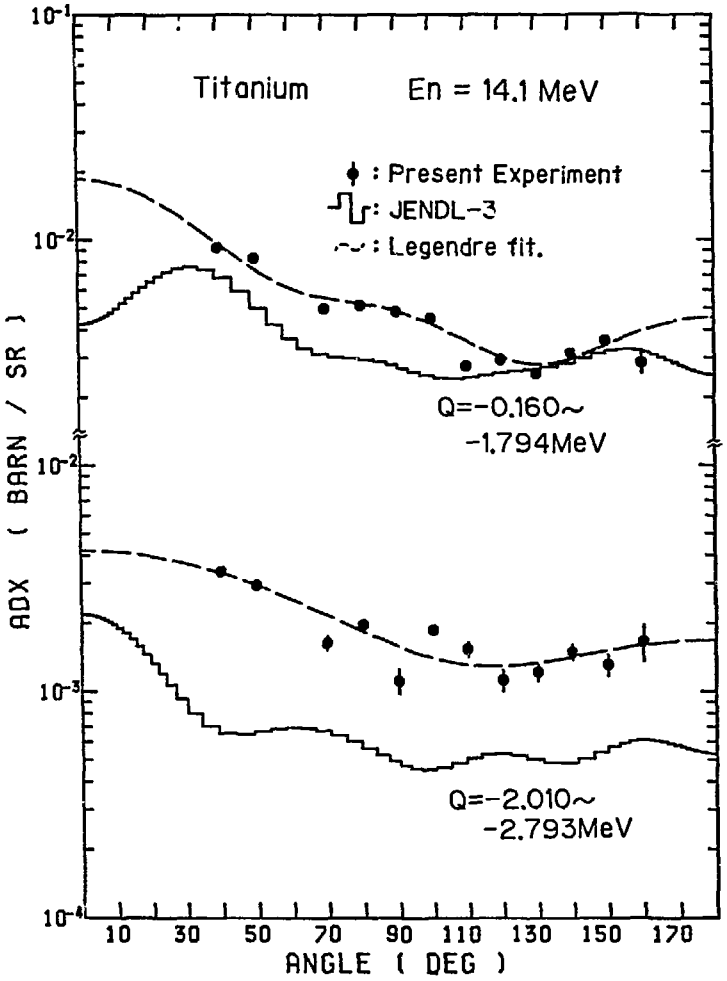

Fig.T-19 Differential inelastic scattering cross sections, for Ti

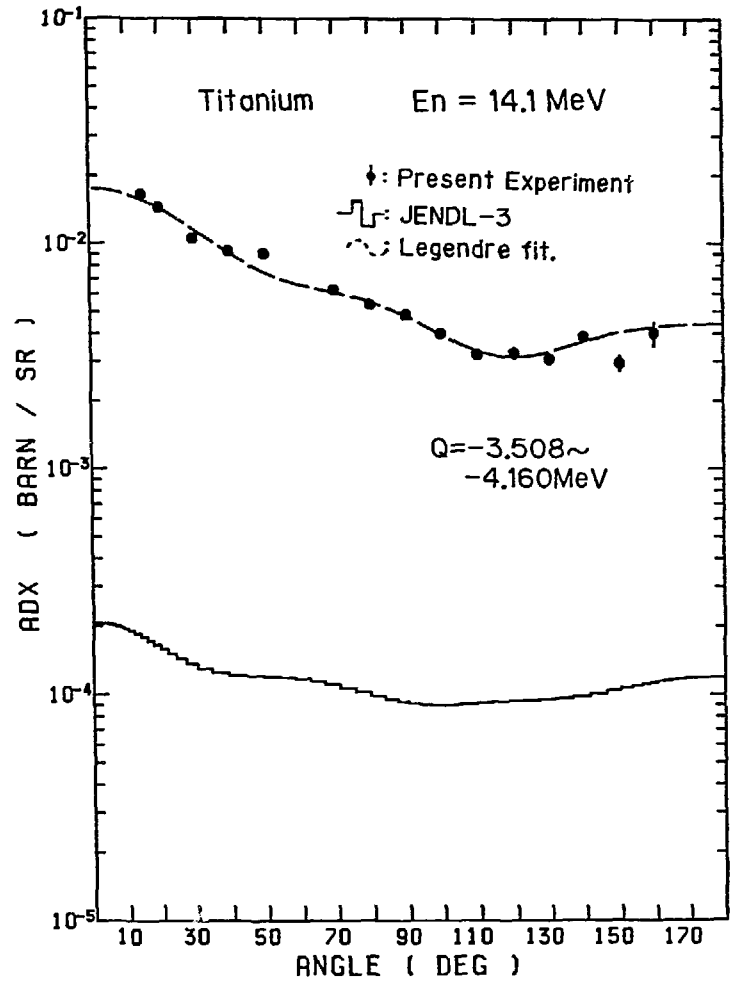

Fig.T-20 Differential inelastic scattering cross sections, for Ti

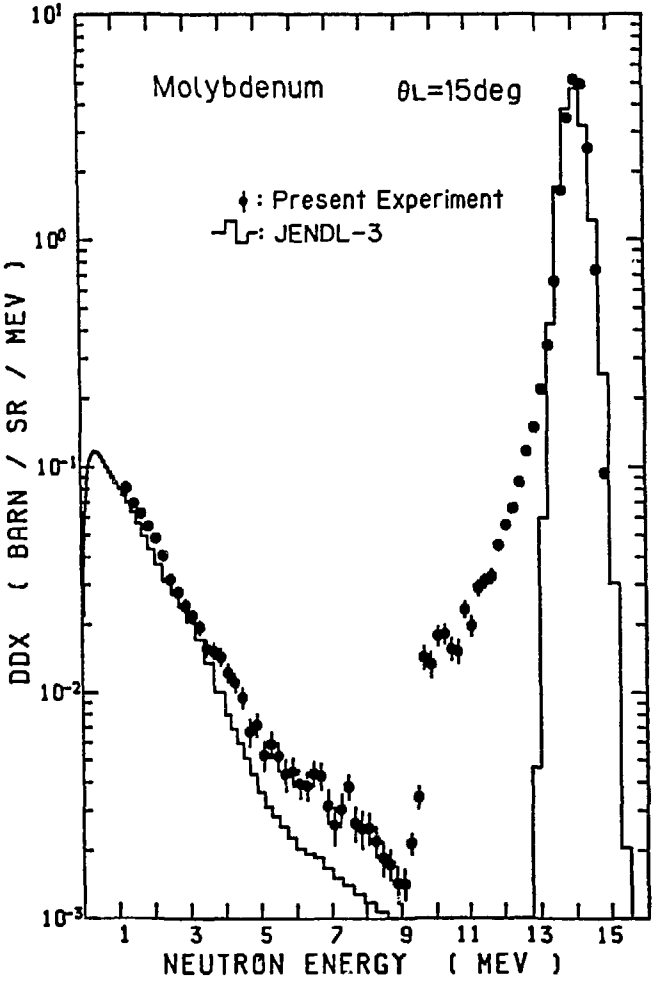

Fig.M-1 Double differential neutron emission cross sections at 15 deg, for Mo

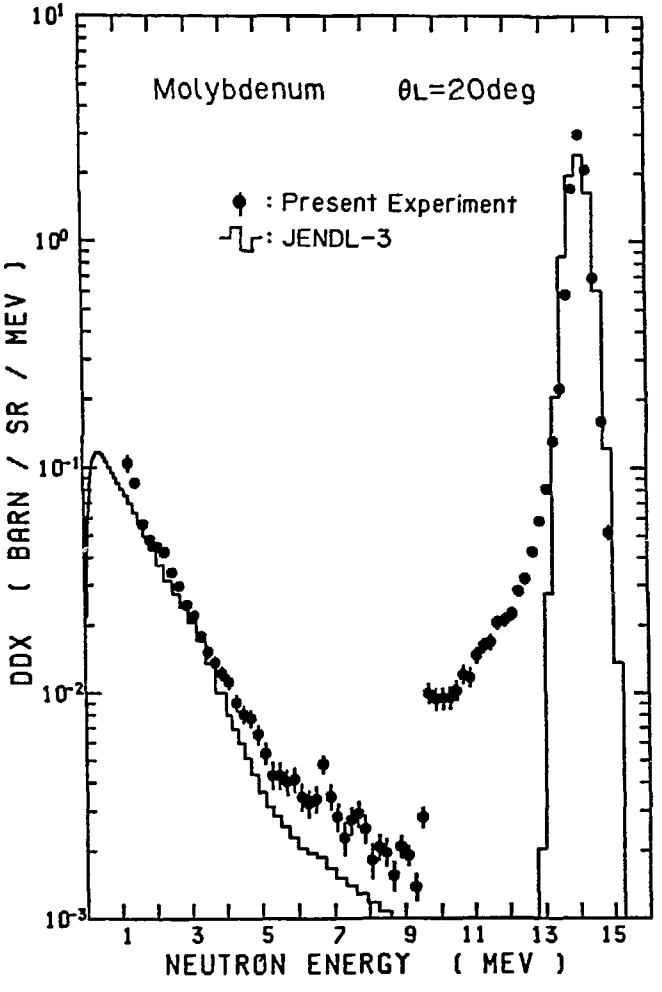

Fig.M-2 Double differential neutron emission cross sections at 20 deg, for Mo

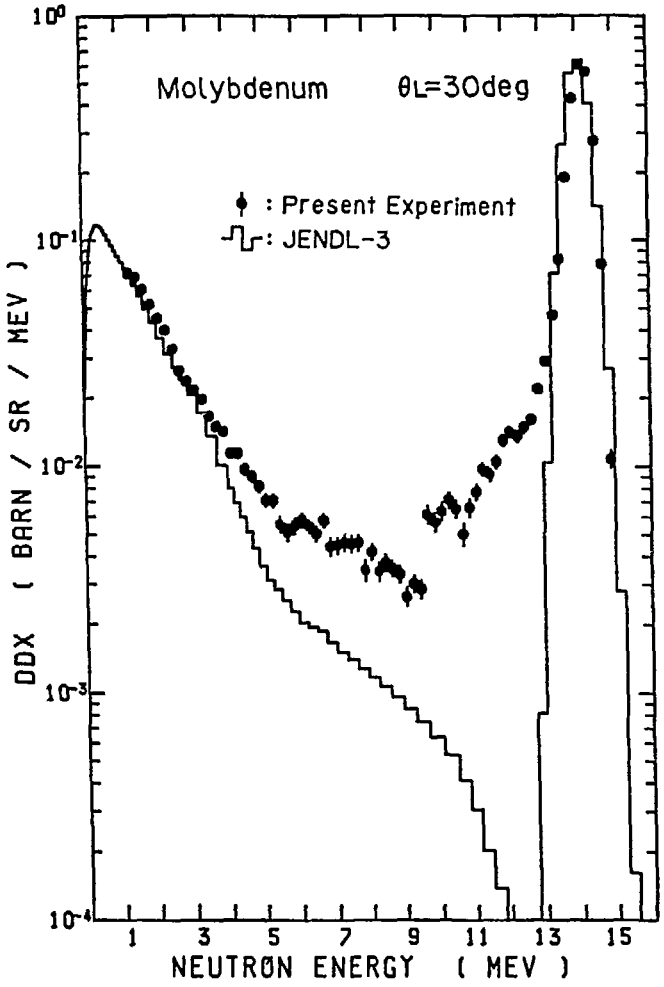

Fig.M-3 Double differential neutron emission cross sections at 30 deg, for Mo

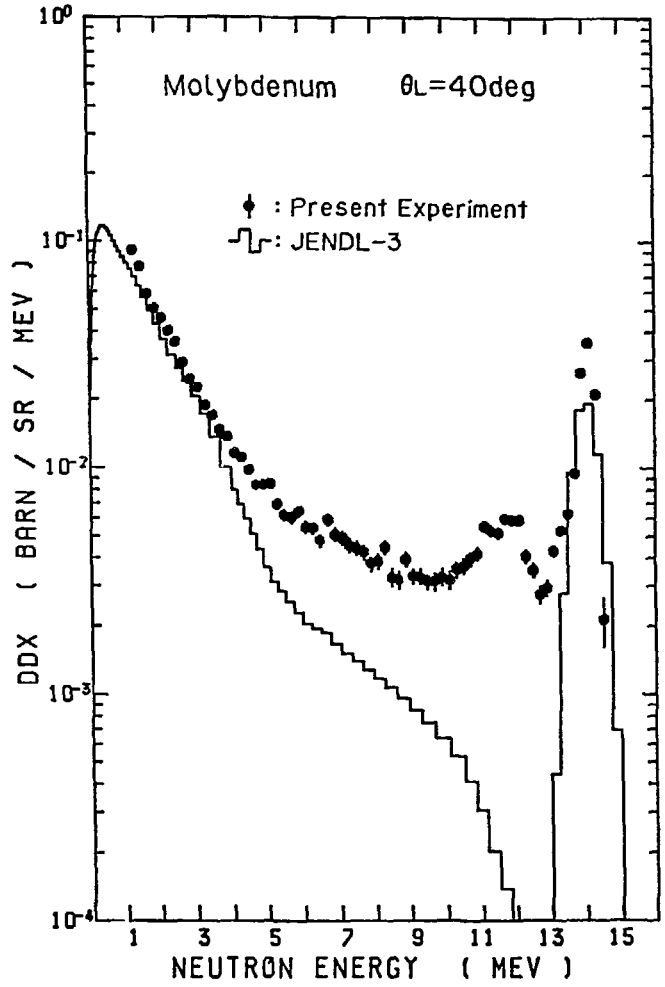

Fig.M-4 Double differential neutron emission cross sections at 40 deg, for Mo

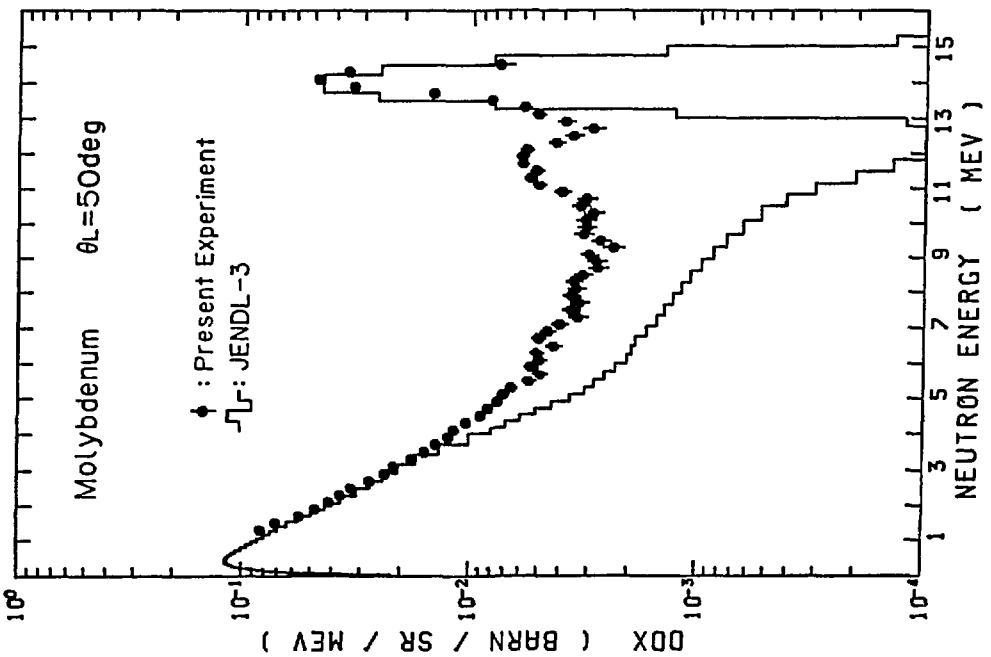

Fig.M-5 Double differential neutron emission cross sections at 50 deg, for Mo

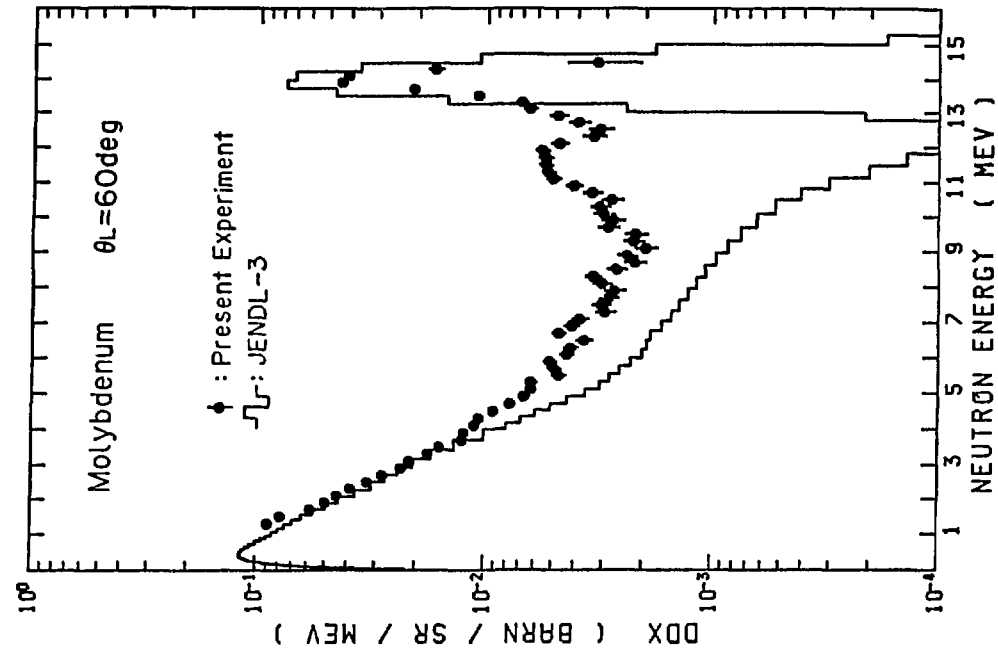

Fig.M-6 Double differential neutron emission cross sections at 60 deg, for Mo

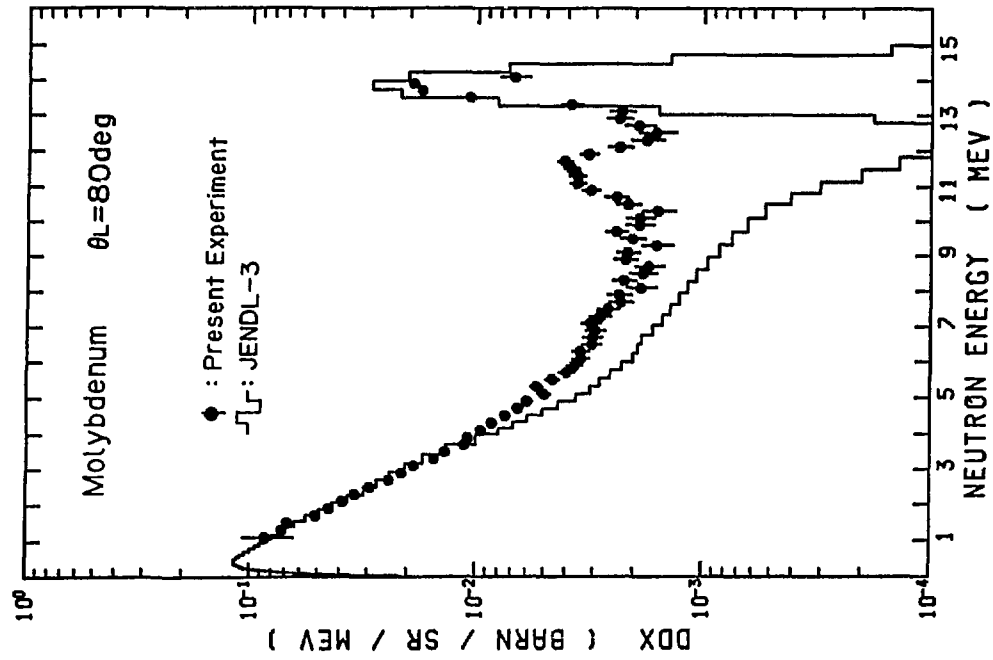

Fig.M-8 Double differential neutron emission cross sections at 80 deg, for Mo

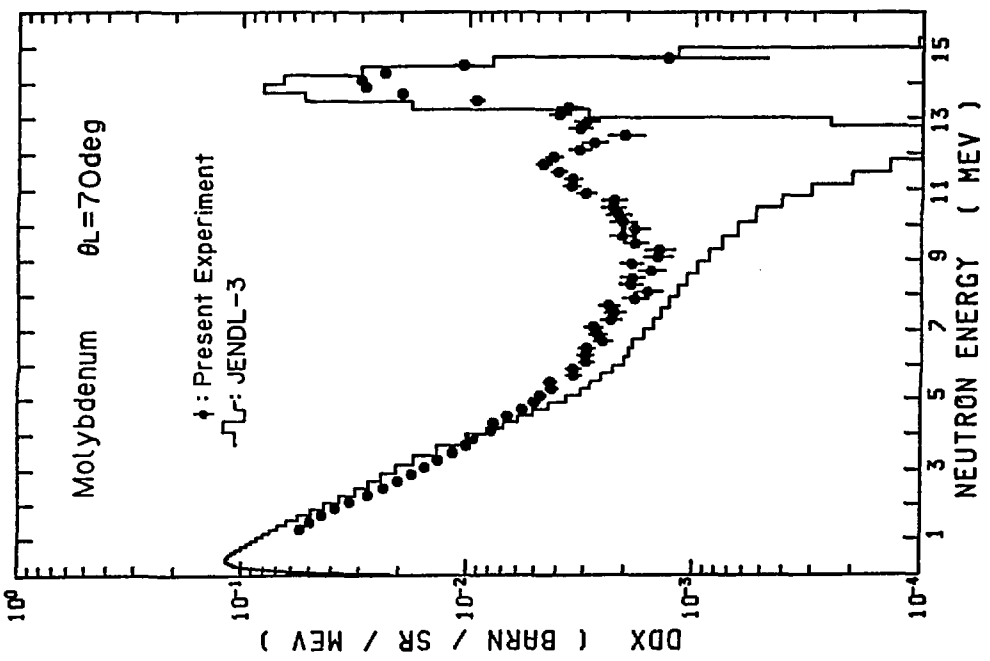

Fig.M-7 Double differential neutron emission cross sections at 70 deg, for Mo

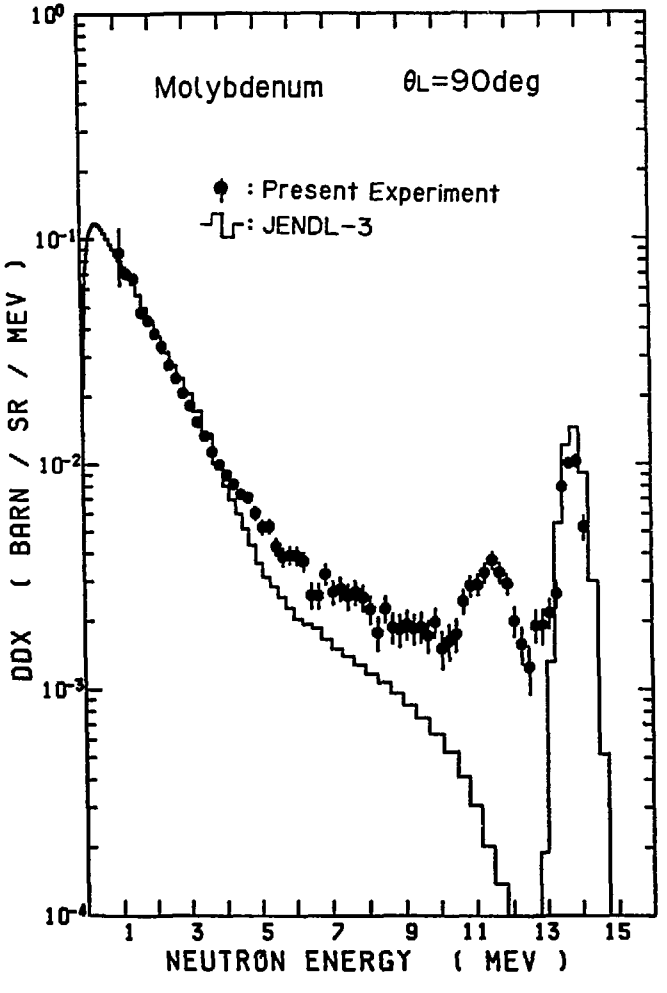

Fig.M-9 Double differential neutron emission cross sections at 90 deg, for Mo

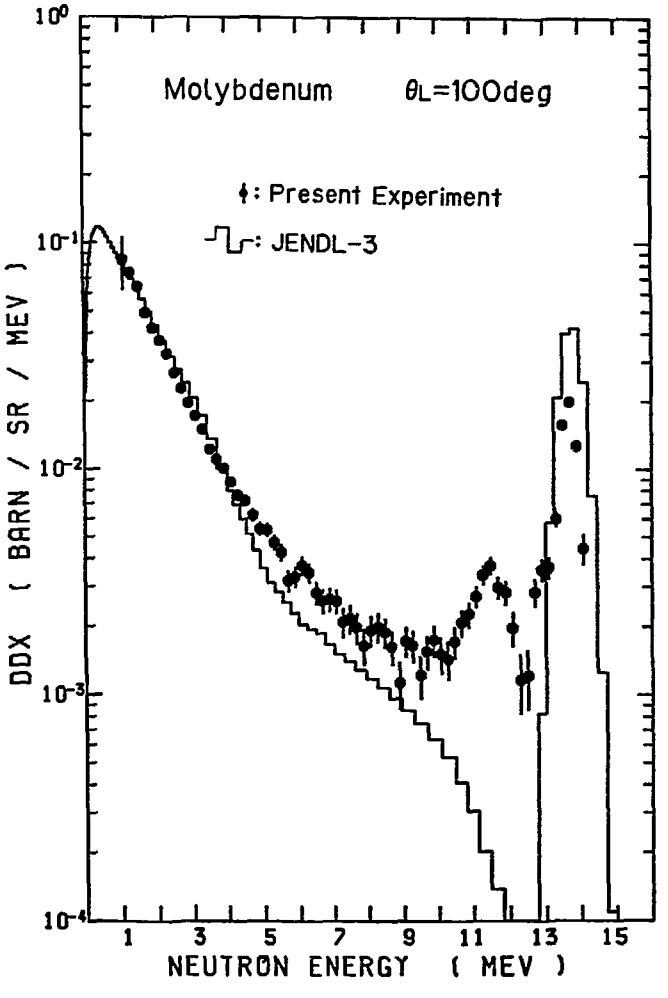

Fig.M-10 Double differential neutron emission cross sections at 100 deg, for Mo

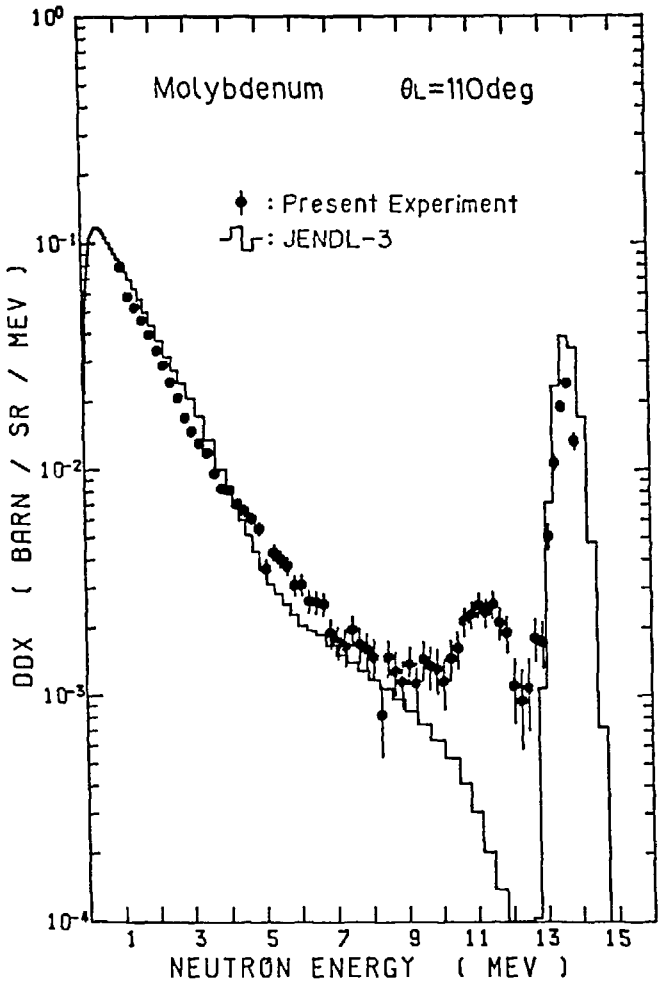

Fig.M-11 Double differential neutron emission cross sections at 110 deg, for Mo

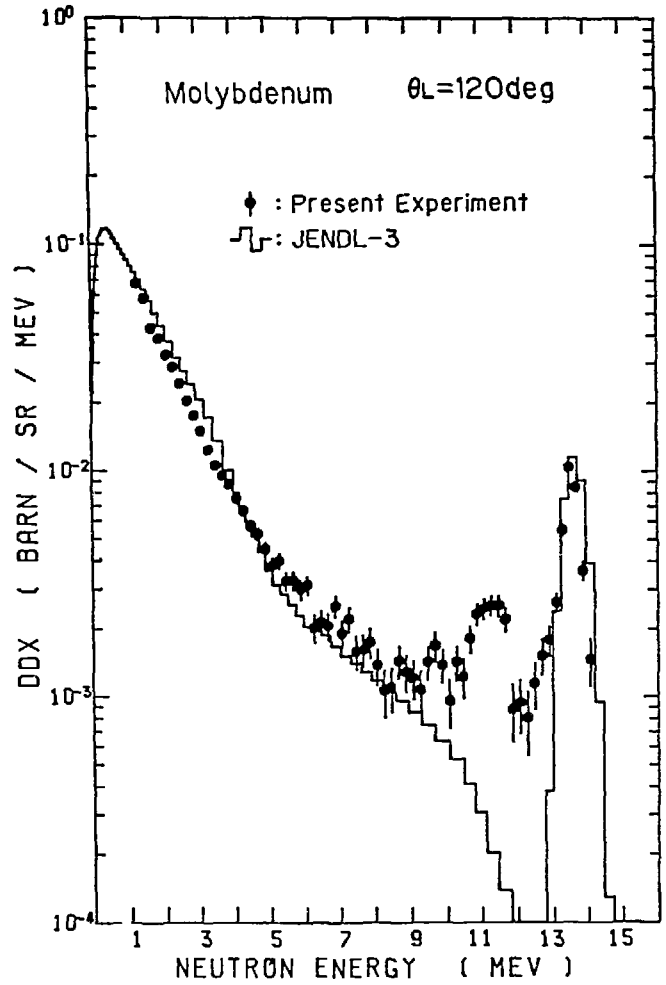

Fig.M-12 Double differential neutron emission cross sections at 120 deg, for Mo

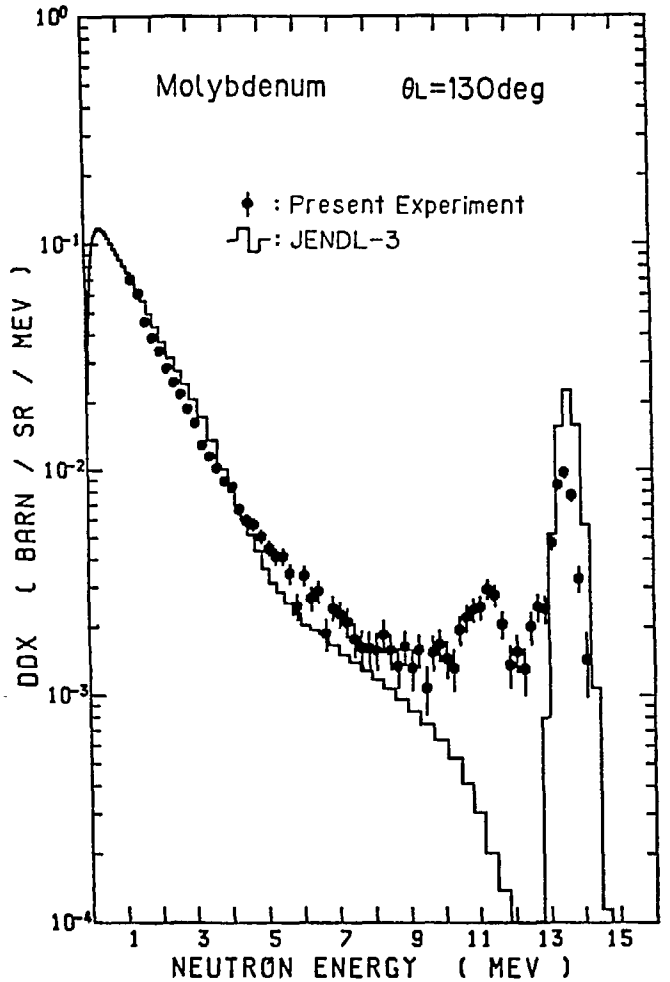

Fig.M-13 Double differential neutron emission cross sections at 130 deg, for Mo

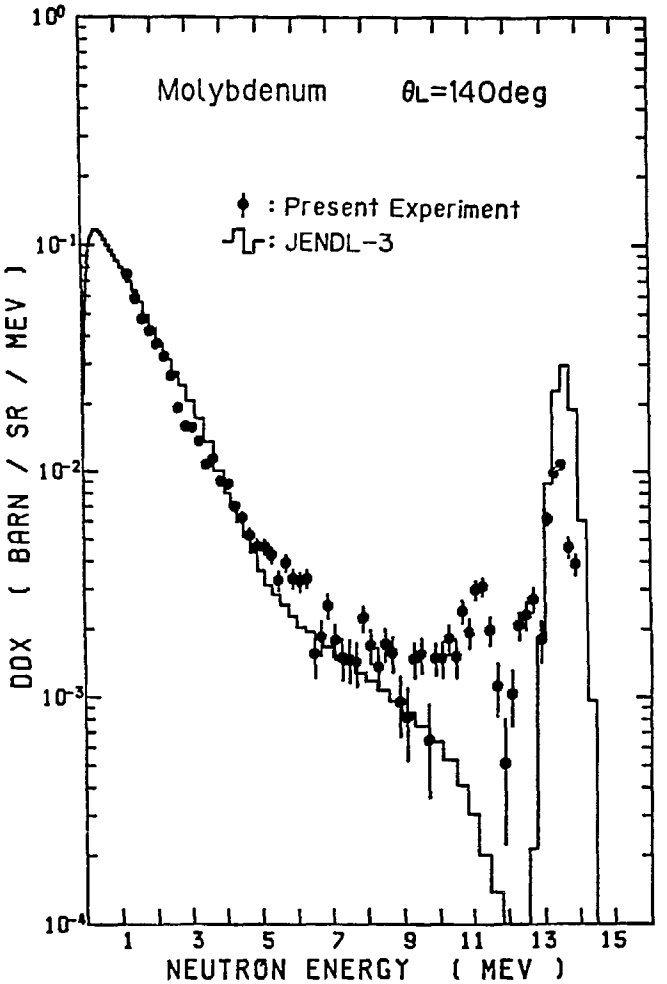

Fig.M-14 Double differential neutron emission cross sections at 140 deg, for Mo

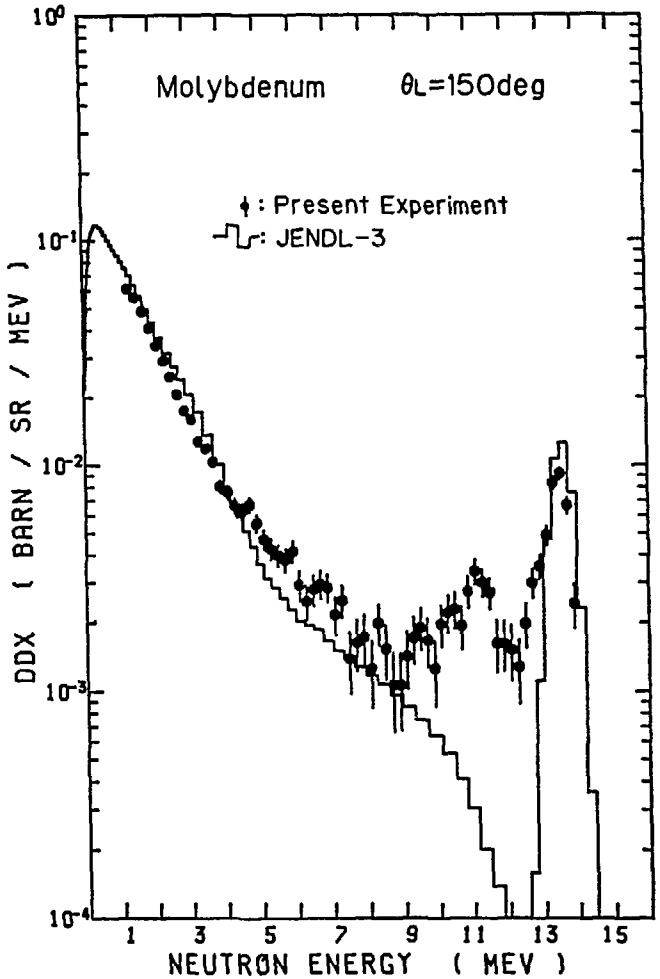

Fig.M-15 Double differential neutron emission cross sections at 150 deg, for Mo

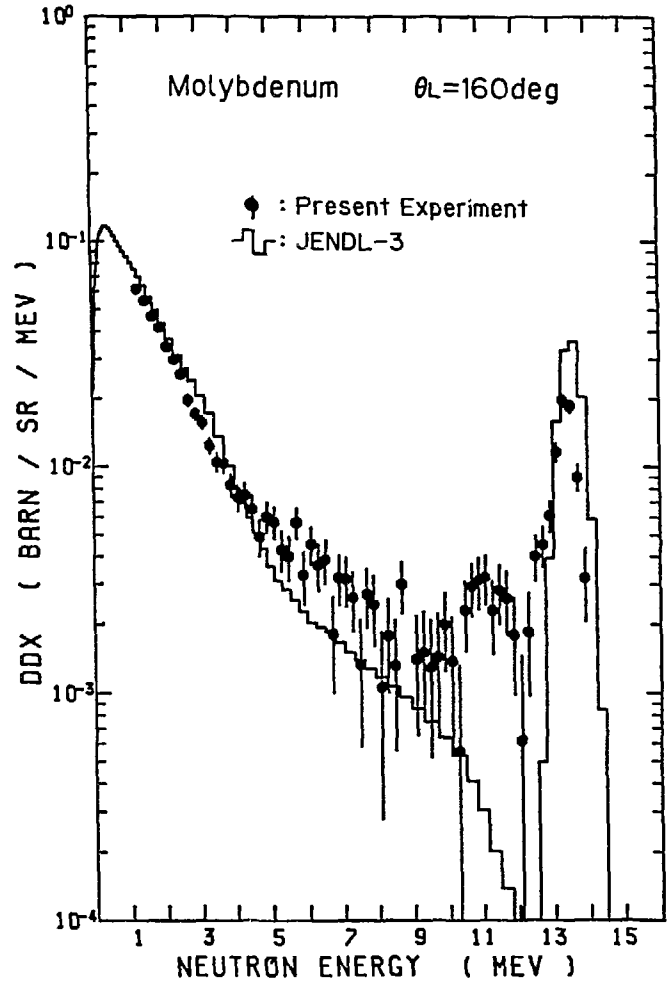

Fig.M-16 Double differential neutron emission cross sections at 160 deg, for Mo

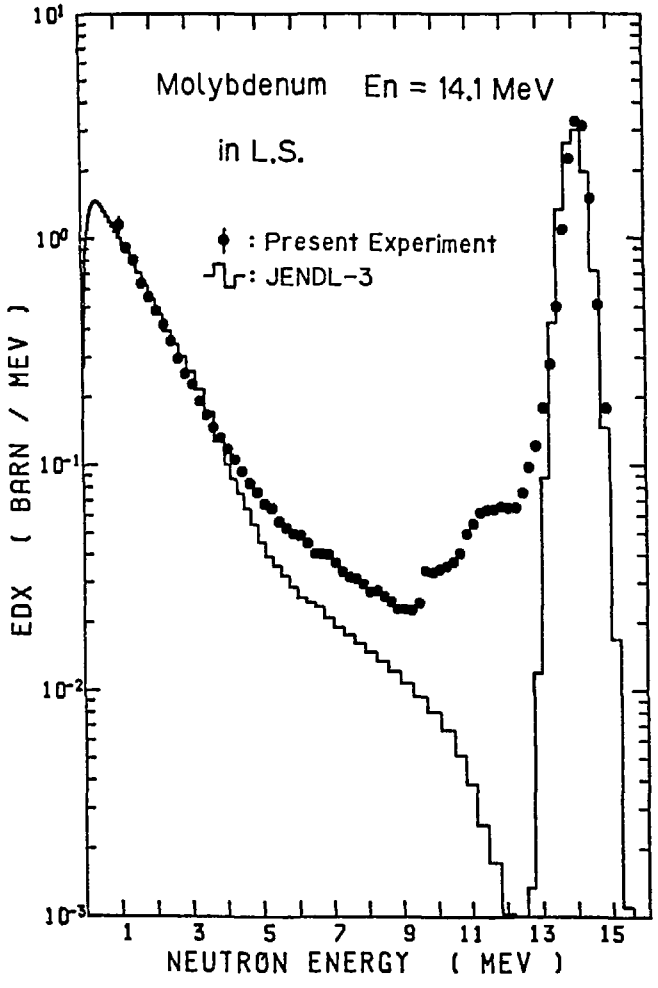

Fig.M-17 Angle-integrated neutron emission spectra in LAB system, for Mo

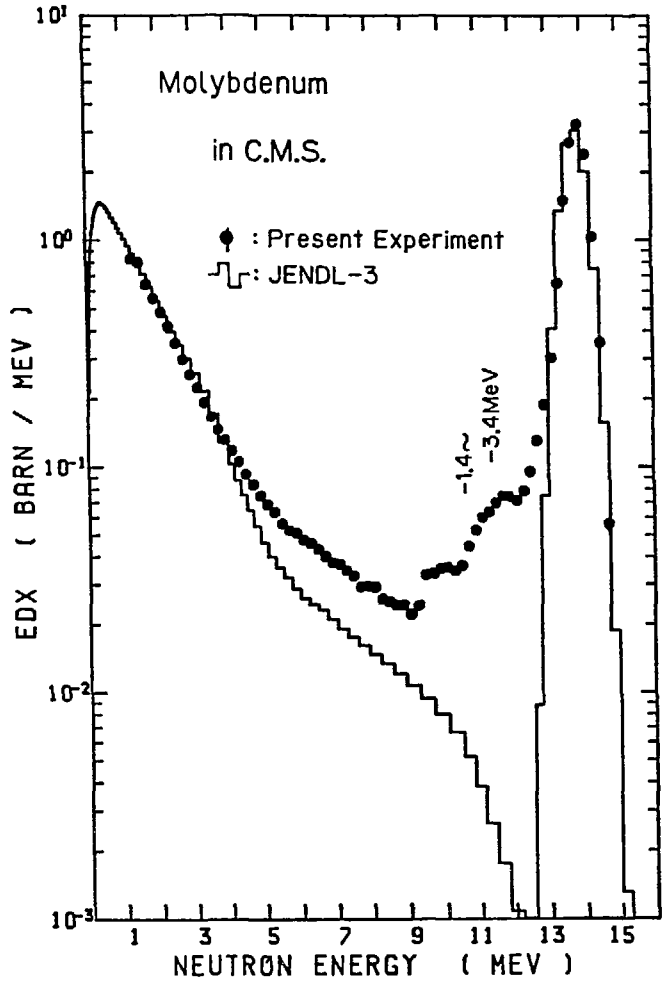

Fig.M-18 Angle-integrated neutron emission spectra in CMS, for Mo

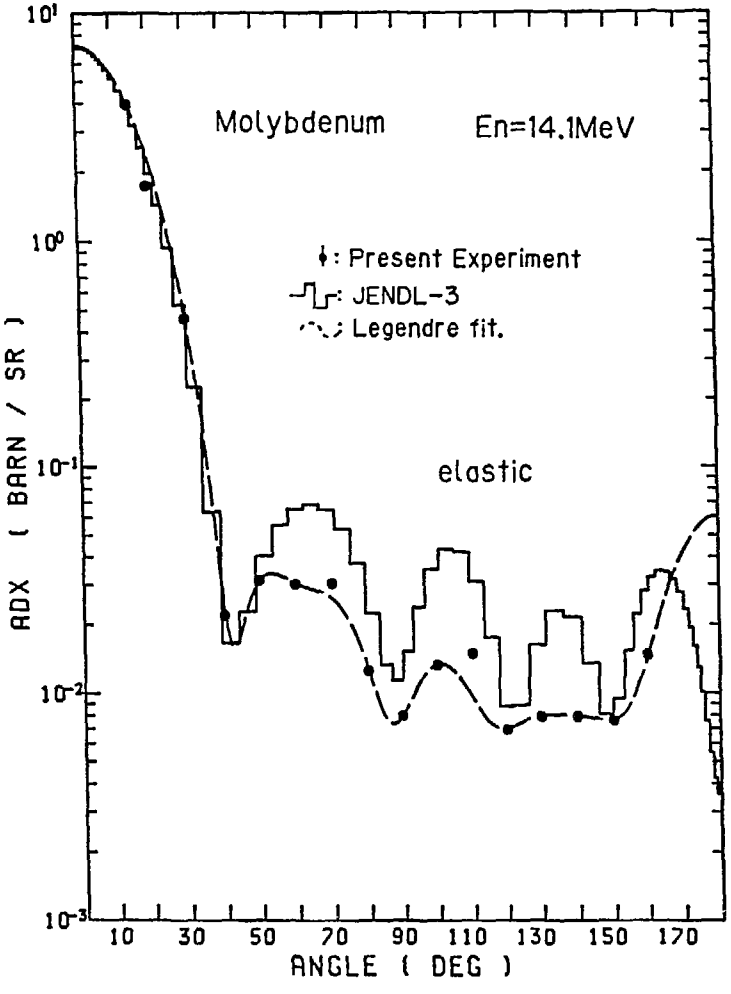

Fig.M-19 Differential elastic scattering cross sections, for Mo

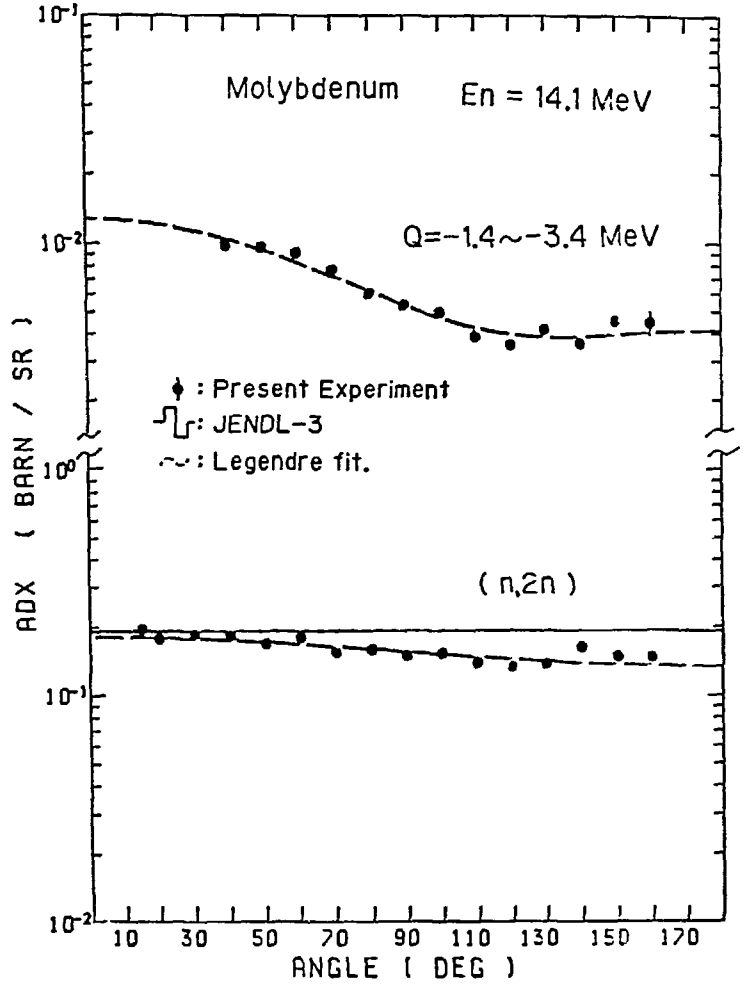

Fig.M-20 Differential cross sections of inelastic scattering (upper) and (n,2n) reaction (lower), for Mo

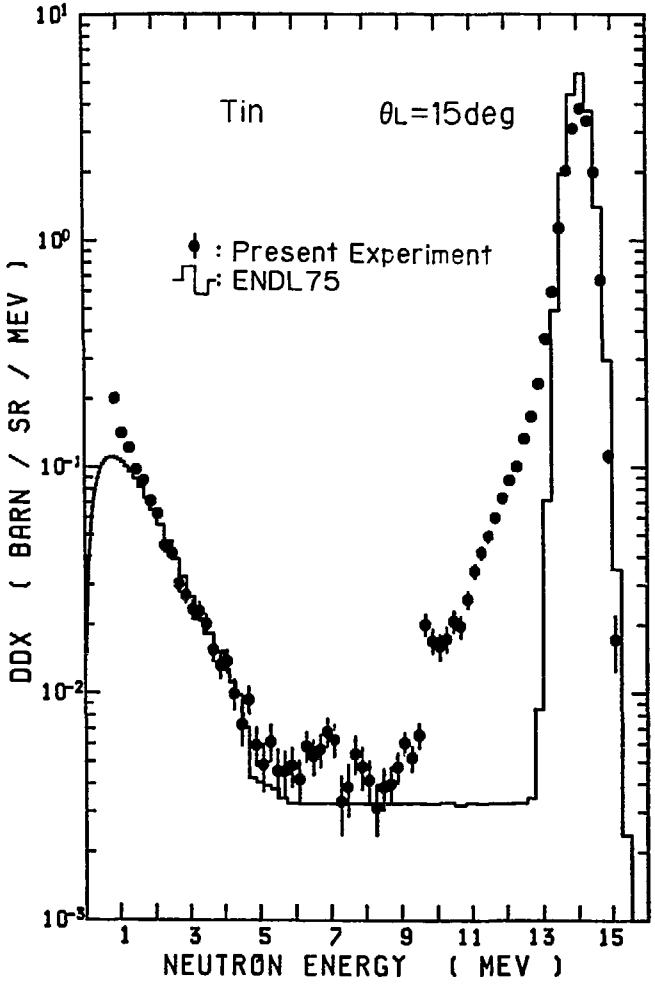

Fig.S-1 Double differential neutron emission cross sections at 15 deg, for Sn

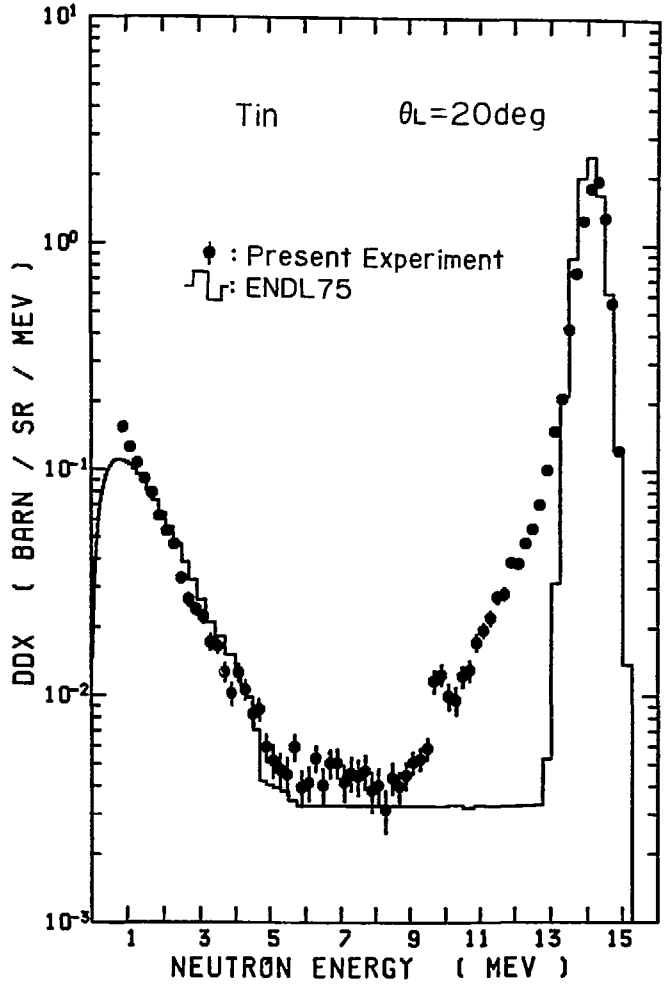

Fig.S-2 Double differential neutron emission cross sections at 20 deg, for Sn

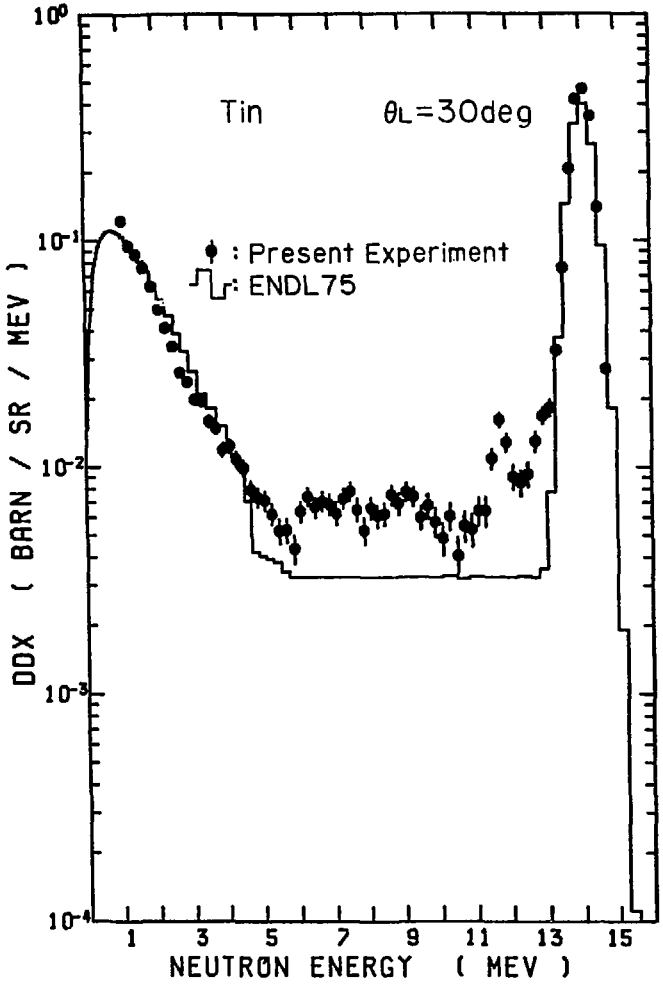

Fig.S-3 Double differential neutron emission cross sections at 30 deg, for Sn

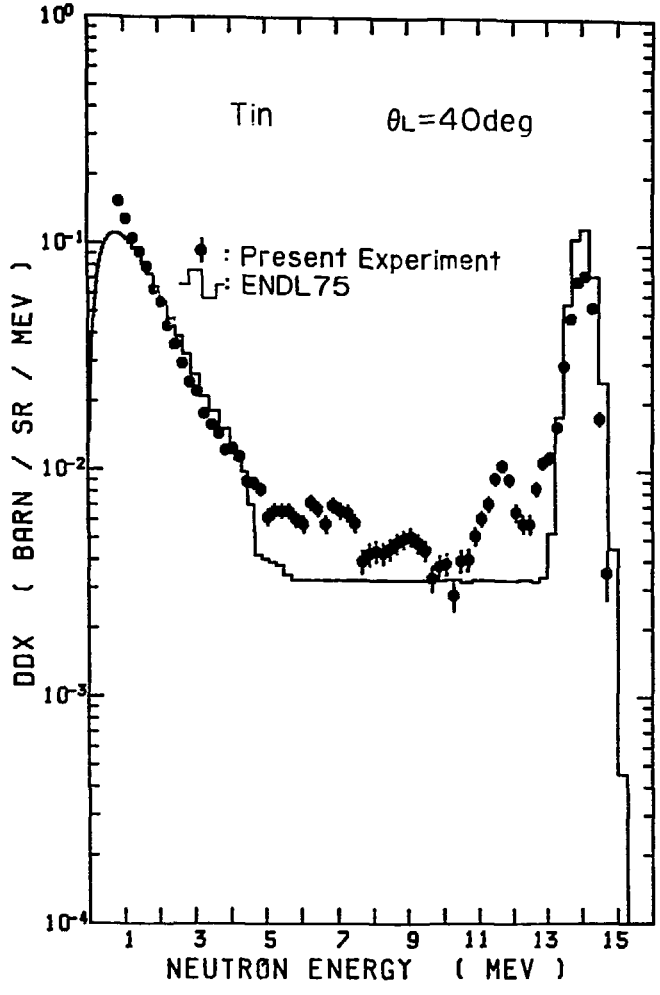

Fig.S-4 Double differential neutron emission cross sections at 40 deg, for Sn

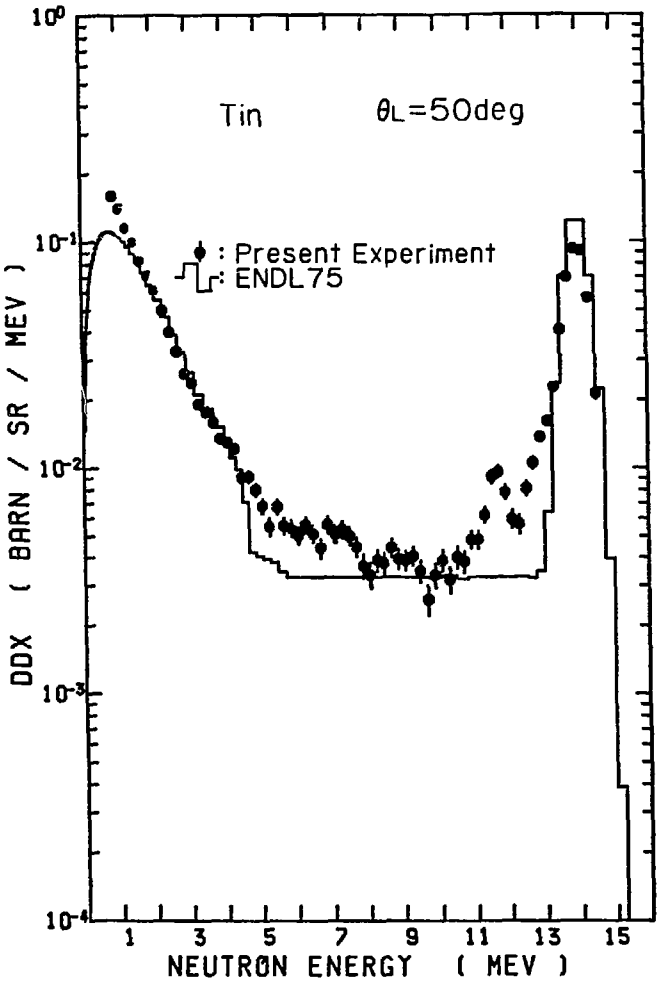

Fig.S-5 Double differential neutron emission cross sections at 50 deg, for Sn

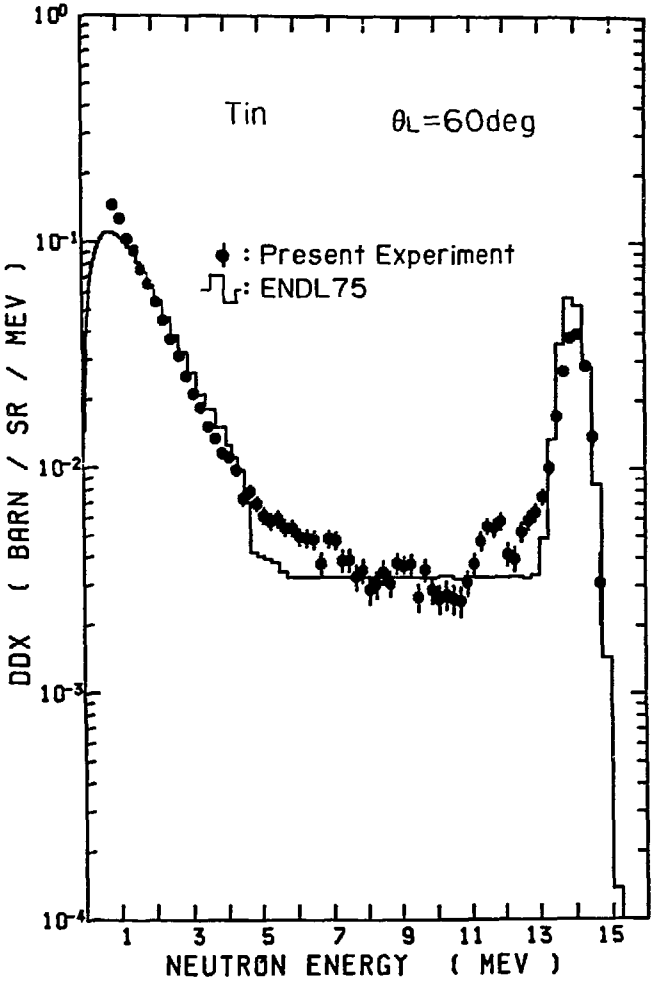

Fig.S-6 Double differential neutron emission cross sections at 60 deg, for Sn

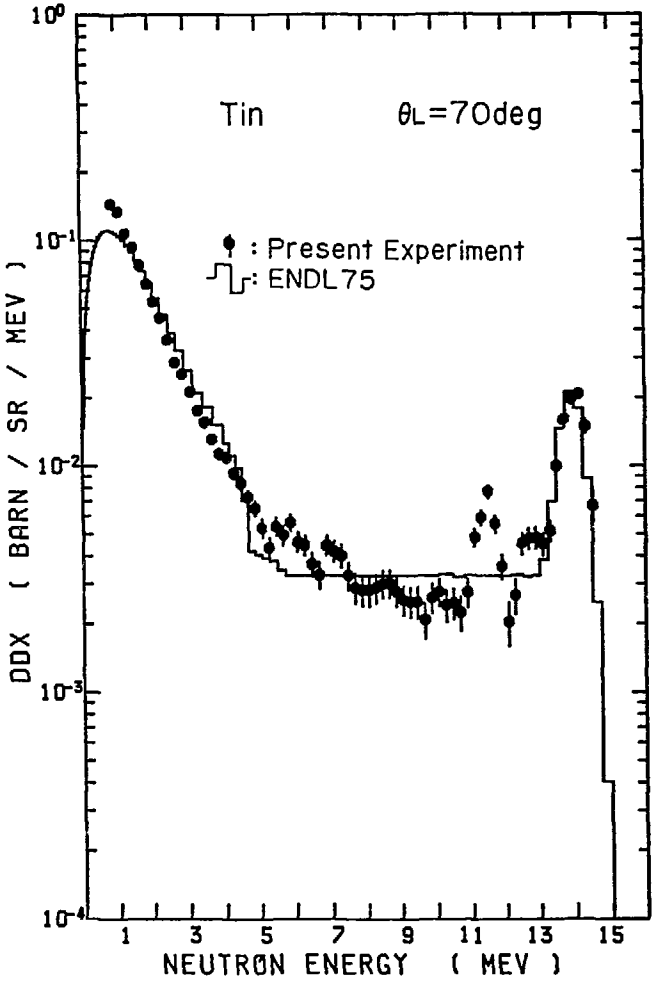

Fig.S-7 Double differential neutron emission cross sections at 70 deg, for Sn

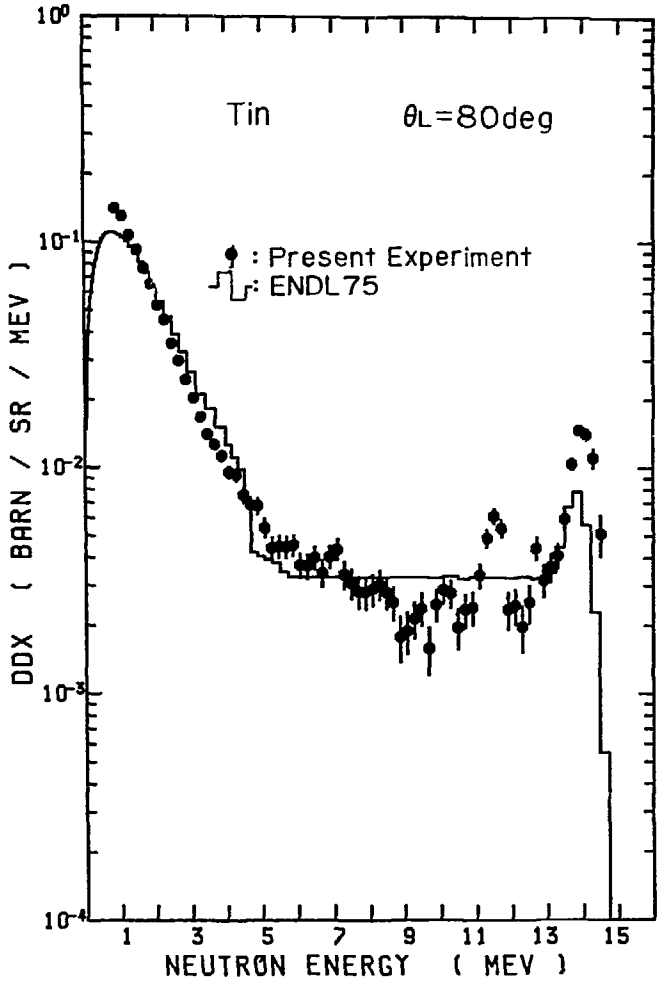

Fig.S-8 Double differential neutron emission cross sections at 80 deg, for Sn

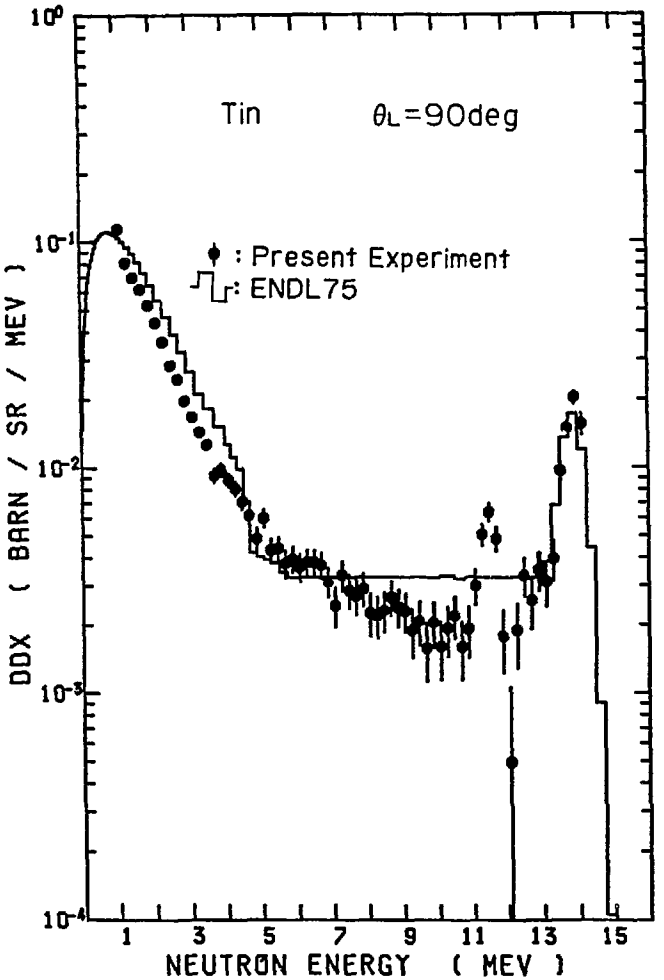

Fig.S-9 Double differential neutron emission cross sections at 90 deg, for Sn

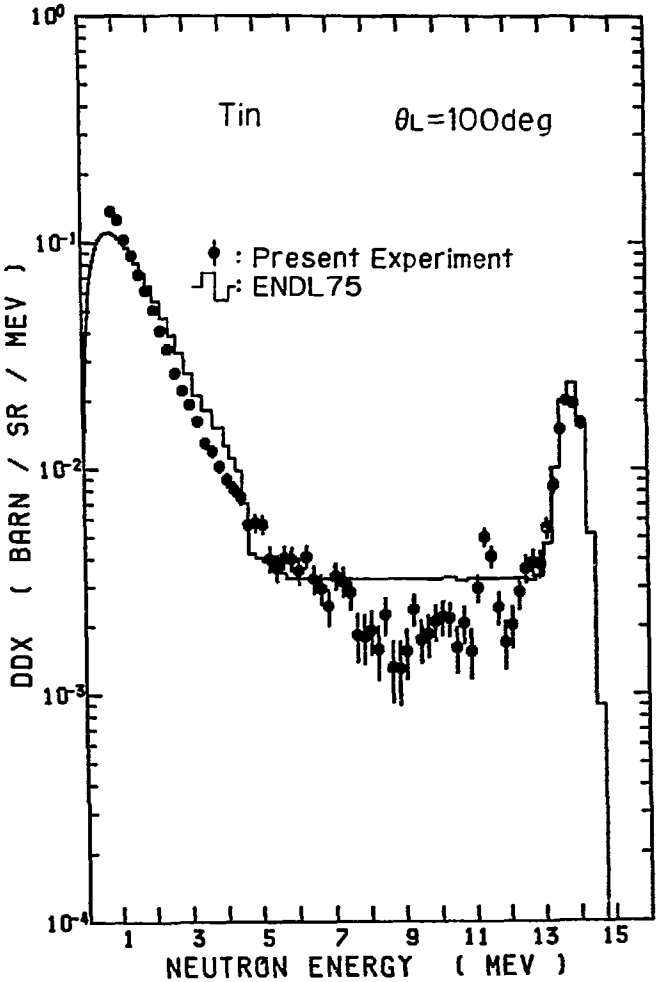

Fig.S-10 Double differential neutron emission cross sections at 100 deg, for Sn

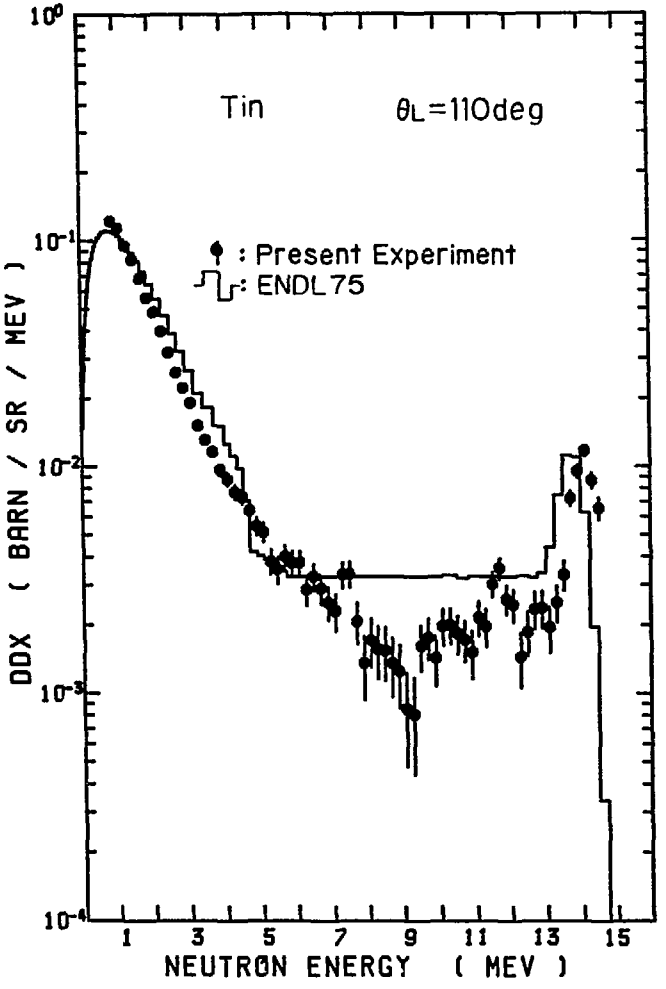

Fig.S-11 Double differential neutron emission cross sections at 110 deg, for Sn

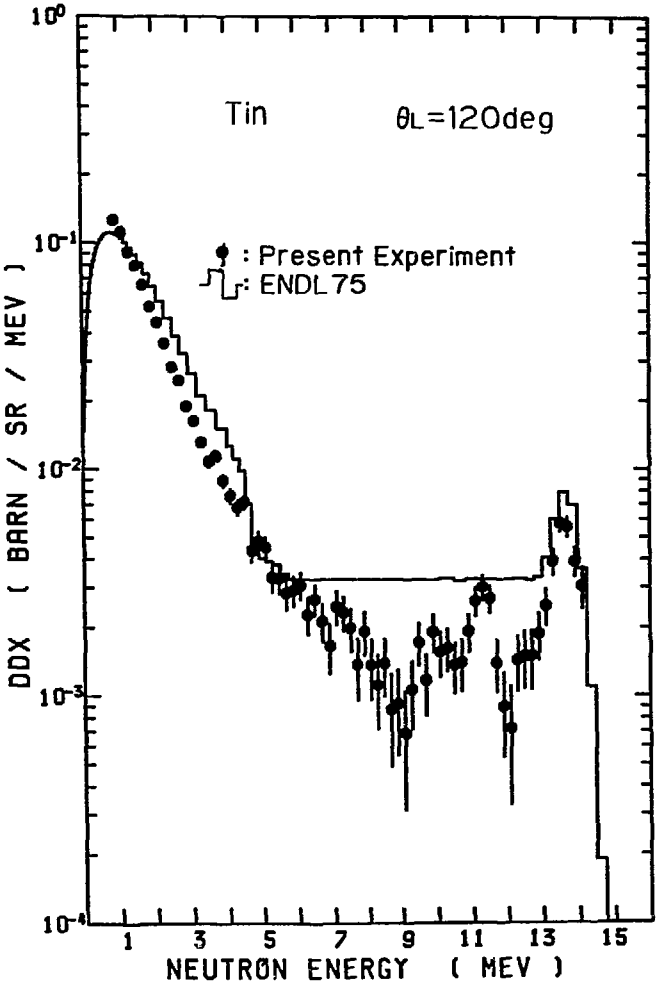

Fig.S-12 Double differential neutron emission cross sections at 120 deg, for Sn

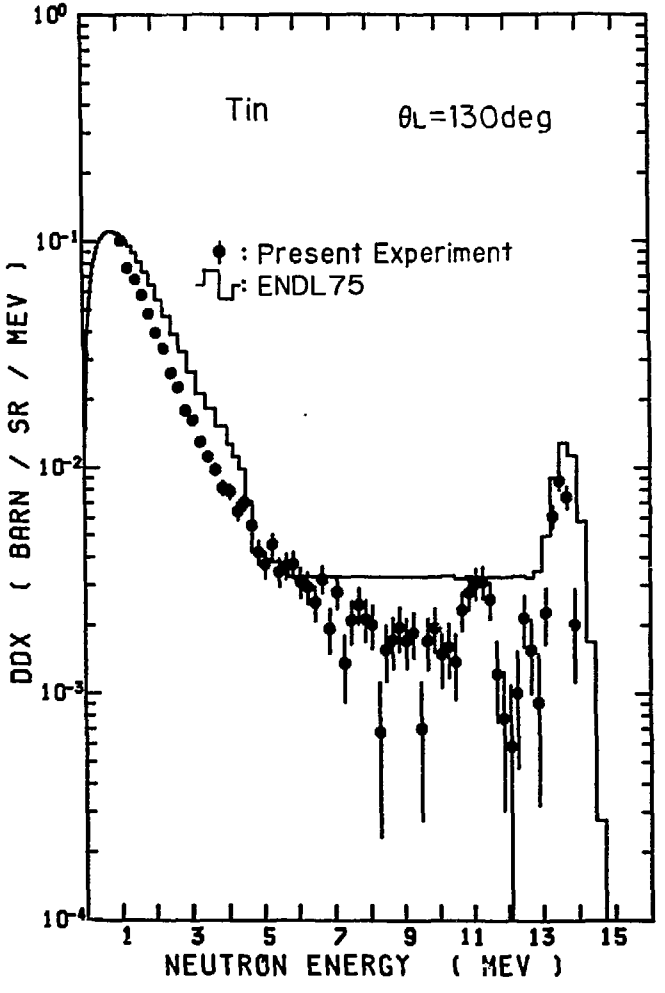

Fig.S-13 Double differential neutron emission cross sections at 130 deg, for Sn

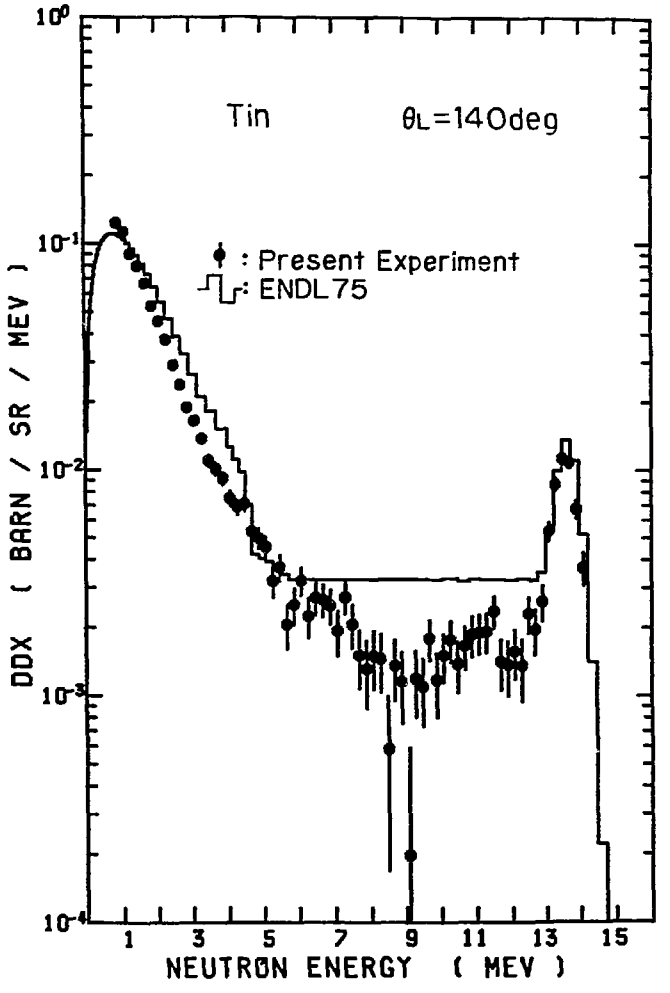

Fig.S-14 Double differential neutron emission cross sections at 140 deg, for Sn

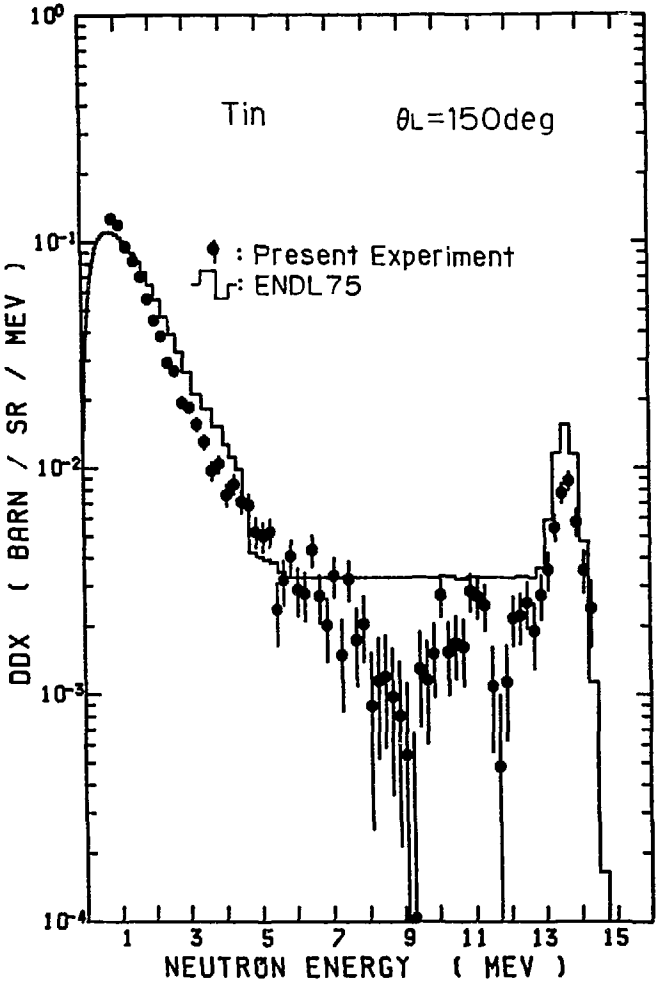

Fig.S-15 Double differential neutron emission cross sections at 150 deg, for Sn

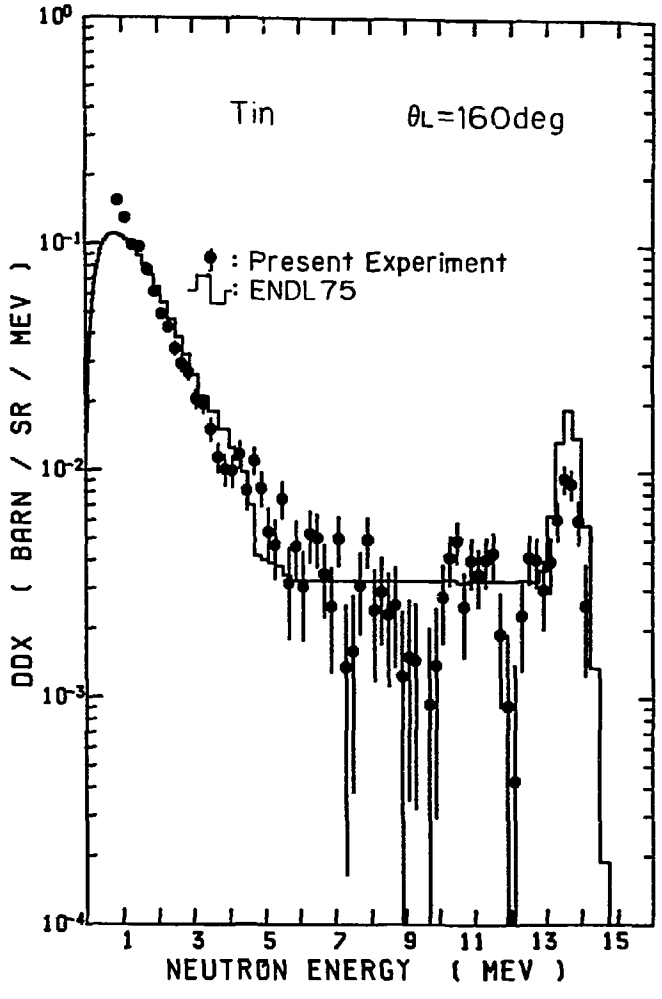

Fig.S-16 Double differential neutron emission cross sections at 160 deg, for Sn

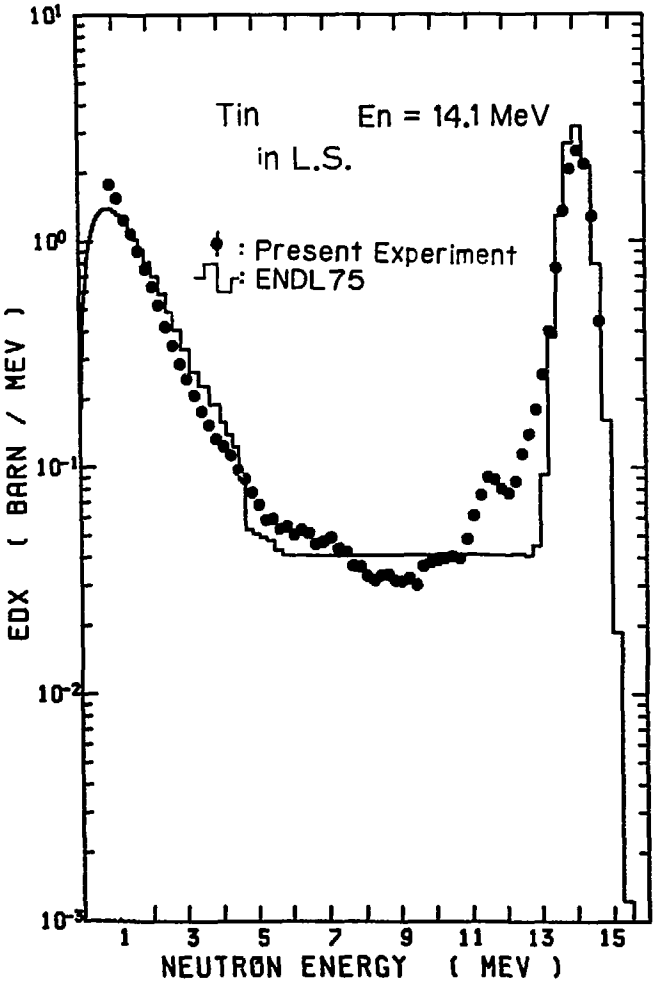

Fig.S-17 Angle-integrated neutron emission spectra in LAB system, for Sn

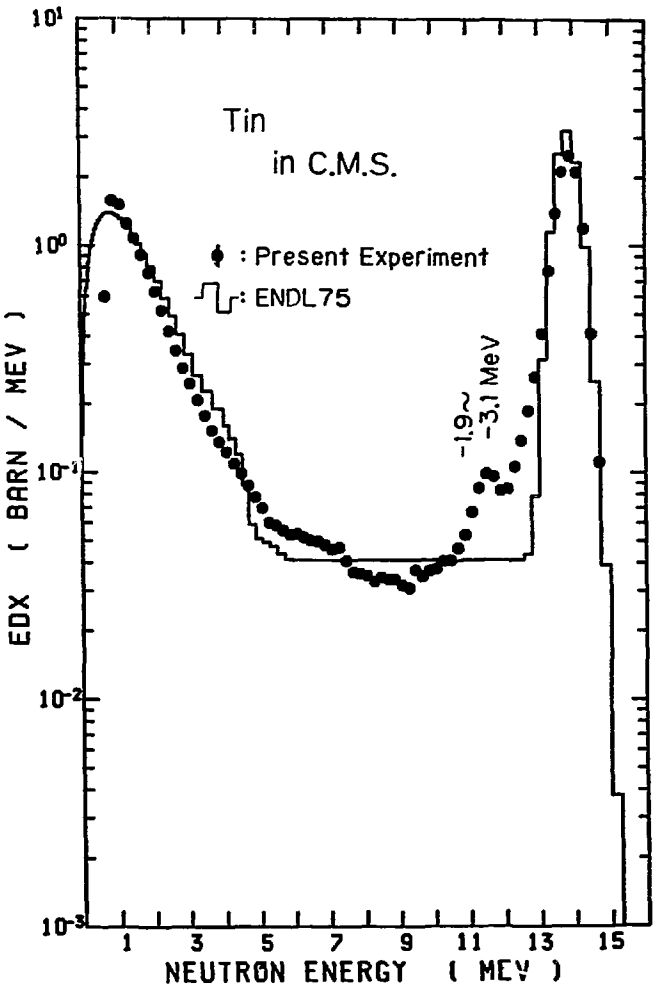

Fig.S-18 Angle-intgrated neutron emission spectra in CMS, for Sn

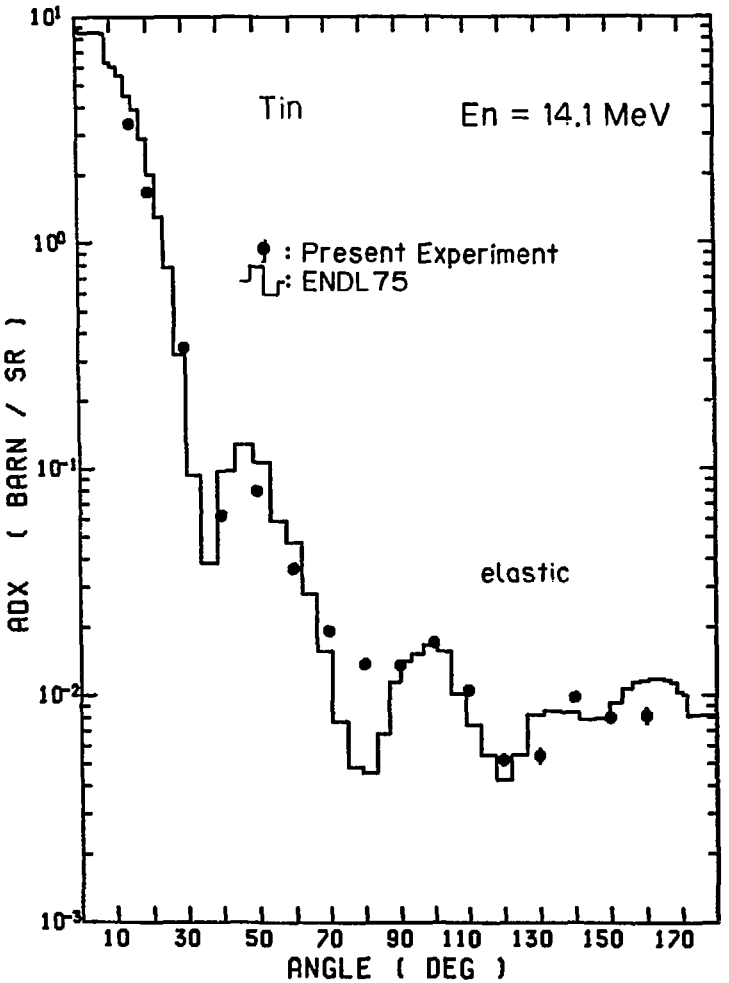

Fig.S-19 Diferential elastic scattering cross sections, for Sn

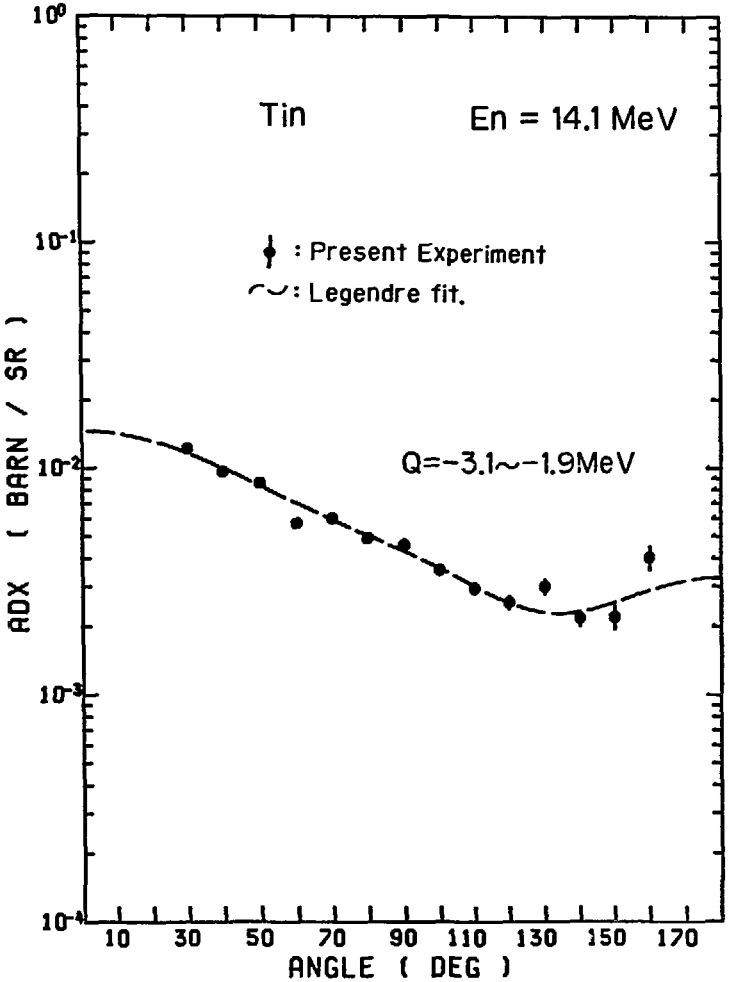

Fig.S-20 Differential inelastic scattering cross sections, for Sn