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Progress on CENDL−3

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CENDL−3 was started in 1996. Since then, great progress has been made at CNDC(Chinese Nuclear Data Center) and CNDN(Chinese Nuclear Data Network). The main progress in 1997 is summarized as following.

1 General Purpose File

According to the plan, CENDL−3 will be completed by 2000, and will contain 200 nuclides. Among them, the data of following nuclides will be newly or reevaluated: fissile nuclides 15, structure materials 18, light nuclides 5, fission products 91. It will contain consistent data between natural elements and their isotopes for structure material, newly evaluated data for fission products, much improved secondary neutron spectra for light nuclides and more γ-production data(files 12−15), double differential cross section(file 6), covariance matrix(files 31−35).

1.1 Fissile Nuclides

The codes for calculating complete data of fissile nuclides have been formed a complete set, including APOM(automatically adjusting parameter optical model program), FUNF(Hauser-Feshbach theory, exiton model) and ECIS95(coupled channel optical model). The first two codes were developed at CNDC.

The evaluation of ^{238}U complete data is under way. The cross section of inelastic scattering was evaluated and calculated by using ECIS95, the result(Fig.1) is consistent with what recommended by the subgroup on ^{238}U inelastic scattering of NEA WP on International Evaluation cooperation.

The theoretical calculations have been primarily completed for ^{239}Pu as well as ^{238,240,241,242}Pu and ^{235}U as well as ^{233,234}U.

1.2 Structure Material

Much effort has been made to make energy balance between energy taken by the outgoing particles and available energy for data calculated by means of NUNF, a code of Hauser-Feshbach theory and exiton model for natural element. In this regard, the Q-value for natural element is ill defined in the ENDF/B−6 format. This must be paid attention to when check energy balance by using ENDF utility program and make some correction for available energy.

A code has been developed and improved for adjusting data consistence between natural element and its isotopes.

The evaluation of complete data for natural Ni and its isotopes ^{58,60,61,62}Ni have been completed. The data of natural Fe and its isotopes ^{54,56,57,58}Fe, natural Hf and its isotopes ^{176,177,178,179,180}Hf have been calculated. The evaluations and calculations for natural Zr and its isotopes ^{90,91,92,94,96}Zr, natural Cu and its isotopes ^{63,65}Cu are under progress.

1.3 Light Nuclides

A method and some programs in the frame of statistical theory model have been developed for calculating complete data of light nuclide, especially for the double differential cross section. And good results have been obtained. The method is based on pre-equilibrium emission of exiton model not for continuous state but for concrete level. It has been approved that the main process(more than 80%) is pre-equilibrium emission. The different reaction mechanisms, including two and three bodies, are taken into account, the ratios between two and three body processes are determined by fitting experimental data. Using the method and programs, the calculations have been done and the primary results have been got for ^{9}Be(Fig.2), ^{12}C (Fig.3), ^{6}Li(Fig.4) and ^{14}N. The program for ^{7}Li is being improved.

The experimental double differential cross sections for ^{9}Be, ^{6,7}Li have been evaluated, and compared with the data of ENDF/B−6. It was found that differences between the data measured by different laboratories are quite large, even the shapes are different.

1.4 Fission Product Nuclides

For fission product nuclides, only files 1−5 are required, but there are large amount of nuclides to be involved(according to the plan, 91 nuclides for CENDL−3) and the measured data are quite scare for most of them. Taken into above fact, the program SUNF (simplified UNF) was developed and the systematics on the parameters for theory calculation has been studied.

So far the complete data of 11 nuclides have been finished, including theoretical calculation, experimental data evaluation, comprehensive adjusting and checking. The theoretical calculations have been completed for 30 nuclides.

2 Special Purpose File

According to the plan, also the special files for fission yield, activation cross section, and intermediate data will be developed.

2.1 Fission Yield

The fission yield data in Chinese Evaluated Nuclear Data Library CENDL/FY were evaluated in 1987, they need to be updated and supplemented. Great effort has been made for this goal since last year.

2.1.1 Reference fission yield

The 72 cumulative fission yield from $^{235,238}U$ fission, which can be used as reference yield, for 39 product nuclides were evaluated based on available experimental data up to now. Only absolute yield measurements and ratios were used, in other word, no standard yield was used in the evaluation. The data have been updated and their errors are reduced. The data have been used as standards in the fission yield evaluation.

2.1.2 Fission Yield Data Evaluation

Total about 230 cumulative fission yield data of 140 nuclides for $^{235,238}U$ and ^{239}Pu fission were evaluated, based on available experimental data and processed by means of code AVERAG for averaging with weight and code ZOTT for simultaneous evaluation. Also a set of programs has been developed for fission yield EXFOR data retrieval and format processing.

2.1.3 Dependence of Fission Yield on Energy

The dependence of fission yield on incident neutron energy has been studied for some important products from $^{235,238}U$ fission. It was found that it is linear for some product nuclides such as ^{95}Zr and ^{144}Ce, but it is not for others, such as ^{99}Mo(Fig.5) and ^{147}Nd(Fig.6). This is an interesting matter and need to be studied further experimentally and theoretically.

2.1.4 Model Calculation

The chain yields and independent yields were calculated with multi-Gauss model and Zp model and corresponding codes respectively for ^{235}U, ^{238}U and ^{239}Pu at thermal energy, fission spectrum and 14 MeV. In general, the results are in good agreement with experimental data, but multi-Gauss model could not describe the fine structures shown by experimental data, and the results of Zp model at fission spectrum need to be improved.

2.2 Activation cross section

The activation cross section file of Chinese Evaluated Nuclear Data Library CENDL−ACF was established. At present, it contains data of more than 500 reaction channels of about 100 nuclides, which were mainly evaluated in China, most of them were specially evaluated as activation and dosimetry data according to the requirement at home and of international cooperation(RCPs and CRP), and some were collected from the general purpose file of CENDL−2.1 and revised.

Follows were evaluated last year:

(1) Dosimetry data for reactor

^{46}Ti(n,p)^{46}Sc, ^{54}Fe(n,p)^{54}Mn, ^{59}Co(n,p)^{59}Fe, ^{60}Ni(n,p)^{60}Co, ^{181}Ta(n,2n)^{180m}Ta, ^{93}Nb(n,2n)^{92m}Nb, ^{93}Nb(n,n')^{93m}Nb etc.

(2) Activation cross section for astrophysics
^{63}Cu, ^{182}Os, ^{197}Au, ^{151}Eu, ^{175,176}Lu, ^{168,189}Tm(n,γ); ^{187}Re(n,p) etc.

(3) Neutron induced helium production
^{55}Mn, ^{54}Fe, ^{59}Co, ^{62}Ni, ^{63}Cu(n,α) etc.

(4) Activation cross section for fusion, safety, waste maintenance
^{58,60}Ni, ^{63}Cu(n,P); ^{58}Ni(n,d); ^{63}Cu(n,α); ^{59}Ni, ^{65}Cu, ^{153}Eu, ^{187}Re, ^{191}Ir(n,γ); ^{60}Ni, ^{65}Cu, ^{93}Nb, ^{187}Re(n,2n) etc.

2.3 Intermediate Energy Data

The spallation neutron sources induced by proton on Pb, W targets were studied. The calculations were made for following reactions with codes CCRMN or SNSP, which were developed at CNDC:

(1) Pb thin target, Ep = 300 MeV, calculated quantities include cross section, neutron multiplicity and the yield of product nuclides.

(2) Pb, W thick target, Ep = 150 MeV, calculated quantities include neutron yields and spectra.

2.4 Photonulear reaction data

The complete data of photonuclear reaction up to 30 MeV, including cross section, double differential cross section, gamma production data of all possible reactions, have been evaluated and calculated by using code GUNF for nuclides ^{180,182,183,184,186}W, ^{90,91,92,94,96}Zr and ^{51}V.

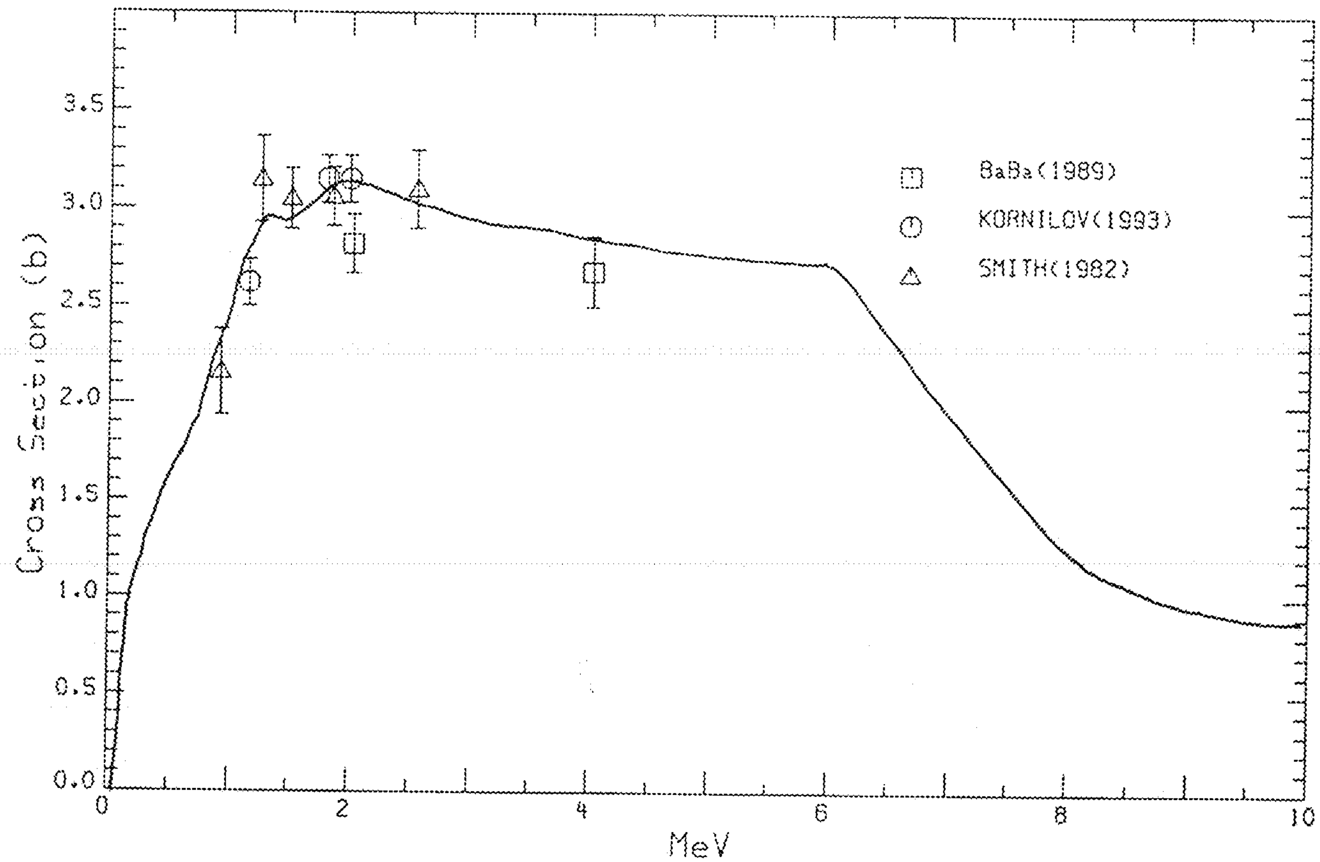

Fig.1 New evaluated $^{238}U(n,n')$ cross section

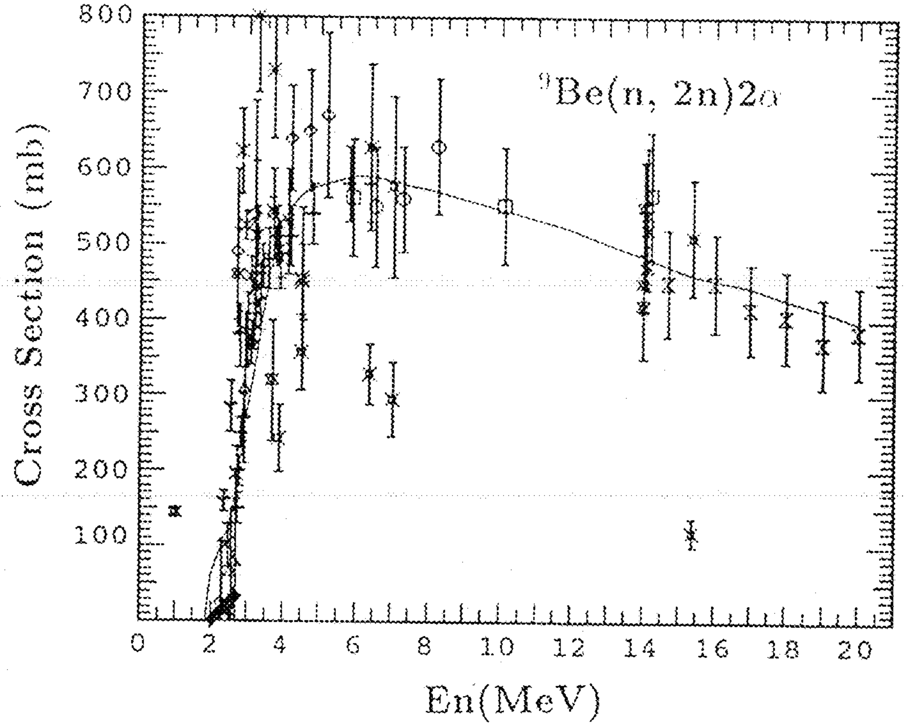

Fig.2.1 Calculated $^{9}Be(n,2n)$ cross section

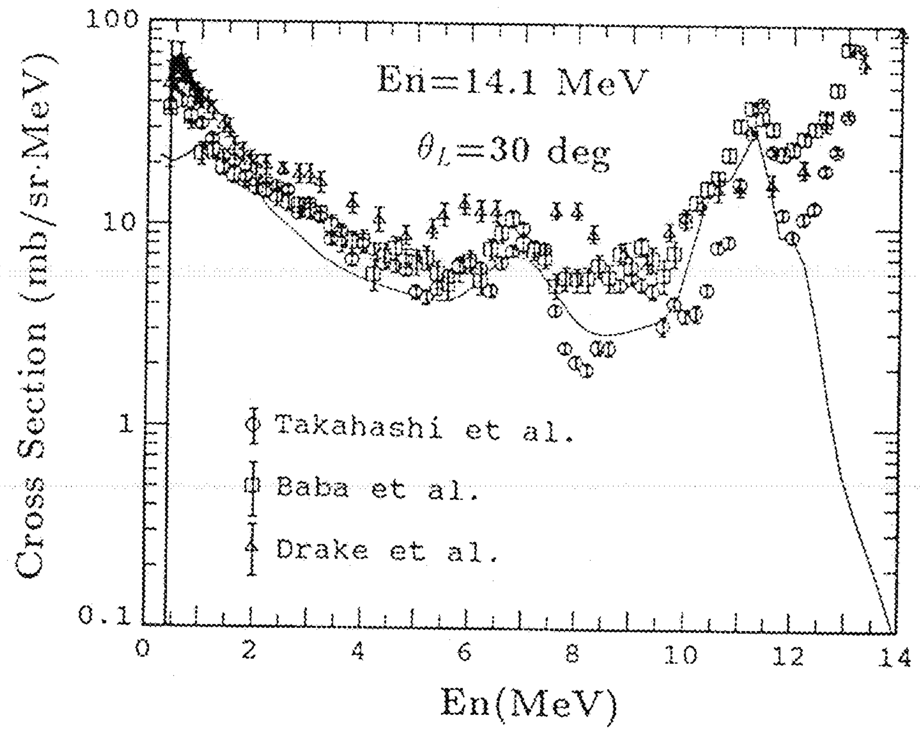

Fig.2.2 Calculated $^{9}Be(n,2n)$ double differential cross section

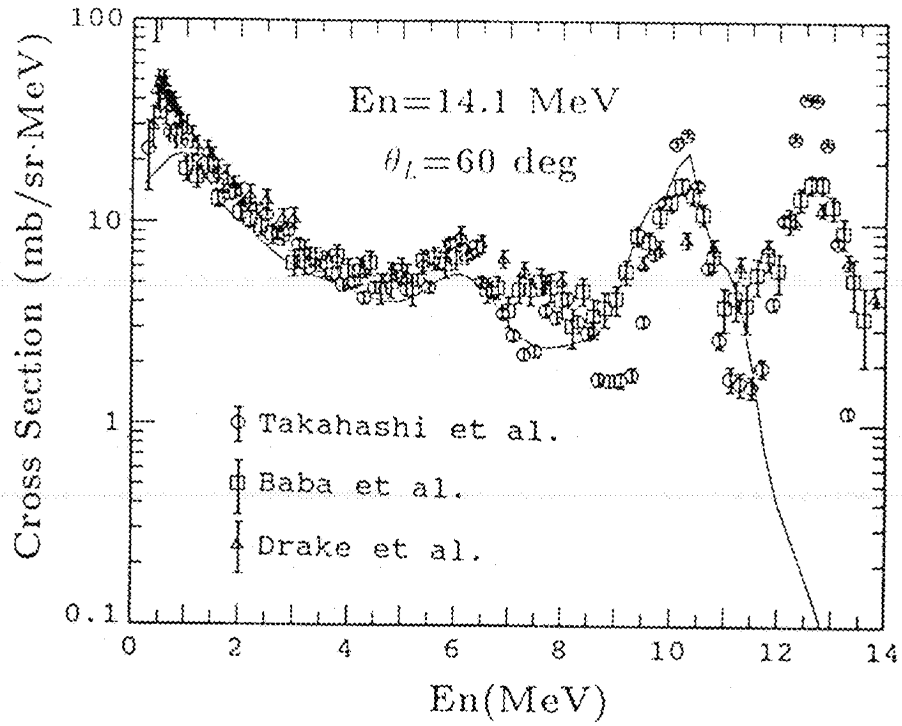

Fig.2.2 Calculated $^{9}Be(n,2n)$ double differential cross section(continue)

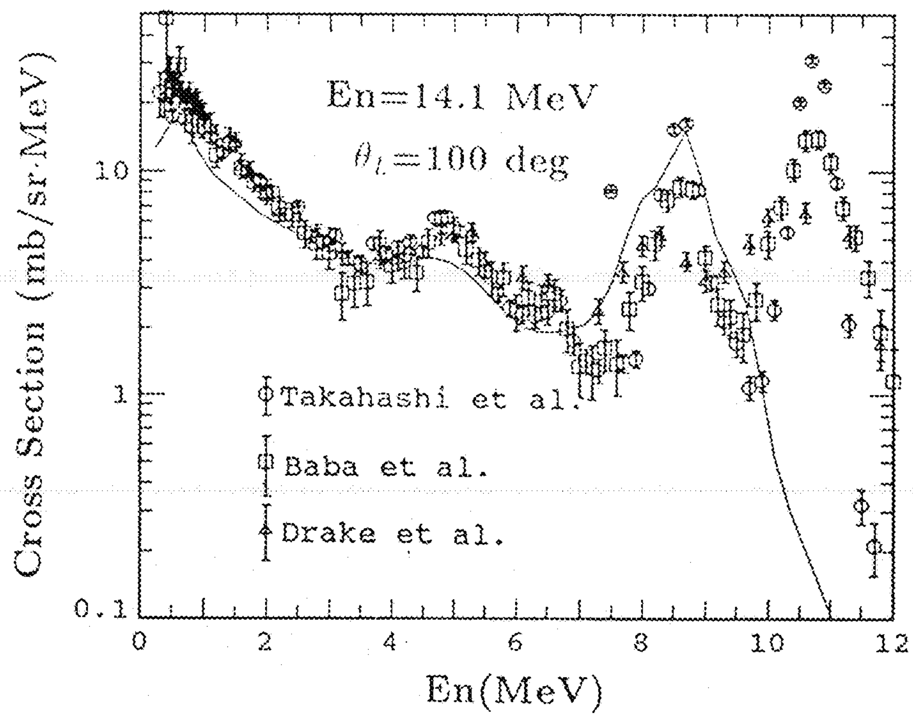

Fig.2.2 Calculated $^{9}Be(n,2n)$ double differential cross section(continue)

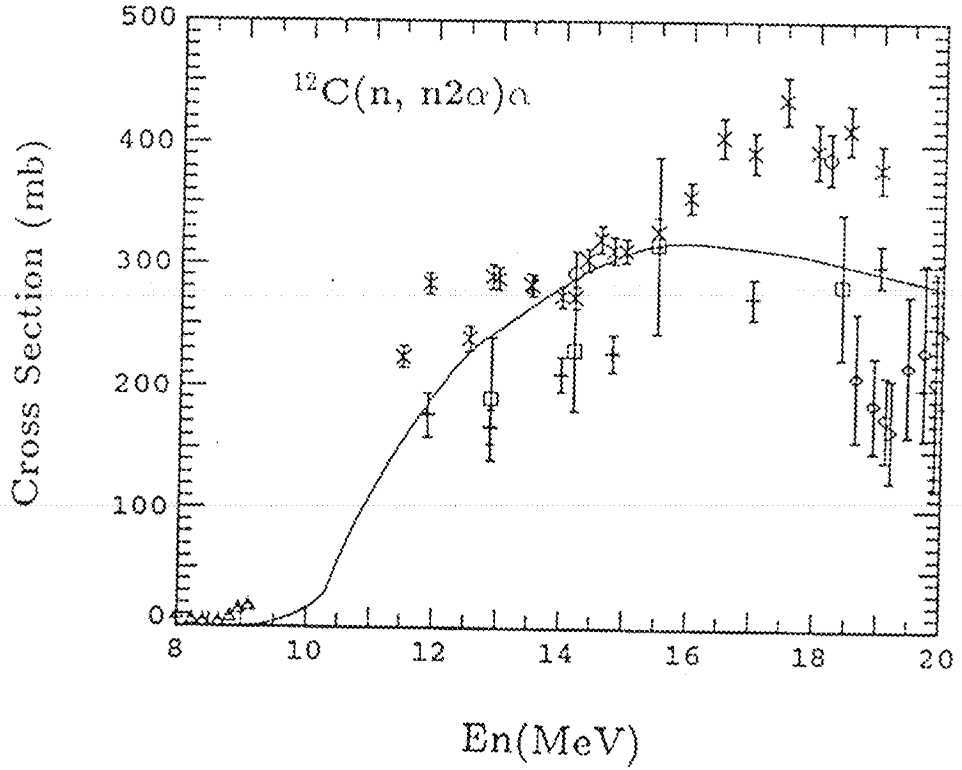

Fig. 3.1 Calculated $^{12}C(n,n'2\alpha)$ cross section

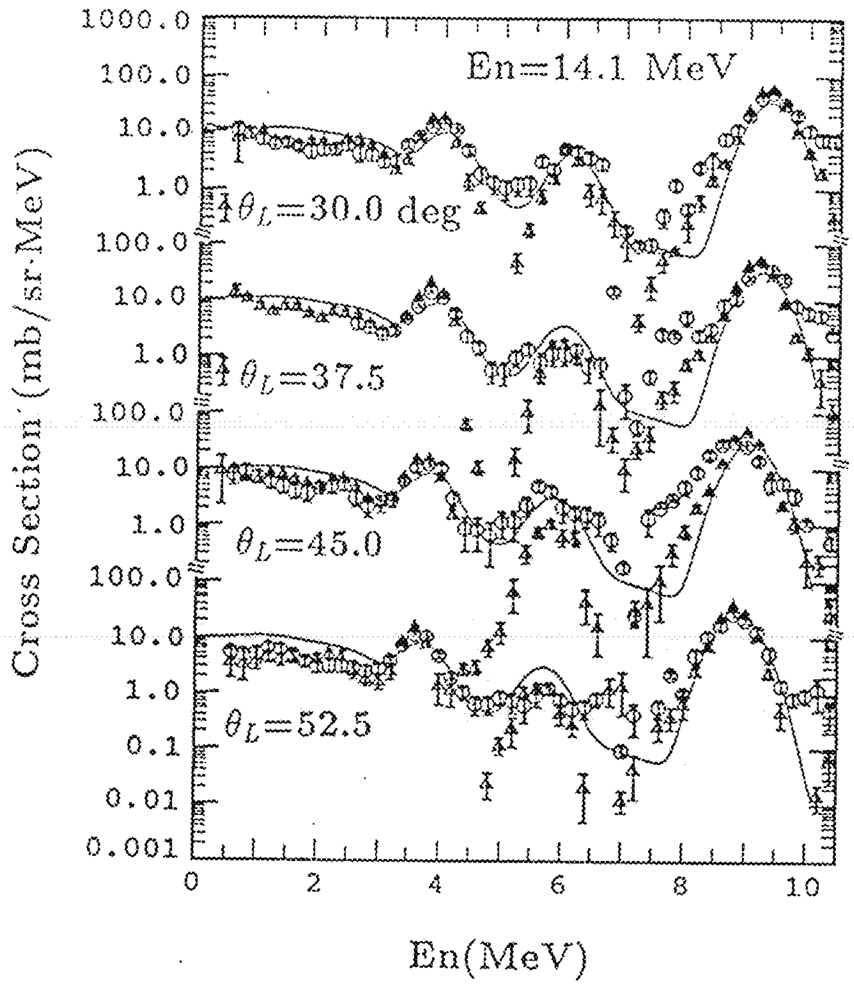

Fig.3.2 Calculated ^{12}C(n,n emission) double differential cross section .

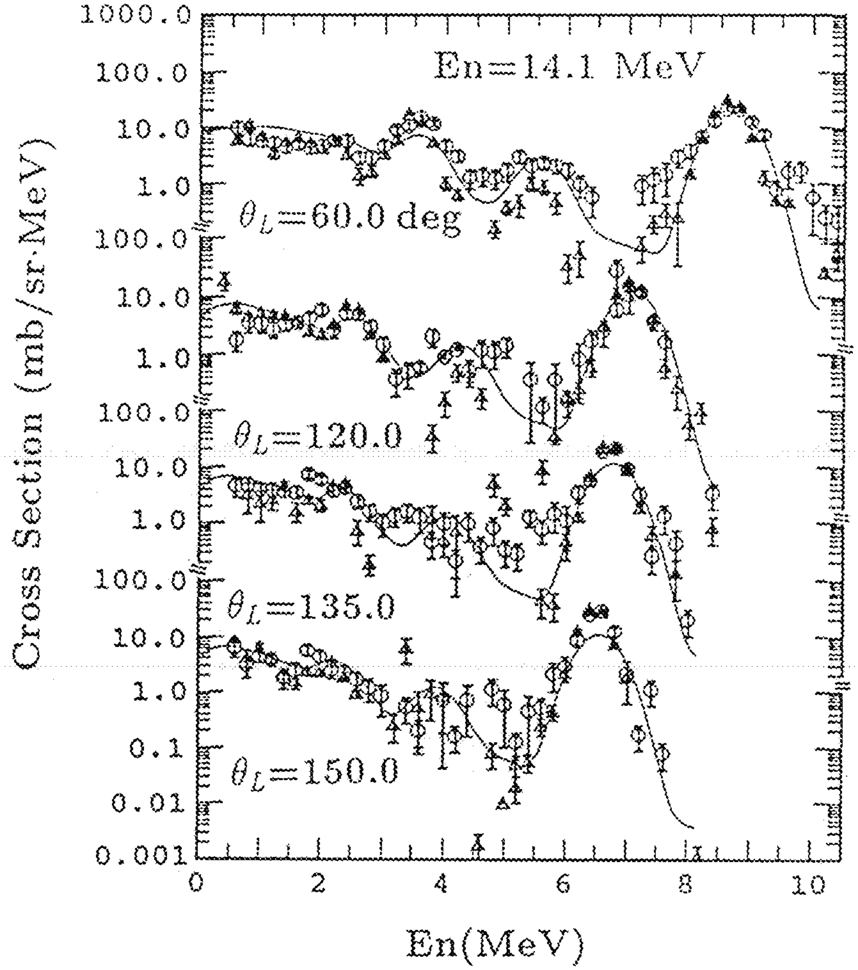

Fig.3.2 Calculated ^{12}C(n,n emission) double differential cross section(continue)

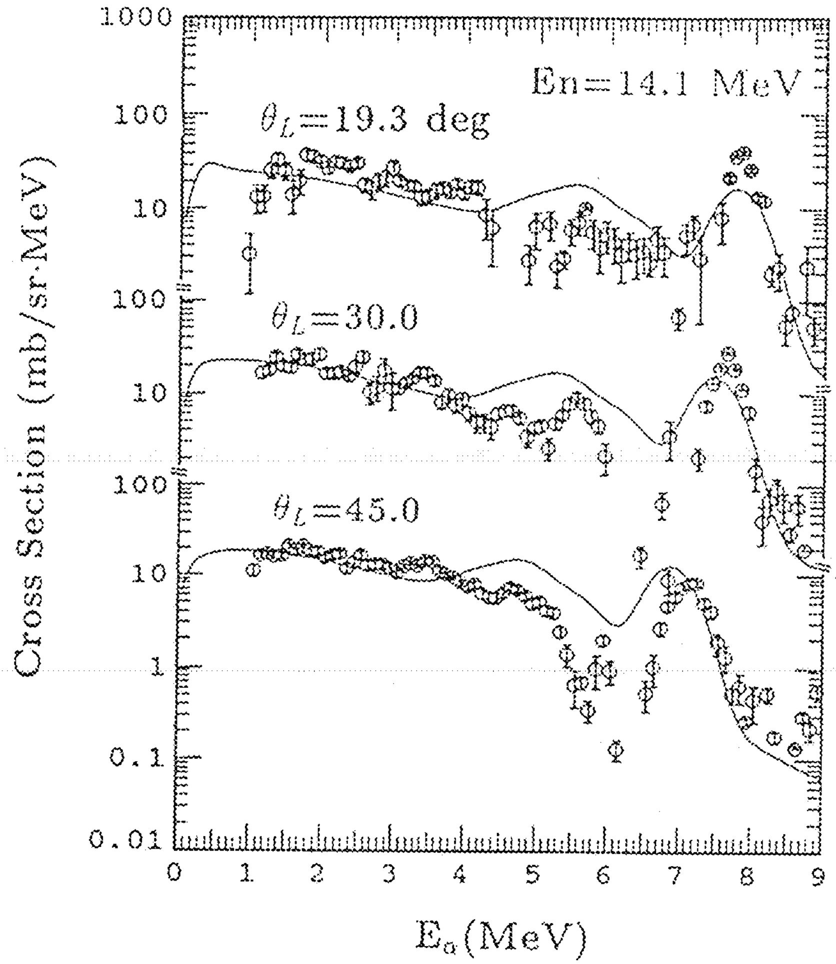

Fig.3.3 Calculated ^{12}C(n,α emission) double differential cross section

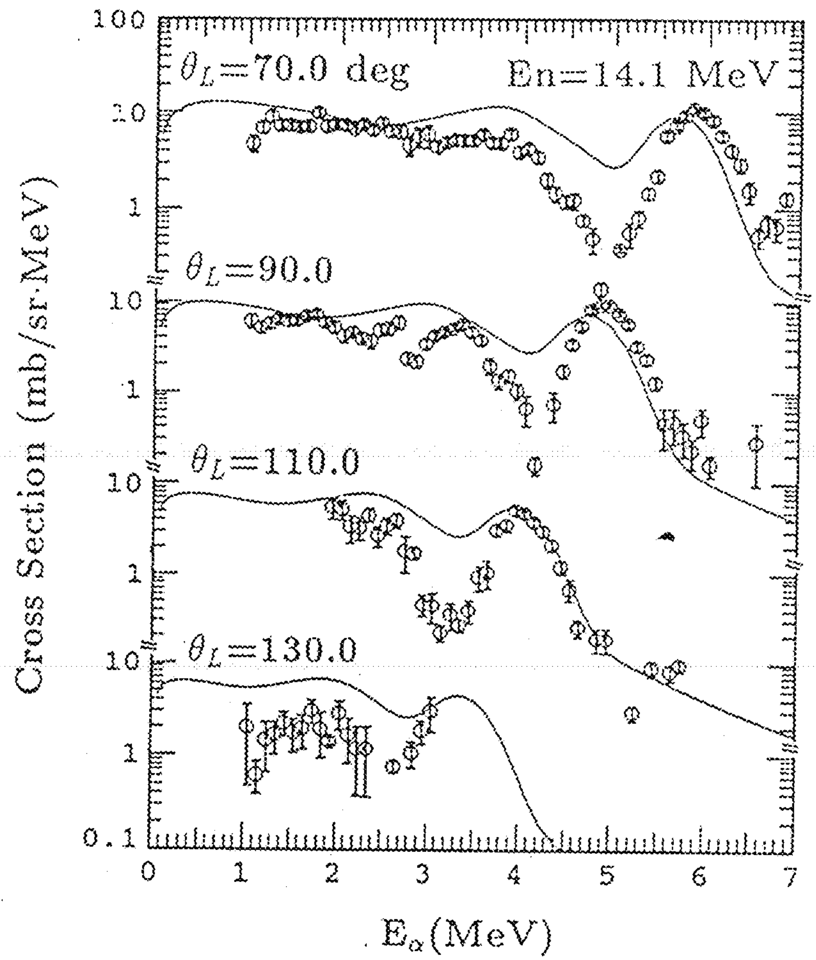

Fig.3.3 Calculated $^{12}C(n,\alpha$ emission) double differential cross section(continue)

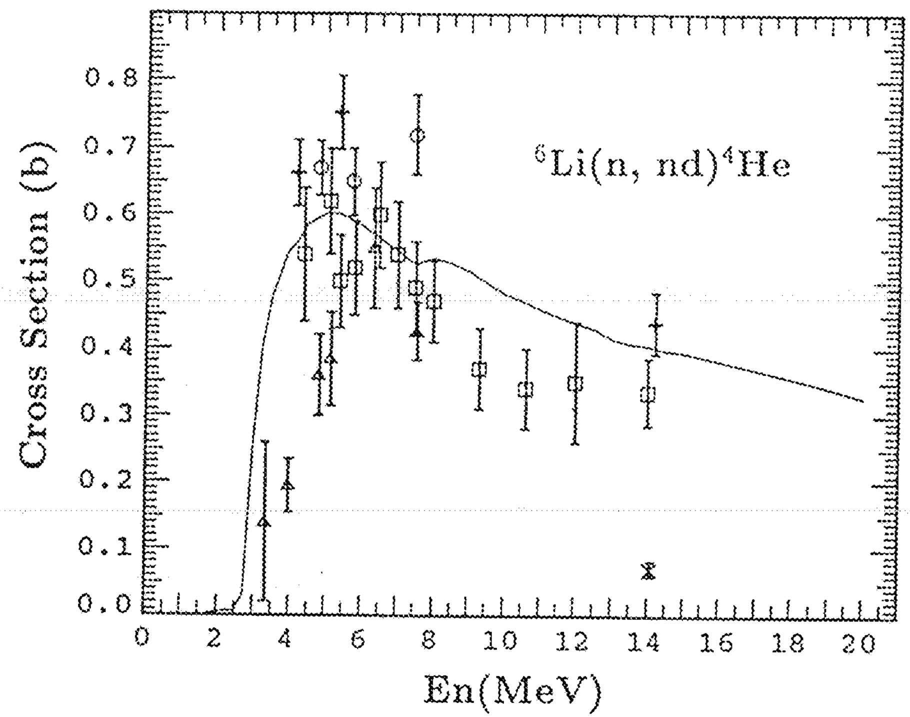

Fig.4.1 Calculated ^{6}Li(n,n'd) cross section

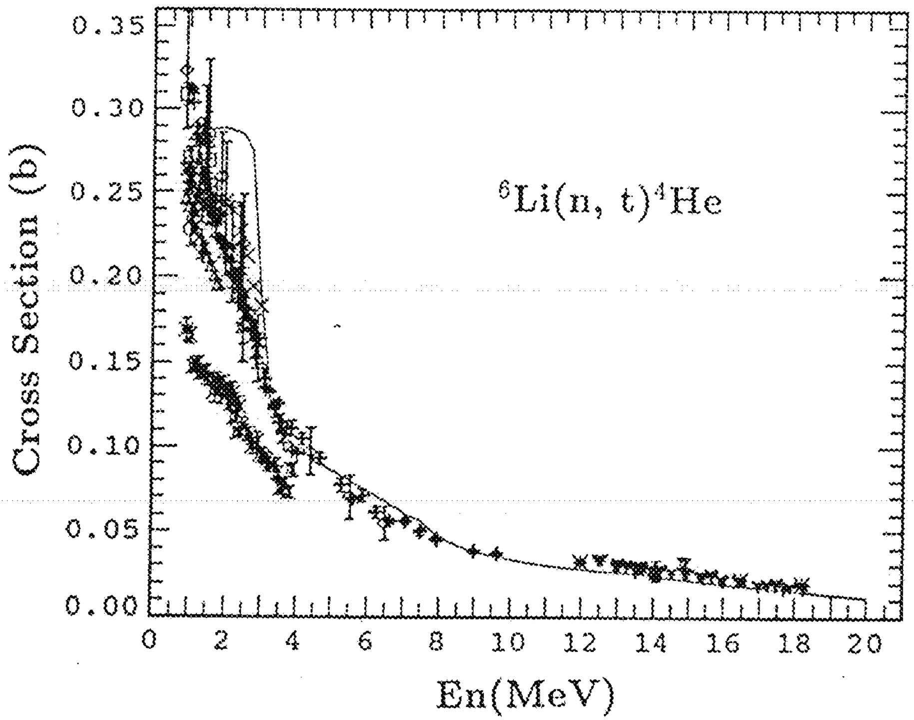

Fig.4.2 Calculated $^{6}Li(n,t)$ cross section

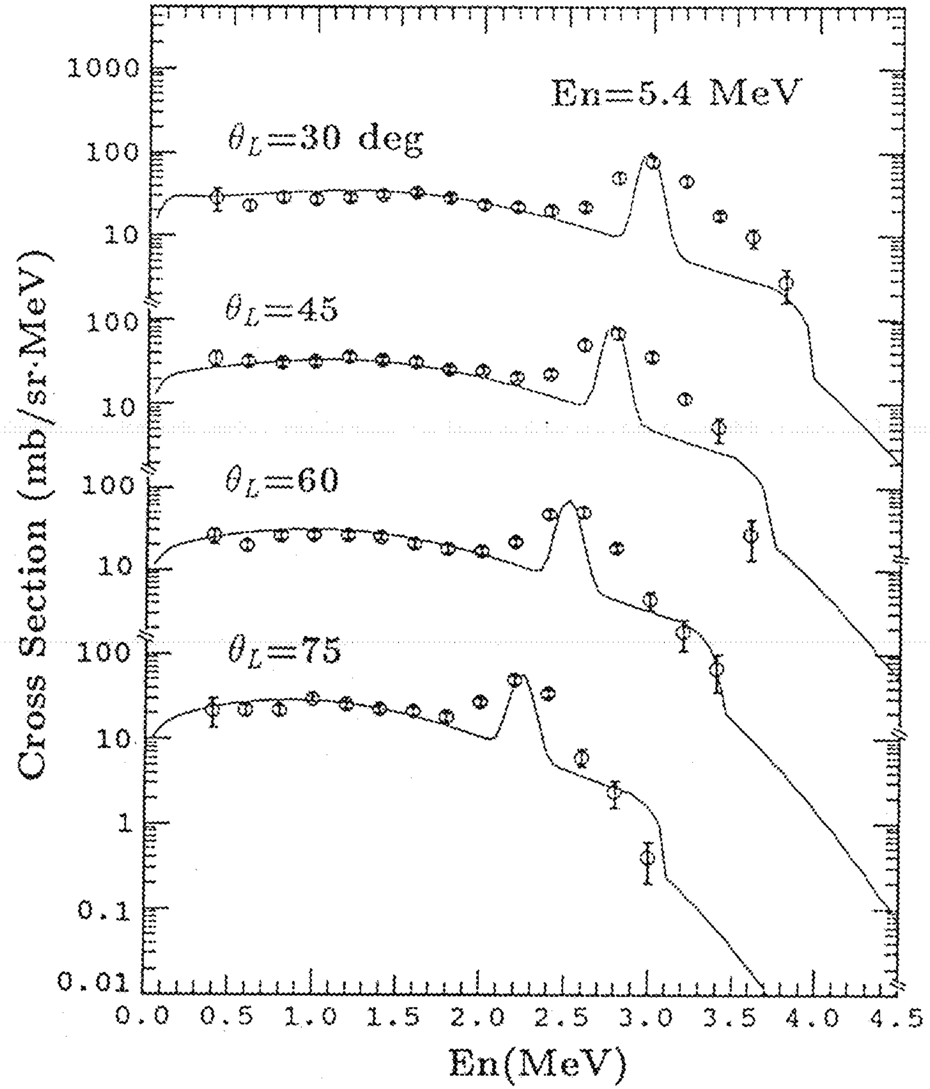

Fig.4.3 Calculated ^{6}Li(n,n emission) double differential cross section

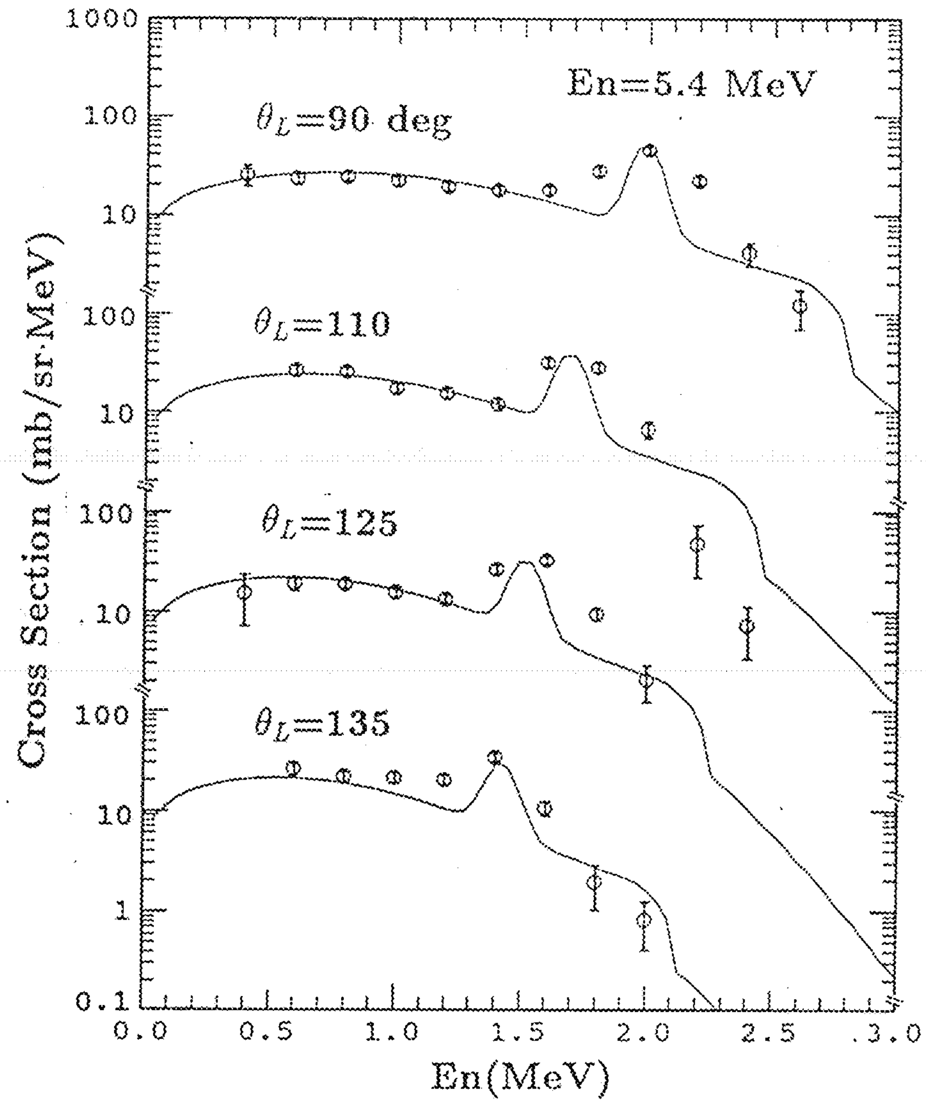

Fig.4.3 Calculated ^{6}Li(n,n emission) double differential cross section(continue)

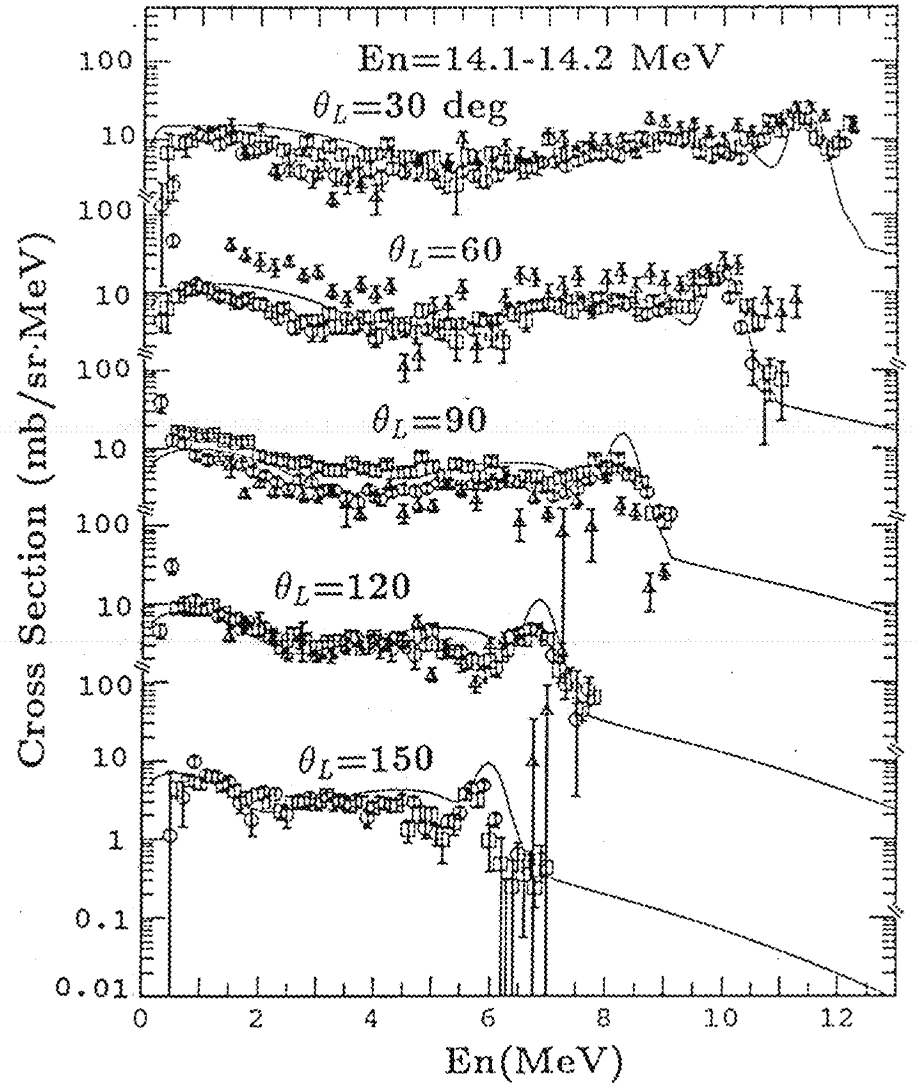

Fig.4.3 Calculated ^{6}Li(n,n emission) double differential cross section(continue)

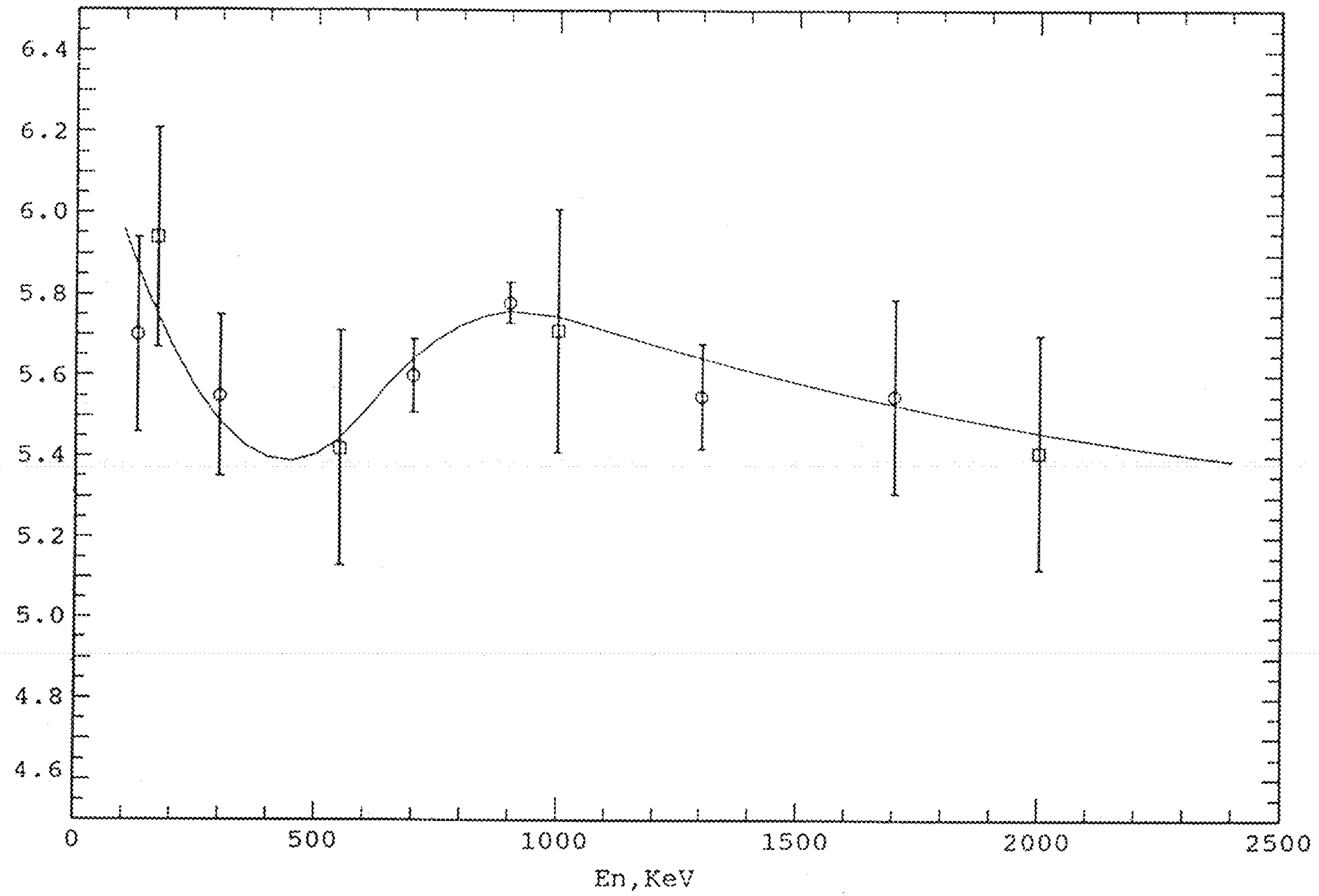

Fig.5 ^{99}Mo cumulative yield of ^{235}U fission (measured at monoenergies)

SPLINE FIT
12729002
20769002

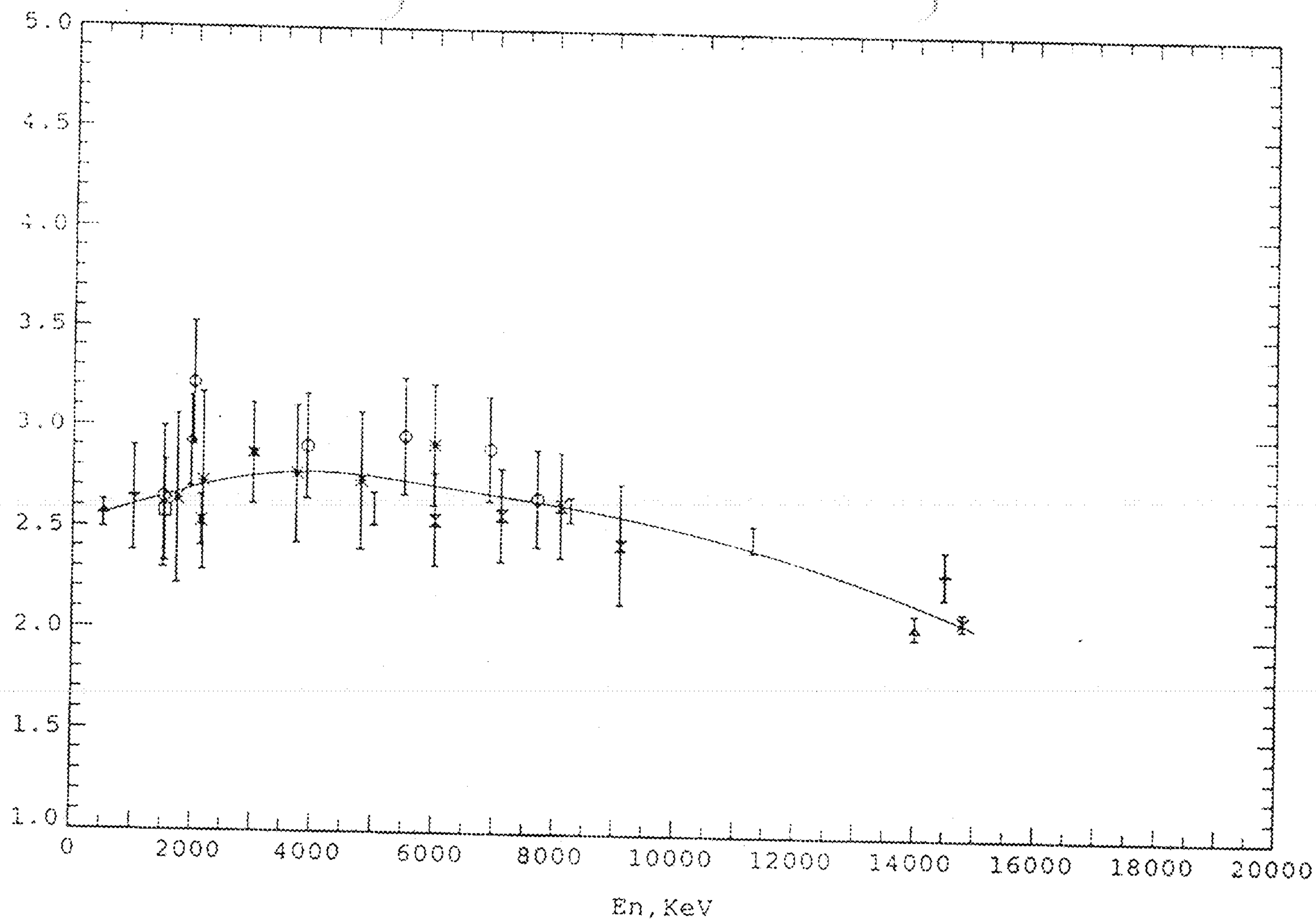

Fig.6 ^{147}Nd cumulative yield of ^{238}U fission

□	10683002	○	10798002
△	00014000	+	00014500
×	00014800	◇	32641195
✦	00000500	ᛉ	21155007
⌘	21306213	*	22111002
⌛	10828003	⌑	30743002
	32629002		30751811