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FSXLIB-J3R2 :
A CONTINUOUS ENERGY CROSS SECTION LIBRARY FOR MCNP BASED ON JENDL-3.2

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The continuous energy cross section library for the Monte Carlo transport code MCNP, FSXLIB-J3R2, has been generated from the latest version of Japanese Evaluated Nuclear Data Library Version 3 Revision 2 (JENDL-3.2) released in June, 1994. The nuclear data processing system, NJOY, and the compilation and verification code for MCNP libraries, MACROS, have been employed to produce the library after necessary modifications. Validity of the generated library has been confirmed by comparing it with JENDL-3.2. The FSXLIB-J3R2 library contains all the 340 nuclides stored in JENDL-3.2, and it is expected that the library will widely contribute to the field of nuclear energy.

Keywords: Cross Section Library, Nuclear Data, Continuous Energy, MCNP, NJOY, MACROS, JENDL-3.2, FSXLIB-J3R2, Monte Carlo Code

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FSXLIB-J3R2：
JENDL-3.2 に基づいた MCNP 用連続エネルギー断面積ライブラリ

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1994 年 6 月に公開された最新の日本の評価済み核データファイルである JENDL-3.2 に基づいた，モンテカルロ輸送計算コード MCNP 用の連続エネルギー断面積ライブラリ，FSXLIB-J3R2 を作成した。ライブラリの作成には，核データ処理システムNJOY と MCNP ライブラリ編集・検証コード MACROS に必要な修正を行い，これを使用した。ライブラリ中のデータを JENDL-3.2 と比較し，その妥当性を確認した。FSXLIB-J3R2 ライブラリは JENDL-3.2 に収納されている全 340 核種を含んでおり，今後原子力分野での幅広い貢献が期待される。

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1. Introduction

The MCNP code [1] is a three-dimensional general Monte Carlo code which has been widely used in various fields of atomic energy all over the world. In particular, MCNP is one of the standard codes at present in the field of nuclear designs of fusion engineering such as blanket and shielding designs. The primal feature of MCNP is that cross section data are treated as the point-wise, that is, the continuous energy form, in transport calculations. Hence, the cross section data in evaluated nuclear data files such as JENDL-3.1 [2], ENDF/B-VI [3] and so on, are reproduced in the libraries with high precision without any averaging of cross sections. In Japan, the FSXLIB-J3 [4,5] library produced from JENDL-3.1 has been used as a standard continuous energy cross section library for MCNP.

The general purpose Japanese Evaluated Nuclear Data Library Version 3 Revision 1 (JENDL-3.1) was released in 1990. Many cross section libraries for various transport calculation codes derived from JENDL-3.1 including FSXLIB-J3, were prepared and they were used for various applications. After releasing oh the JENDL-3.1, some problems were pointed out, such as the data inconsistency and the insufficient data accuracy. Thus, re-evaluation of JENDL-3 was carried out in order to solve the above problems by adding new evaluations and improving accuracy of the data. At the end of June, 1994, JENDL-3.2 (JENDL-3 Revision 2) [6,9] has been released for public use. In JENDL-3.2, the cross section data of 340 nuclides are stored and the associated gamma-ray data are given for 66 nuclides.

In company with the re-evaluation work of JENDL-3.2, the continuous energy cross section library for MCNP based on JENDL-3.2, FSXLIB-J3R2, has been produced. The production of the FSXLIB-J3R2 library had been started since 1993 during the re-evaluation of JENDL-3.2. Benchmark tests of preliminary data of JENDL-3.2 were partly performed by using MCNP and FSXLIB-J3R2 in order to examine accuracies of the nuclear data and to find out problems in the nuclear data library. Several problems were pointed out by the benchmark test, and they were notified to the data evaluators to solve them. Thus, the FSXLIB-J3R2 library has already contributed to improve the accuracy of JENDL-3.2.

Chapter 2 describes the production procedure of FSXLIB-J3R2 including modifications performed to the NJOY [7] code and the MACROS [4] code. In chapter 3, results of verification of FSXLIB-J3R2 are outlined. Chapter 4 summarizes a prospect of future work.

2. Production of FSXLIB-J3R2

2.1 Modification of NJOY for Processing of JENDL-3.2

The NJOY code [7] is a nuclear data processing system used as a standard code throughout the world. The NJOY code was developed at Los Alamos National Laboratory in the United States. The NJOY code is one of a few nuclear data processing codes to be able to treat nuclear data files in the ENDF/B-VI format. Further, the NJOY code produces cross section libraries in various formats. Since there is no nuclear data processing code other than NJOY to produce ACE (A Compact ENDF) type cross section data from nuclear data files in the ENDF/B format, the adoption of NJOY is inevitable to produce continuous energy cross section libraries for MCNP.

The nuclear data file JENDL-3.2 employs not only the ENDF/B-VI format but also the ENDF/B-V format [3] because the most of nuclear data processing codes used in Japan are currently not able to process nuclear data files in the ENDF/B-VI format. In the present work, JENDL-3.2 in the ENDF/B-V format has been processed. The modified version [4] of NJOY83/6, which could process nuclear data files in the ENDF/B-V format, was used for processing of JENDL-3.1. Further modifications, however, have been found necessary in order to process JENDL-3.2. The modified parts are as follows (square brackets represent the name of corresponding module in NJOY):

1) an expansion of dimension sizes to store a large number of point-wise cross sections [ACER],
2) changes of the identification method of nuclides to convert photon production transition probability array (LO=2) into photon production multiplicities (LO=1) [HEATR, GROUPR, ACER],
3) a special treatment for lack of an inelastic photon production level (MF=12, MT=53) of ^{207}Pb [ACER],
4) a program bug for representation of the angular distributions for inelastic scattering reactions, in which very fine structures are seen especially for heavy nuclides such as ^{235}U and ^{238}U and high incident neutron energies. [ACER],
5) special treatments for plural subsections of NK in unresolved resonance parameter [UNRESR],
6) modification for processing of resolved resonance parameters in the Reich-Moore form [RECONR], and
7) processing of the averaged total and prompt numbers of neutrons per fission ($\bar{\nu}$ and $\bar{\nu}_p$; MF=1, MT=452 and 456, respectively) of ^{235}U in which a number of interpolation ranges

is larger than 1 [RECONR].

Since the program bug for the angular distribution as described in the item 4), has not been resolved, only renormalization has been performed. Therefore, small distortions of the angular distribution still remained for some nuclides in the library after the renormalization.

The module structure and input data for NJOY are kept unchanged as those for the original version of NJOY. The format of output files for the NJOY used in this work is the same as that for the previously modified version [4] of NJOY.

2.2 Update of MACROS

The MACROS code [4] is a compilation and verification code of continuous energy cross section libraries for MCNP. As for compilation functions of MACROS, addition, deletion and replacement of cross section data in MCNP libraries are furnished. The ACE type cross section data from NJOY are automatically converted into continuous energy type cross section data for MCNP when they are added to a library. Both a directory file and a continuous energy cross section library are produced at the same time. As regards verification functions, cross section, angular distribution and energy distribution data of secondary particles in MCNP libraries can be compared with the original data in evaluated nuclear data files.

The MACROS code has been updated for the production of FSXLIB-J3R2 (MACROS version B). The updated items are as follows:

1) a change of the type of directory files, direct access file to sequential file, because of consistency with the original format of MCNP libraries,
2) a change of the reference method of directory information for each nuclide, and
3) an addition of two new options for the verification functions (a function to plot difference between two nuclides, and a function to plot neutron reaction cross section).

The input manual of the updated MACROS code is attached in the Appendix.

2.3 Processing of JENDL-3.2

The continuous energy cross section library for MCNP based on JENDL-3.2, FSXLIB-J3R2, has been prepared by following the same procedures used for FSXLIB-J3. The procedure is as follows (see Fig. 2.1).

1) JENDL-3.2 is processed by the modified version of NJOY to produce ACE type cross section data for each nuclide.

2) The ACE type cross section data are compiled into FSXLIB-J3R2 by using the updated MACROS code.
3) Cross section data in FSXLIB-J3R2, that is, cross sections and angular- and energy-distribution data of secondary neutron and photon, are verified by using MACROS. If a problem is found through the verification, NJOY is modified and the procedures 1) and 2) are repeated.

The modules in Fig. 2.1 have been used among various NJOY modules in order to obtain the ACE type cross section data.

The input data settings for NJOY to process JENDL-3.2 have been selected as shown in Table 2.1 considering broad application areas of MCNP. The processing conditions have been the same as those adopted to produce FSXLIB-J3.

The cross section data of natural chlorine in JENDL-3.2 could not be processed by the modified NJOY code because of a difficulty found in processing, the energy dependent expression of the scattering radius in the resonance parameters (MF=2). The expression is not allowed by the ENDF/B-V format but by the ENDF/B-VI format, hence the modified NJOY could not treat it. Therefore, the point-wise cross section data of natural chlorine has been produced by the RESENDD code [8] with the liner-liner interpolation mode. Then the processing has been succeeded by NJOY code to obtain ACE type cross section data.

The processed ACE type cross sections were compiled into the FSXLIB-J3R2 library by MACROS. Finally, the FSXLIB-J3R2 library was completed in September, 1994.

2.4 Characteristics of FSXLIB-J3R2

Essential informations of the FSXLIB-J3R2 library are shown in Table 2.2. The library includes all the 340 nuclides stored in JENDL-3.2. Gamma-ray production data are supplied for 66 nuclides as similar to JENDL-3.2. The temperature considered in Doppler broadening is 2.53×10^{-8} MeV (equal to 300 K). The neutron energy range covers from 10^{-11} to 20 MeV, the same as that of JENDL-3.2. There are two library identifier, namely, 36 and 37. The identifier 37 is adopted for elements and isotopes in the ground states while 36 is for isotopes in meta-stable states. For example, the nuclides specified by 95241.36c and 95241.37c stand for ^{241m}Am and ^{241g}Am, respectively. The nuclides stored in the FSXLIB-J3R2 library are summarized in Table 2.3 with some other useful informations.

Data size of FSXLIB-J3R2 is about 328 MBytes in the type-1 (sequential file, text format) and about 62 MBytes in the type-2 (direct access file, binary format). Since the file sizes are huge and are not convenient to transfer the library and to store the data on computers as one single file, the library are divided into three files; File-A, -B and -C. Important 76 nuclides out of 340 are selected and stored in the File-A. The 76 nuclides are selected by applying the following three criteria.

1) When cross section data for an element consist of both data for natural abundance and those for each isotope, the latter data are excluded; i.e., 12-Mg-0 is included for the selected version but 12-Mg-24, -25 and -26 are not.
2) Nuclides related to fusion and shielding applications are chosen for the selected version. Those related fission application, that is, most of actinoides and fission products, are not chosen.
3) Unstable isotopes are excluded.

The rest of the nuclides are stored in the File-B and -C. In the File-B, isotopes of medium-heavy nuclei and actinoids except fission products are stored. The fission products, that is, from 34-Se-79 to 65-Tb-159, are stored in the File-C. Data sizes of the three files in the type-1 are 116, 82 and 130 MBytes, respectively. Each can be stored in one 150 MBytes 1/4" cartridge tape for work stations.

3. Verification of FSXLIB-J3R2

It is essential to verify the consistency of the produced FSXLIB-J3R2 library with the original JENDL-3.2 file and to check whether all the cross section data are compiled to meet with the specified format. Although some discrepancies have been exist between them, such as Doppler broadening of resonance peaks, treatment of resonance parameter, interpolation scheme and expression of angular distribution, the continuous energy cross section data have a nearly one-to-one correspondence to the original nuclear data libraries. Hence, verification of the library is possible by directly comparing the cross section data in FSXLIB-J3R2 with those in JENDL-3.2.

The MACROS code [4] have been used to verify the FSXLIB-J3R2 library. The direct comparisons between numerical data stored in original nuclear data files and in MCNP libraries are possible by using the MACROS code as well as visual checking of plots of cross section data. Number of data in the library are so huge that verification of all the data contained in the library have not been carried out. Thus, several important nuclides have been selected out of 340 nuclides for the verification. The selected nuclides are listed in Table 3.1 with verified items.

Neutron cross sections of iron in the FSXLIB-J3R2 library have been compared with those in JENDL-3.2. Figures 3.1 to 3.3 shows the elastic scattering, inelastic scattering and neutron capture cross sections of iron, as examples of the comparisons. The angular distributions of secondary neutrons in 32 equal probability bins stored in FSXLIB-J3R2 have been plotted with the distribution taken directly from JENDL-3.2. Figures 3.4 to 3.6 shows the angular distributions of the elastic scattering for oxygen, iron and uranium-238. The direct comparison between FSXLIB-J3R2 and JENDL-3.2 have been performed for numerical data for energy distributions of secondary neutrons. When the distributions are given in tabulated function, the data are plotted as presented in Figs. 3.7 to 3.9. These figures show the secondary energy distributions emitted from Mo(n,2n), Mo(n,n'_{cont}) and ^{235}U(n,fission) contained in the library. Figures 3.10 to 3.16 show a part of gamma-ray production cross sections of aluminum-27. They consist of gamma-ray production multiplicities, emission probabilities of discrete gamma-rays, gamma-ray production cross sections and energy spectra of secondary gamma-rays. The direct comparison of numerical data for multiplicities between FSXLIB-J3R2 and JENDL-3.2 have been made. It is seen from all the figures that the cross section data in FSXLIB-J3R2 agree with those in the original JENDL-3.2 and no invalid or inconsistent data are found.

As another attempt of verification, the nuclear data in FSXLIB-J3R2 have been compared with those in FSXLIB-J3. Figures 3.17 to 3.20 are the comparison plots for total and elastic scattering cross sections of iron. Differences of nuclear data between two libraries

are clearly seen in the figures, however, they are found to be small enough and can be disregarded. This fact is one of the evidences supporting validity of the data.

According to the verification, it is safe to say that the cross section data in FSXLIB-J3R2 for the verified nuclide are equivalent to JENDL-3.2. Although all the data contained in FSXLIB-J3R2 have not been verified in the present work, it is considered that all the data in the library are valid as long as the original data in JENDL-3.2 are stored in the specified format, the modified NJOY deals with JENDL-3.2 correctly and there has been no human mistake during the work.

4. Summary

The continuous energy cross section library for the Monte Carlo transport code MCNP, FSXLIB-J3R2, has been generated from the latest version of Japanese Evaluated Nuclear Data Library JENDL-3.2 released in June, 1994. The nuclear data processing system, NJOY, and the compilation and verification code for MCNP libraries, MACROS, has been used to produce the library after necessary modifications. Validation of the generated library has been confirmed by comparing it with JENDL-3.2. The FSXLIB-J3R2 library contains all the 340 nuclides stored in JENDL-3.2, and it is expected that the library will widely contribute to the field of nuclear energy.

We have some future plans concerning a continuous energy cross section library for MCNP. These plans are as follows: 1) improvement of the verification methods, 2) improvement of the treatment for angular distribution of inelastic scattering, 3) adoption of the latest version of NJOY91 and 4) processing of coming JENDL Fusion File.

Acknowledgments

The authors would like to express their thanks to Dr. T. Nakagawa, S. Chiba, T. Fukahori, K. Shibata and Y. Kikuchi of the Nuclear Data Center of JAERI, and Dr. M. Takano of Department of Nuclear Fuel Cycle Safety Engineering of JAERI for their useful advice. The authors are indebted to Dr. T. Iijima and Dr. T. Suzuki of Nuclear Energy Data Center, and Dr. N. Yamano and Dr. H. Matsunobu of Sumitomo Atomic Energy Industries, Ltd. who have given us comprehension and opportunity for producing FSXLIB-J3R2.

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Table 2.1 Processing parameters for NJOY to produce FSXLIB-J3R2.

Module	Processing Parameter	Adopted Condition
RECONR	precision of pointwise cross sections	0.5 %
BROADR	precision of Doppler broadening	0.5 %
	temperature of cross sections	300 K (2.53×10^{-8} MeV)
THERMR	upper-limit energy of thermal energy region	4.6 eV
	inelastic option of thermal energy region	free gas model
GROUPR	multigroup photon production cross sections	neutron 30-groups, photon 94-groups, 1/E weight, P_L=5
ACER	number of equal-probability angular intervals	32

Table 2.2 Basic informations of FSXLIB-J3R2

Items	Description
reference evaluated nuclear data file	JENDL-3.2
number of nuclides included in the library	340 [nuclides]
number of nuclides including gamma-ray production data	66 [nuclides]
temperature	2.53×10^{-8} [MeV] (300K)
neutron energy range	10^{-11} to 20 [MeV]
total sizes of FSXLIB-J3R2 standard version, type-1 (text format) standard version, type-2 (binary format) sizes of each file of FSXLIB-J3R2 File-A, type-1 (text format) -B, -C, File-A, type-2 (binary format) -B, -C,	 328.2 [MBytes] 65.8 [MBytes] 116.4 [MBytes] 82.0 [MBytes] 129.8 [MBytes] 23.3 [MBytes] 16.5 [MBytes] 26.0 [MBytes]
evaluation identification ground state meta-stable	 37 36
type of nuclear data table	continuous energy neutron interaction data (identification: c)

Table 2.3 List of nuclides contained in the FSXLIB-J3R2 library.

Nuclide	ZAID	MAT	GPD	Length	NUBAR	Status	File
1-H - 1	1001.37c	125	yes	2422		revised	A
1-H - 2	1002.37c	128		6376		revised	A
2-He- 3	2003.37c	225	yes	3176		revised	A
2-He- 4	2004.37c	228		3319			A
3-Li- 6	3006.37c	325	yes	14049		revised	A
3-Li- 7	3007.37c	328	yes	19526		revised	A
4-Be- 9	4009.37c	425	yes	18522			A
5-B - 10	5010.37c	525	yes	29424			A
5-B - 11	5011.37c	528	yes	42876			A
6-C - 12	6012.37c	625	yes	24085		revised	A
7-N - 14	7014.37c	725	yes	53444		revised	A
7-N - 15	7015.37c	728	yes	25625		revised	A
8-O - 16	8016.37c	825	yes	43085		revised	A
9-F - 19	9019.37c	925	yes	34979		revised	A
11-Na- 23	11023.37c	1125	yes	49630		revised	A
12-Mg- 0	12000.37c	1200	yes	46291		revised	A
12-Mg- 24	12024.37c	1225		11976		revised	B
12-Mg- 25	12025.37c	1228		16019			B
12-Mg- 26	12026.37c	1231		12135			B
13-Al- 27	13027.37c	1325	yes	47340		revised	A
14-Si- 0	14000.37c	1400	yes	75373		revised	A
14-Si- 28	14028.37c	1425	yes	43048		revised	B
14-Si- 29	14029.37c	1428	yes	38103		revised	B
14-Si- 30	14030.37c	1431	yes	33007		revised	B
15-P - 31	15031.37c	1525	yes	31224		revised	A
16-S - 0	16000.37c	1600	yes	79771		revised	A
16-S - 32	16032.37c	1625		45010		revised	B
16-S - 33	16033.37c	1628		17858		revised	B
16-S - 34	16034.37c	1631		13634		revised	B
16-S - 36	16036.37c	1637		7934		revised	B
17-Cl- 0	17000.37c	1700		83467		new	A
17-Cl- 35	17035.37c	1725		52970		new	B
17-Cl- 37	17037.37c	1731		35357		new	B
18-Ar- 40	18040.37c	1837		99238		new	A
19-K - 0	19000.37c	1900	yes	64640		revised	A
19-K - 39	19039.37c	1925		28841		revised	B
19-K - 40	19040.37c	1928		9460		revised	B
19-K - 41	19041.37c	1931		23643		revised	B
20-Ca- 0	20000.37c	2000	yes	117187		revised	A
20-Ca- 40	20040.37c	2025	yes	51987		revised	B
20-Ca- 42	20042.37c	2031		32236		revised	B
20-Ca- 43	20043.37c	2034		25933		revised	B
20-Ca- 44	20044.37c	2037		26742		revised	B
20-Ca- 46	20046.37c	2043		9982		revised	B
20-Ca- 48	20048.37c	2049		11282		revised	B
21-Sc- 45	21045.37c	2125		79770		revised	A
22-Ti- 0	22000.37c	2200	yes	77625		revised	A
22-Ti- 46	22046.37c	2225		28667		revised	B
22-Ti- 47	22047.37c	2228		37002		revised	B
22-Ti- 48	22048.37c	2231		19525		revised	B

Table 2.3 Continued.

Nuclide	ZAID	MAT	GPD	Length	NUBAR	Status	File
22-Ti- 49	22049.37c	2234		24470		revised	B
22-Ti- 50	22050.37c	2237		17788		revised	B
23-V - 51	23051.37c	2328	yes	47006		revised	A
24-Cr- 0	24000.37c	2400	yes	122736		revised	A
24-Cr- 50	24050.37c	2425		47558		revised	B
24-Cr- 52	24052.37c	2431		37854		revised	B
24-Cr- 53	24053.37c	2434		32074		revised	B
24-Cr- 54	24054.37c	2437		24727		revised	B
25-Mn- 55	25055.37c	2525	yes	194580		revised	A
26-Fe- 0	26000.37c	2600	yes	229660		revised	A
26-Fe- 54	26054.37c	2625	yes	63040		revised	B
26-Fe- 56	26056.37c	2631	yes	73619		revised	B
26-Fe- 57	26057.37c	2634	yes	61520		revised	B
26-Fe- 58	26058.37c	2637	yes	66638		revised	B
27-Co- 59	27059.37c	2725	yes	104347		revised	A
28-Ni- 0	28000.37c	2800	yes	329664		revised	A
28-Ni- 58	28058.37c	2825	yes	84502		revised	B
28-Ni- 60	28060.37c	2831	yes	105048		revised	B
28-Ni- 61	28061.37c	2834	yes	47155		revised	B
28-Ni- 62	28062.37c	2837	yes	45262		revised	B
28-Ni- 64	28064.37c	2843	yes	44279		revised	B
29-Cu- 0	29000.37c	2900	yes	137439		revised	A
29-Cu- 63	29063.37c	2925	yes	100587		revised	B
29-Cu- 65	29065.37c	2931	yes	78326		revised	B
31-Ga- 0	31000.37c	3100		57691		new	A
31-Ga- 69	31069.37c	3125		41693		new	B
31-Ga- 71	31071.37c	3131		42315		new	B
32-Ge- 0	32000.37c	3200		83252		new	A
32-Ge- 70	32070.37c	3225		34305		new	B
32-Ge- 72	32072.37c	3231		35896		new	B
32-Ge- 73	32073.37c	3234		58132		new	B
32-Ge- 74	32074.37c	3237		30954		new	B
32-Ge- 76	32076.37c	3243		29597		new	B
33-As- 75	33075.37c	3325		77786		revised	A
34-Se- 74	34074.37c	3425		19708			A
34-Se- 76	34076.37c	3431		35946			A
34-Se- 77	34077.37c	3434		41079			A
34-Se- 78	34078.37c	3437		26314			A
34-Se- 79	34079.37c	3440		20862			C
34-Se- 80	34080.37c	3443		24794		revised	A
34-Se- 82	34082.37c	3449		16796			A
35-Br- 79	35079.37c	3525		83756		revised	C
35-Br- 81	35081.37c	3531		85693		revised	C
36-Kr- 78	36078.37c	3625		24815			C
36-Kr- 80	36080.37c	3631		24452			C
36-Kr- 82	36082.37c	3637		14543			C
36-Kr- 83	36083.37c	3640		14792			C
36-Kr- 84	36084.37c	3643		16026			C
36-Kr- 85	36085.37c	3646		12561			C
36-Kr- 86	36086.37c	3649		49024			C

Table 2.3 Continued.

Nuclide	ZAID	MAT	GPD	Length	NUBAR	Status	File
37-Rb- 85	37085.37c	3725		50322			C
37-Rb- 87	37087.37c	3731		18507			C
38-Sr- 86	38086.37c	3831		52678			C
38-Sr- 87	38087.37c	3834		58783			C
38-Sr- 88	38088.37c	3837		40801		revised	C
38-Sr- 89	38089.37c	3840		12408			C
38-Sr- 90	38090.37c	3843		9919		revised	C
39-Y - 89	39089.37c	3925		39216		revised	A
39-Y - 91	39091.37c	3931		24611			C
40-Zr- 0	40000.37c	4000	yes	154919		revised	A
40-Zr- 90	40090.37c	4025		54471		revised	C
40-Zr- 91	40091.37c	4028		69794		revised	C
40-Zr- 92	40092.37c	4031		57721		revised	C
40-Zr- 93	40093.37c	4034		20857			C
40-Zr- 94	40094.37c	4037		51131		revised	C
40-Zr- 95	40095.37c	4040		17236			C
40-Zr- 96	40096.37c	4043		34683		revised	C
41-Nb- 93	41093.37c	4125	yes	114171		revised	A
41-Nb- 94	41094.37c	4128		24425			C
41-Nb- 95	41095.37c	4131		18651			C
42-Mo- 0	42000.37c	4200	yes	162073		revised	A
42-Mo- 92	42092.37c	4225		55938		revised	C
42-Mo- 94	42094.37c	4231		49991		revised	C
42-Mo- 95	42095.37c	4234		44679		revised	C
42-Mo- 96	42096.37c	4237		53801		revised	C
42-Mo- 97	42097.37c	4240		47623		revised	C
42-Mo- 98	42098.37c	4243		71206		revised	C
42-Mo- 99	42099.37c	4246		16443			C
42-Mo-100	42100.37c	4249		70116		revised	C
43-Tc- 99	43099.37c	4331		88716		revised	C
44-Ru- 96	44096.37c	4425		16141			C
44-Ru- 98	44098.37c	4431		16719			C
44-Ru- 99	44099.37c	4434		36465		revised	C
44-Ru-100	44100.37c	4437		56532			C
44-Ru-101	44101.37c	4440		47242		revised	C
44-Ru-102	44102.37c	4443		61357			C
44-Ru-103	44103.37c	4446		13756			C
44-Ru-104	44104.37c	4449		51240			C
44-Ru-106	44106.37c	4455		9280			C
45-Rh-103	45103.37c	4525		77112		revised	C
45-Rh-105	45105.37c	4531		15893			C
46-Pd-102	46102.37c	4625		18920			A
46-Pd-104	46104.37c	4631		15065			A
46-Pd-105	46105.37c	4634		76148			A
46-Pd-106	46106.37c	4637		19654			A
46-Pd-107	46107.37c	4640		46660		revised	C
46-Pd-108	46108.37c	4643		63986			A
46-Pd-110	46110.37c	4649		50108			A
47-Ag- 0	47000.37c	4700	yes	189009		revised	A
47-Ag-107	47107.37c	4725	yes	152187		revised	C

Table 2.3 Continued.

Nuclide	ZAID	MAT	GPD	Length	NUBAR	Status	File
47-Ag-109	47109.37c	4731	yes	155982		revised	C
47-Ag-110m	47110.36c	4735		31162			C
48-Cd- 0	48000.37c	4800	yes	132651		revised	A
48-Cd-106	48106.37c	4825		19118			C
48-Cd-108	48108.37c	4831		25699			C
48-Cd-110	48110.37c	4837		52320		revised	C
48-Cd-111	48111.37c	4840		51566		revised	C
48-Cd-112	48112.37c	4843		49181			C
48-Cd-113	48113.37c	4846		30549		revised	C
48-Cd-114	48114.37c	4849.		46115			C
48-Cd-116	48116.37c	4855		32904			C
49-In-113	49113.37c	4925		41552			C
49-In-115	49115.37c	4931		71368		revised	C
50-Sn-112	50112.37c	5025		31090			A
50-Sn-114	50114.37c	5031		30430			A
50-Sn-115	50115.37c	5034		21160			A
50-Sn-116	50116.37c	5037		20160			A
50-Sn-117	50117.37c	5040		39999		revised	A
50-Sn-118	50118.37c	5043		25189			A
50-Sn-119	50119.37c	5046		28217			A
50-Sn-120	50120.37c	5049		84753			A
50-Sn-122	50122.37c	5055		28742			A
50-Sn-123	50123.37c	5058		12975			C
50-Sn-124	50124.37c	5061		22509		revised	A
50-Sn-126	50126.37c	5067		9498			C
51-Sb- 0	51000.37c	5100		79971		revised	A
51-Sb-121	51121.37c	5125		62805		revised	C
51-Sb-123	51123.37c	5131		54632		revised	C
51-Sb-124	51124.37c	5134		11059			C
51-Sb-125	51125.37c	5137		21070			C
52-Te-120	52120.37c	5225		15342			C
52-Te-122	52122.37c	5231		73000		revised	C
52-Te-123	52123.37c	5234		40252		revised	C
52-Te-124	52124.37c	5237		112471		revised	C
52-Te-125	52125.37c	5240		84614		revised	C
52-Te-126	52126.37c	5243		72049		revised	C
52-Te-127m	52127.36C	5247		17887			C
52-Te-128	52128.37c	5249		21518			C
52-Te-129m	52129.36c	5253		19245			C
52-Te-130	52130.37c	5255		23540			C
53-I -127	53127.37c	5325		66811		revised	C
53-I -129	53129.37c	5331		61456			C
53-I -131	53131.37c	5337		15714			C
54-Xe-124	54124.37c	5425		22726			C
54-Xe-126	54126.37c	5431		17458			C
54-Xe-128	54128.37c	5437		26795			C
54-Xe-129	54129.37c	5440		51090			C
54-Xe-130	54130.37c	5443		23590			C
54-Xe-131	54131.37c	5446		37622			C
54-Xe-132	54132.37c	5449		19661			C

Table 2.3 Continued.

Nuclide	ZAID	MAT	GPD	Length	NUBAR	Status	File
54-Xe-133	54133.37c	5452		15815			c
54-Xe-134	54134.37c	5455		17967			c
54-Xe-135	54135.37c	5458		16749			c
54-Xe-136	54136.37c	5461		36261			c
55-Cs-133	55133.37c	5525		102624			c
55-Cs-134	55134.37c	5528		29109			c
55-Cs-135	55135.37c	5531		13953			c
55-Cs-136	55136.37c	5534		10385			c
55-Cs-137	55137.37c	5537		13735		revised	c
56-Ba-130	56130.37c	5625		44033			c
56-Ba-132	56132.37c	5631		15155			c
56-Ba-134	56134.37c	5637		45785			c
56-Ba-135	56135.37c	5640		90266		revised	c
56-Ba-136	56136.37c	5643		44592			c
56-Ba-137	56137.37c	5646		47431		revised	c
56-Ba-138	56138.37c	5649		36429		revised	c
56-Ba-140	56140.37c	5655		14432			c
57-La-138	57138.37c	5725		24629			c
57-La-139	57139.37c	5728		59281		revised	c
58-Ce-140	58140.37c	5837		72384		revised	c
58-Ce-141	58141.37c	5840		28429			c
58-Ce-142	58142.37c	5843		39561		revised	c
58-Ce-144	58144.37c	5849		11865			c
59-Pr-141	59141.37c	5925		85153		revised	c
59-Pr-143	59143.37c	5931		16083			c
60-Nd-142	60142.37c	6025		46611		revised	c
60-Nd-143	60143.37c	6028		83338		revised	c
60-Nd-144	60144.37c	6031		38345		revised	c
60-Nd-145	60145.37c	6034		116452		revised	c
60-Nd-146	60146.37c	6037		46441			c
60-Nd-147	60147.37c	6040		21072			c
60-Nd-148	60148.37c	6043		58845			c
60-Nd-150	60150.37c	6049		62918		revised	c
61-Pm-147	61147.37c	6149		24995			c
61-Pm-148	61148.37c	6152		13413			c
61-Pm-148m	61148.36c	6153		13355			c
61-Pm-149	61149.37c	6155		18637			c
62-Sm-144	62144.37c	6225		43716		revised	c
62-Sm-147	62147.37c	6234		86852		revised	c
62-Sm-148	62148.37c	6237		55003		revised	c
62-Sm-149	62149.37c	6240		73574			c
62-Sm-150	62150.37c	6243		40898		revised	c
62-Sm-151	62151.37c	6246		52384			c
62-Sm-152	62152.37c	6249		72862		revised	c
62-Sm-153	62153.37c	6252		26643			c
62-Sm-154	62154.37c	6255		44317		revised	c
63-Eu- 0	63000.37c	6300	yes	56629		revised	c
63-Eu-151	63151.37c	6325		42862			c
63-Eu-152	63152.37c	6328		18988			c
63-Eu-153	63153.37c	6331		39189		revised	c

Table 2.3 Continued.

Nuclide	ZAID	MAT	GPD	Length	NUBAR	Status	File
63-Eu-154	63154.37c	6334		20590		revised	C
63-Eu-155	63155.37c	6337		19069		revised	C
63-Eu-156	63156.37c	6340		13682			C
64-Gd-152	64152.37c	6425		99776			C
64-Gd-154	64154.37c	6431		91186			C
64-Gd-155	64155.37c	6434		52934			C
64-Gd-156	64156.37c	6437		61627			C
64-Gd-157	64157.37c	6440		50265			C
64-Gd-158	64158.37c	6443		67903			C
64-Gd-160	64160.37c	6449		41213			C
65-Tb-159	65159.37c	6525		89596			C
72-Hf- 0	72000.37c	7200	yes	85791		revised	A
72-Hf-174	72174.37c	7225	yes	35550		revised	B
72-Hf-176	72176.37c	7231	yes	47559		revised	B
72-Hf-177	72177.37c	7234	yes	62591		revised	B
72-Hf-178	72178.37c	7237	yes	51609		revised	B
72-Hf-179	72179.37c	7240	yes	49847		revised	B
72-Hf-180	72180.37c	7243	yes	39864		revised	B
73-Ta-181	73181.37c	7328	yes	166522		revised	A
74-W - 0	74000.37c	7400	yes	190490		revised	A
74-W -182	74182.37c	7431		107723		revised	B
74-W -183	74183.37c	7434		65592		revised	B
74-W -184	74184.37c	7437		93576		revised	B
74-W -186	74186.37c	7443		85206		revised	B
82-Pb- 0	82000.37c	8200	yes	165801		revised	A
82-Pb-204	82204.37c	8225	yes	73192		revised	B
82-Pb-206	82206.37c	8231	yes	120923		revised	B
82-Pb-207	82207.37c	8234	yes	81634		revised	B
82-Pb-208	82208.37c	8237	yes	63463		revised	B
83-Bi-209	83209.37c	8325	yes	68682		revised	A
88-Ra-223	88223.37c	8825		7233	total		B
88-Ra-224	88224.37c	8828		6174			B
88-Ra-225	88225.37c	8831		4557			B
88-Ra-226	88226.37c	8834		35911	total	revised	B
89-Ac-225	89225.37c	8925		3165			B
89-Ac-226	89226.37c	8928		3174			B
89-Ac-227	89227.37c	8931		5779	total		B
90-Th-227	90227.37c	9025		3405	both	revised	B
90-Th-228	90228.37c	9028		11242	both	revised	B
90-Th-229	90229.37c	9031		9148	both	revised	B
90-Th-230	90230.37c	9034		32422	both	revised	B
90-Th-232	90232.37c	9040		96180	both	revised	A
90-Th-233	90233.37c	9043		10780	both	revised	B
90-Th-234	90234.37c	9046		11577	both	revised	B
91-Pa-231	91231.37c	9131		45480	both		B
91-Pa-232	91232.37c	9134		3512	both	revised	B
91-Pa-233	91233.37c	9137		13592	both		B
92-U -232	92232.37c	9219		26151	both	revised	B
92-U -233	92233.37c	9222		48646	both	revised	B
92-U -234	92234.37c	9225		82289	both	revised	B

Table 2.3 Continued.

Nuclide	ZAID	MAT	GPD	Length	NUBAR	Status	File
92-U -235	92235.37c	9228	yes	124804	both	revised	A
92-U -236	92236.37c	9231		77541	both	revised	B
92-U -237	92237.37c	9234		40028	both	new	B
92-U -238	92238.37c	9237	yes	289606	both	revised	A
93-Np-236	93236.37c	9343		4454	both	new	B
93-Np-237	93237.37c	9346		47092	both	revised	A
93-Np-238	93238.37c	9349		11825	both	new	B
93-Np-239	93239.37c	9352		4401	both	revised	B
94-Pu-236	94236.37c	9428		7521	both	revised	B
94-Pu-238	94238.37c	9434		45558	both	revised	B
94-Pu-239	94239.37c	9437	yes	203872	both	revised	A
94-Pu-240	94240.37c	9440		153542	both	revised	A
94-Pu-241	94241.37c	9443		52050	both	revised	B
94-Pu-242	94242.37c	9446		58701	both	revised	B
95-Am-241	95241.37c	9543		50430	both		B
95-Am-242	95242.37c	9546		6372	both		B
95-Am-242m	95242.36C	9547		13996	both		B
95-Am-243	95243.37c	9549		57829	both		B
95-Am-244	95244.37c	9552		10741	both		B
95-Am-244m	95244.36c	9553		11757	both		B
96-Cm-241	96241.37c	9628		4815	both		B
96-Cm-242	96242.37c	9631		16868	both		B
96-Cm-243	96243.37c	9634		20046	both		B
96-Cm-244	96244.37c	9637		52874	both		B
96-Cm-245	96245.37c	9640		20935	both	revised	B
96-Cm-246	96246.37c	9643		24120	both		B
96-Cm-247	96247.37c	9646		20028	both		B
96-Cm-248	96248.37c	9649		39134	both		B
96-Cm-249	96249.37c	9652		6092	both	revised	B
96-Cm-250	96250.37c	9655		4346	both	revised	B
97-Bk-249	97249.37c	9752		26704	both		B
97-Bk-250	97250.37c	9755		32256	both		B
98-Cf-249	98249.37c	9852		21639	both		B
98-Cf-250	98250.37c	9855		22274	both		B
98-Cf-251	98251.37c	9858		29128	both		B
98-Cf-252	98252.37c	9861		32666	both		B
98-Cf-254	98254.37c	9867		4110	both	revised	B
99-Es-254	99254.37c	9914		4198	both	revised	B
99-Es-255	99255.37c	9915		4656	both	revised	B
100-Fm-255	100255.37c	9936		3971	both	revised	B

Notes: [GPD] yes : Gamma-ray production data are given.
(blank) : Gamma-ray production data are not given.
[NUBAR] both : Number of both prompt fission and total fission neutrons are given.
totoal : Only number of total fission neutrons is given..
(blank) : No data are given for number of fission neutrons.
[Status] revised : Cross section data are revised in the evaluation of JENDL-3.2.
new : Cross section data are newly evaluated for JENDL-3.2.
(blank) : Cross section data in JENDL-3.2 are just the same as those in JENDL-3.1.
[File] A, B, C : When the library is separated into three files, data of the nuclide are stored in the File-A, -B or -C, respectively.

Table 3.1 List of the verified nuclides and items for FSXLIB-J3R2 by MACROS.

nuclide	cross section	angular distribution	energy distribution	photon production	FSXLIB-J3 comparison
3-Li-6	○	○	+	○	○
8-O-16	○	○	○	－	－
13-Al-27	○	－	○	○	－
26-Fe-0	○	○	○	○	○
29-Cu-0	○	－	－	○	－
42-Mo-0	○	○	○	－	○
82-Pb-0	○	－	－	－	－
92-U-235	○	×	○	－	－
92-U-238	○	×	○	○	－

Notes: ○: The data were verified and no problems were found.
×: The data were verified and problems were found.
－: The data were not verified.
＋: The data were verified without plotting.

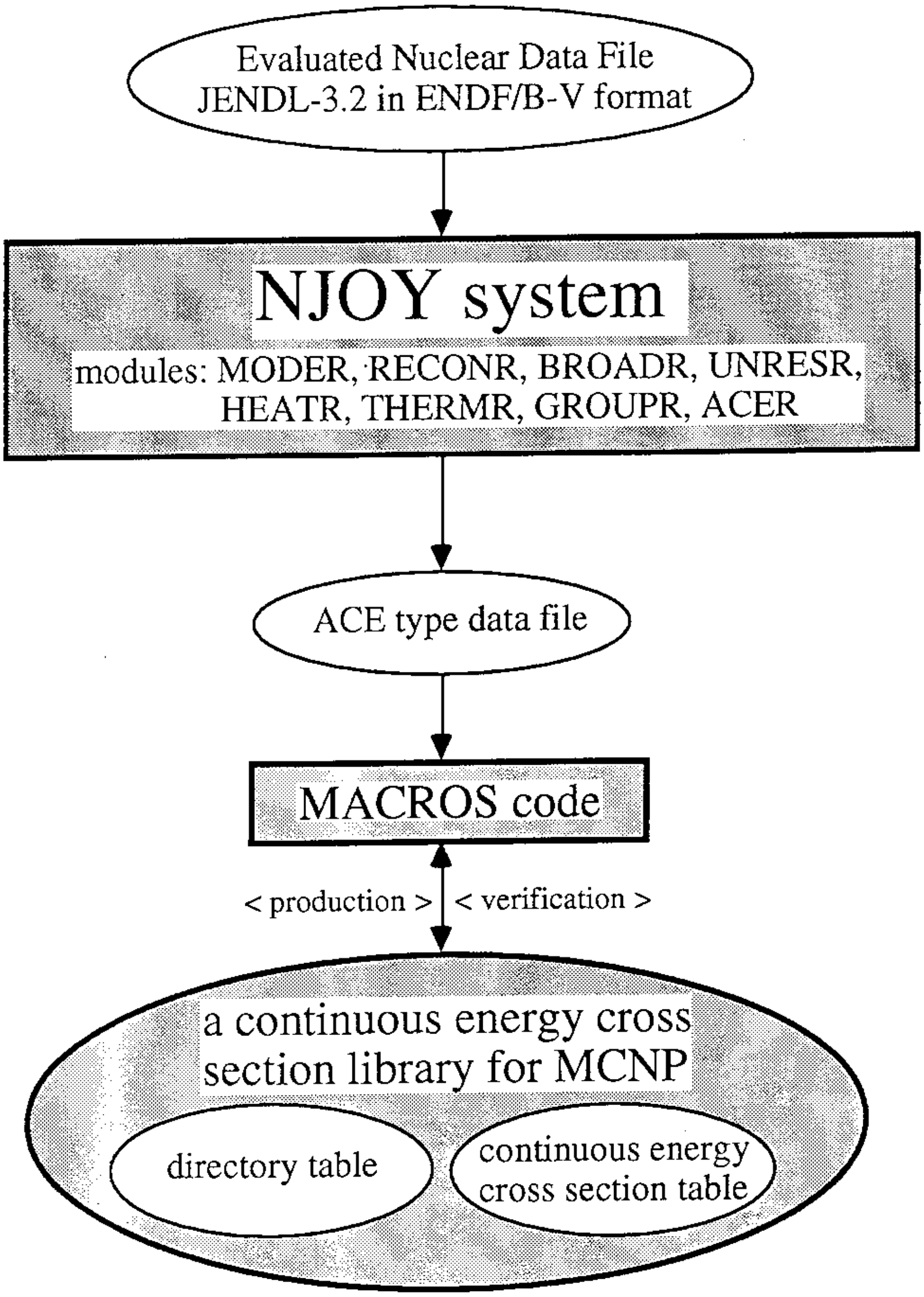

Fig. 2.1 Processing flow to produce a continuous energy cross section library for MCNP.

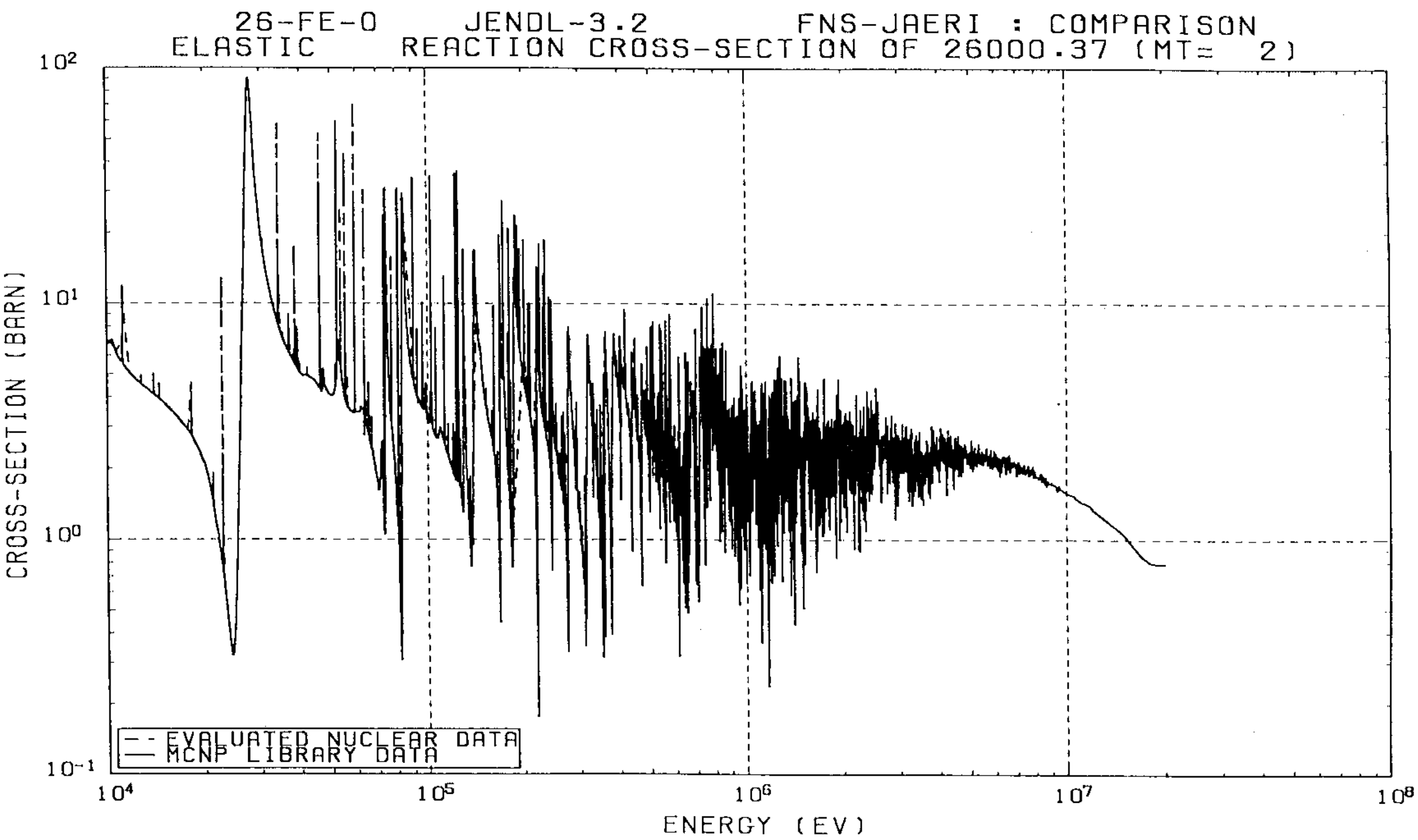

Fig. 3.1 Plot for verification of neutron cross section for the elastic scattering of iron.

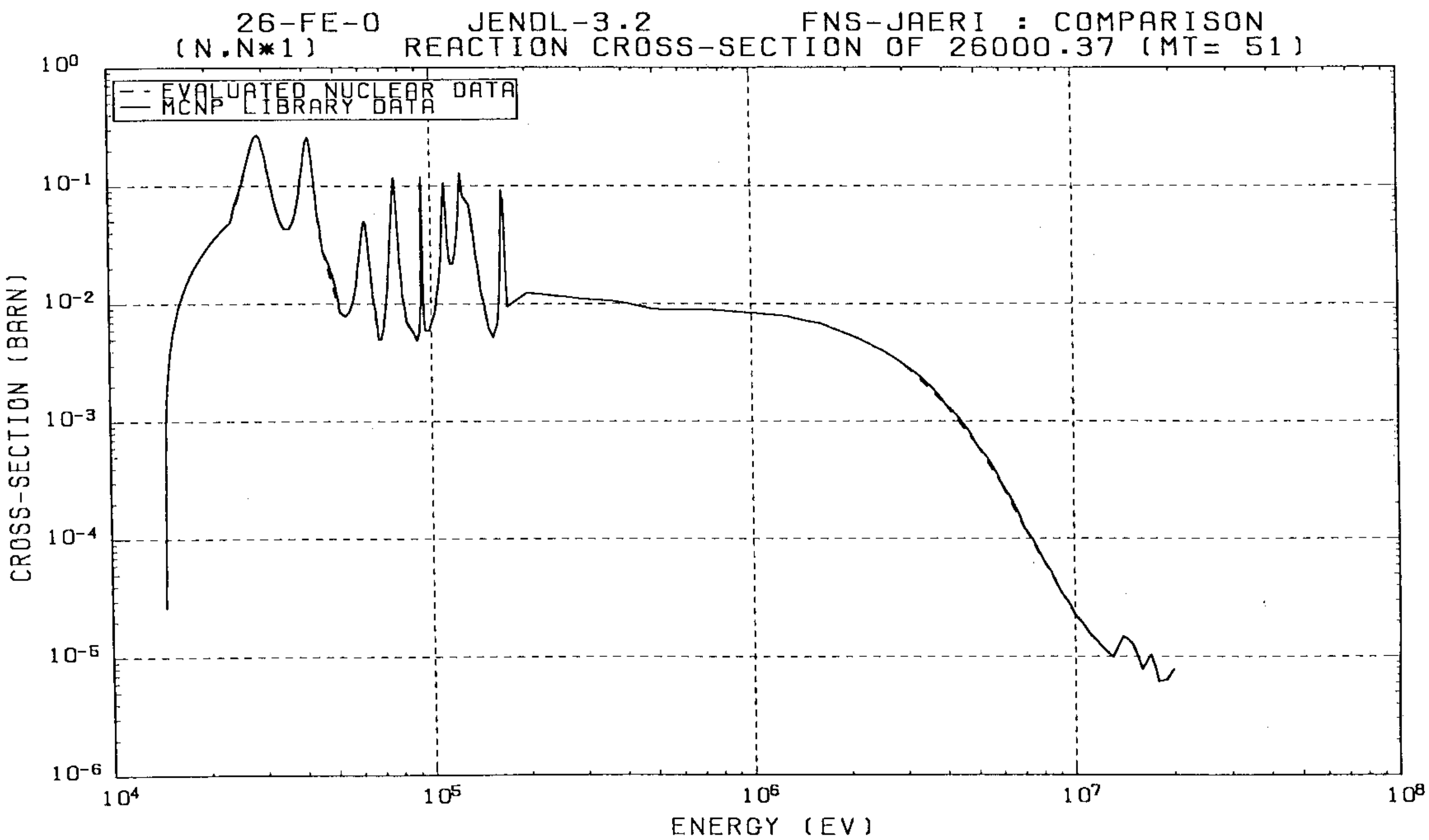

Fig. 3.2 Plot for verification of neutron cross section for one of the inelastic scattering of iron.

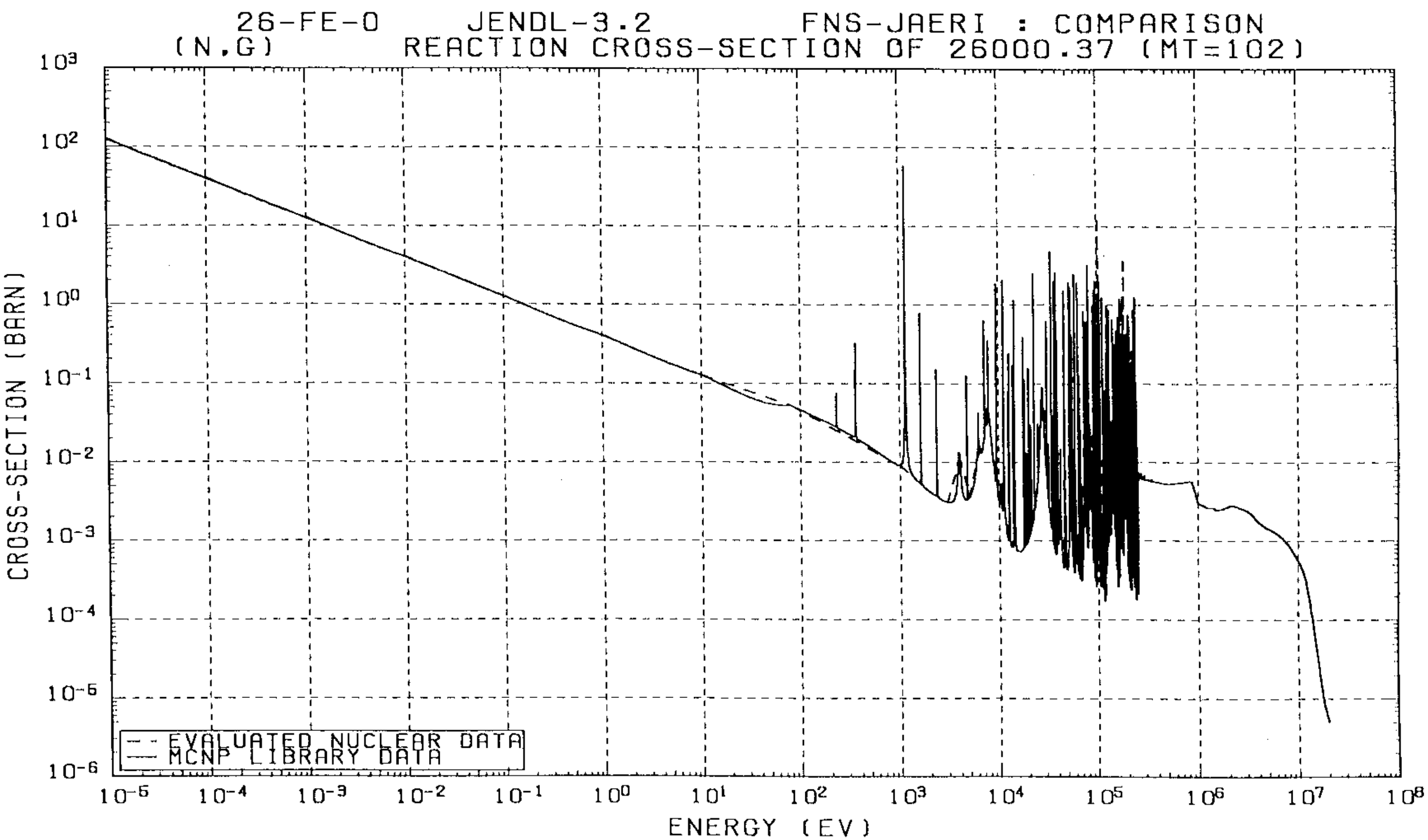

Fig. 3.3 Plot for verification of neutron cross section for the radiative neutron capture reaction of iron.

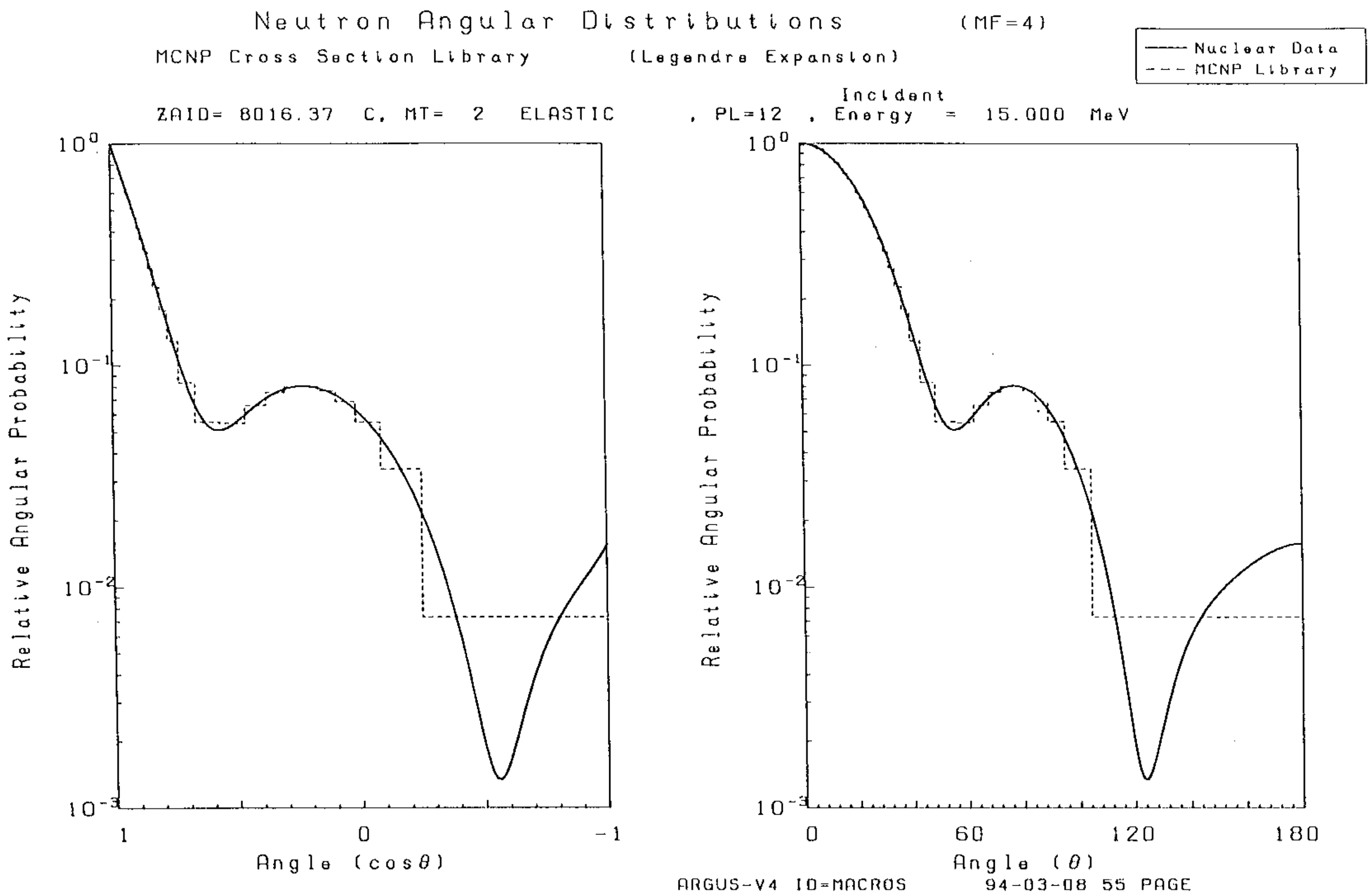

Fig. 3.4 Plot for verification of angular distribution of secondary neutrons emitted by the elastic scattering of oxygen-16 at 15 MeV.

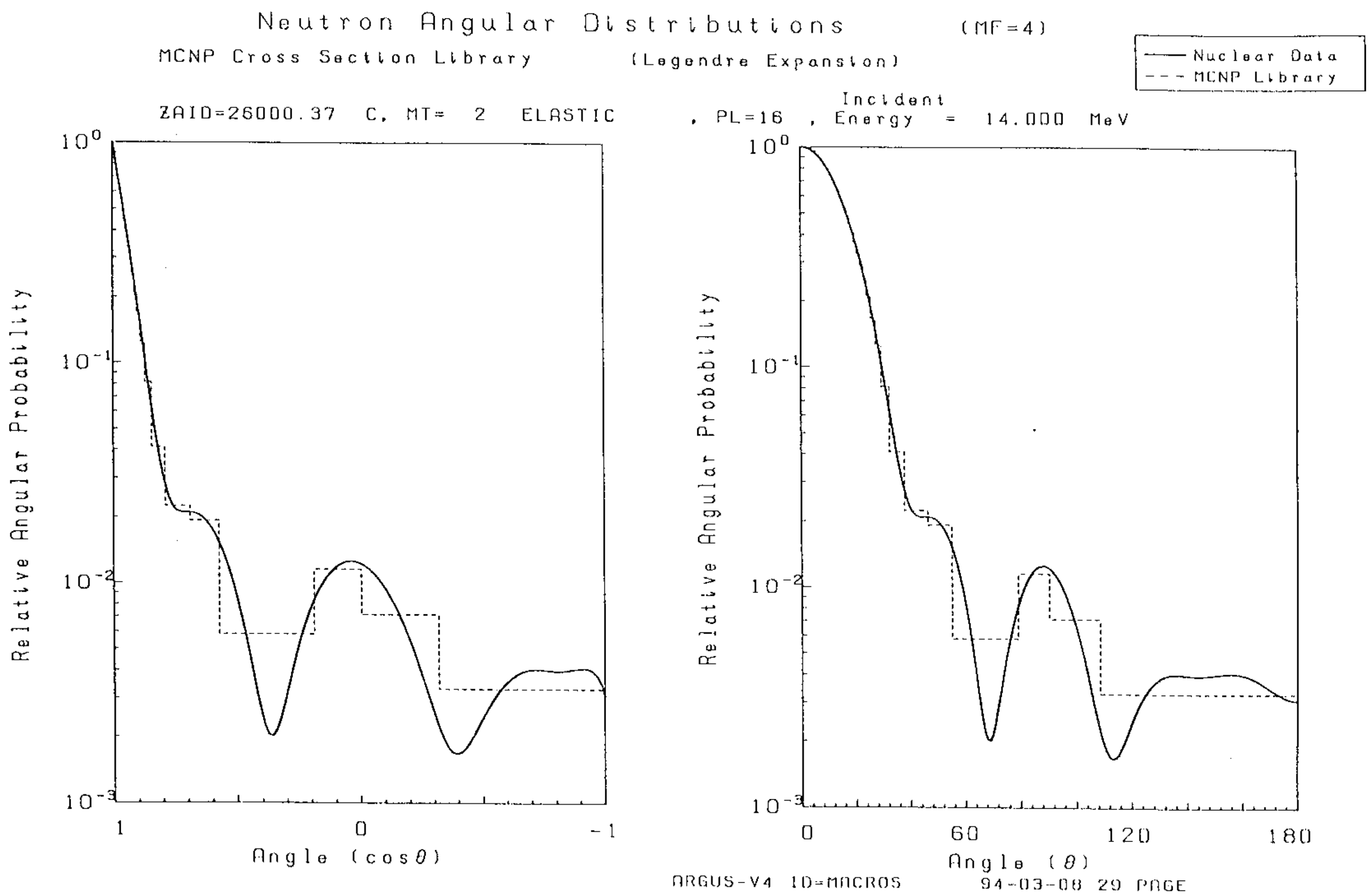

Fig. 3.5 Plot for verification of angular distribution of secondary neutrons emitted by the elastic scattering of iron at 14 MeV.

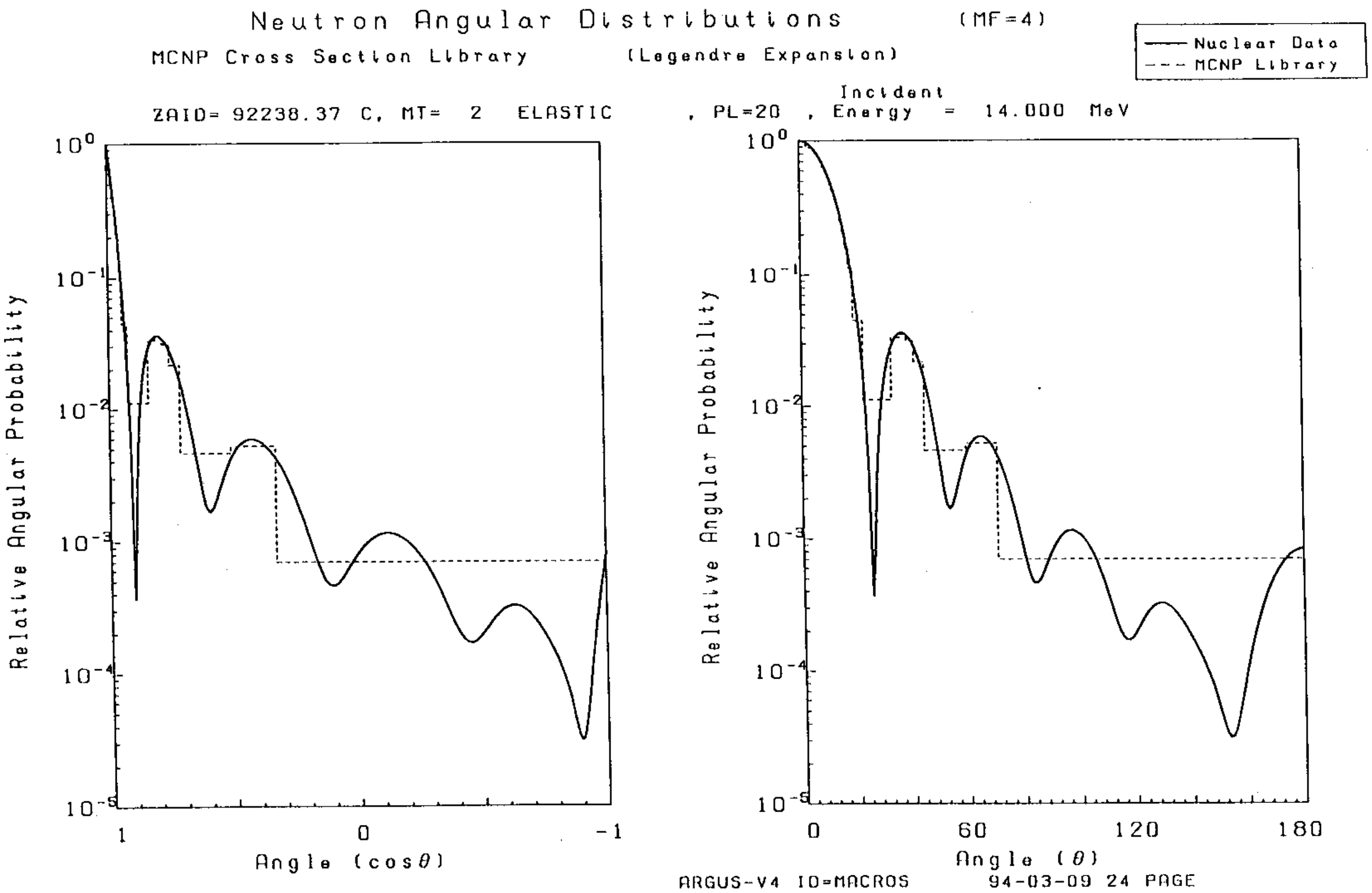

Fig. 3.6 Plot for verification of angular distribution of secondary neutrons emitted by the elastic scattering of uranium-238 at 14 MeV.

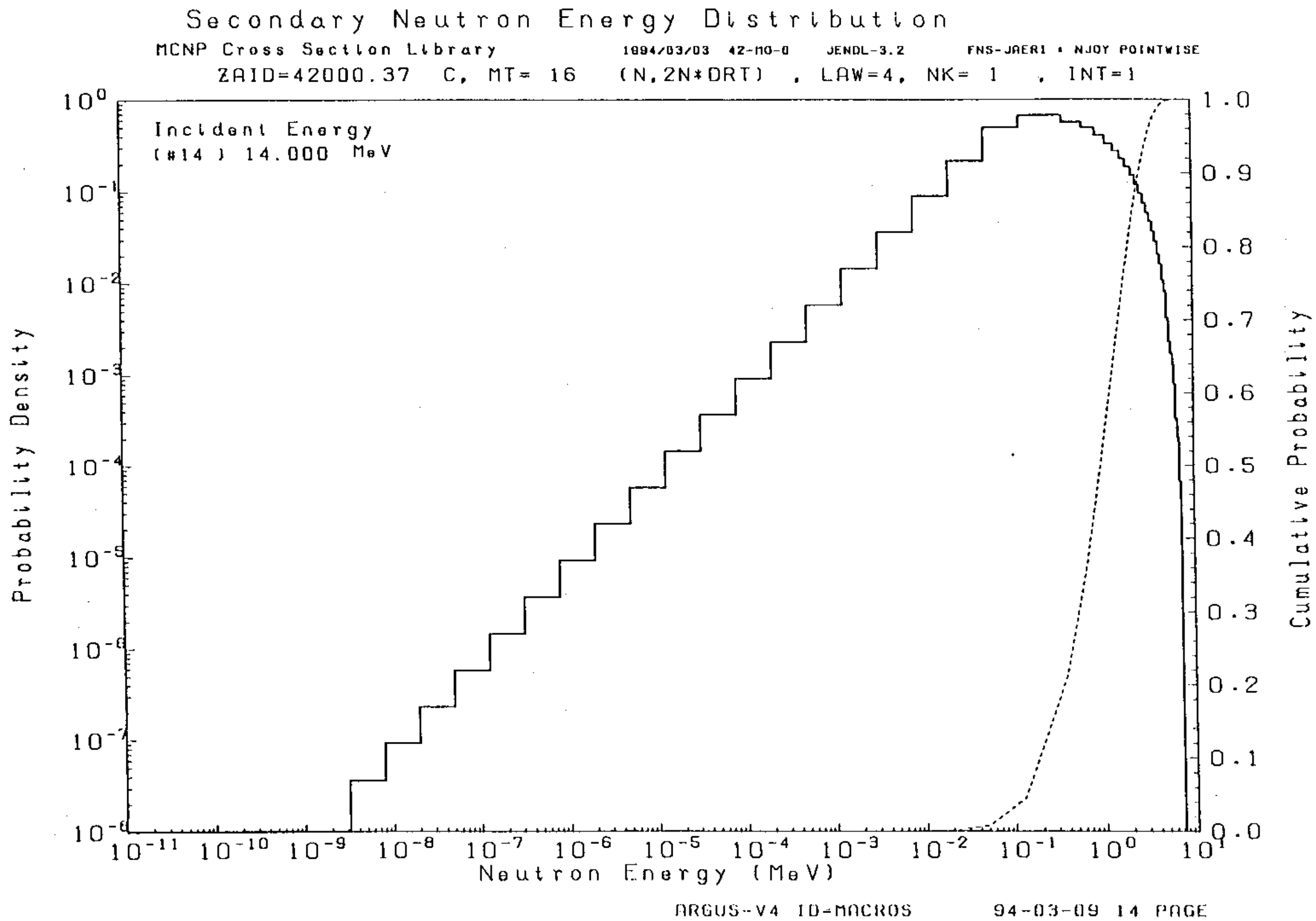

Fig. 3.7 Plot for verification of energy distribution of secondary neutrons emitted by the (n,2n) reaction of molybdenum at 14 MeV.

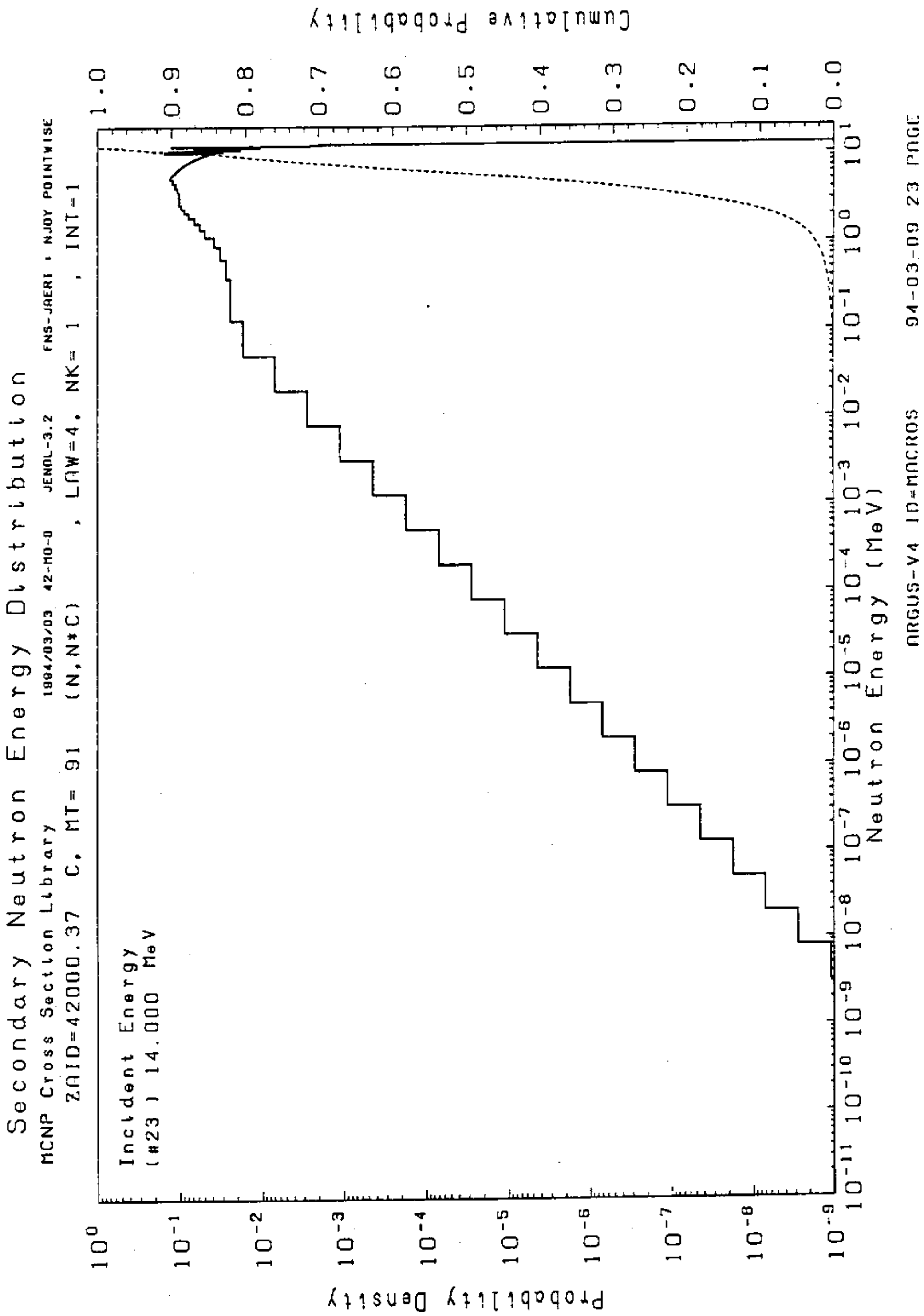

Fig. 3.8 Plot for verification of energy distribution of secondary neutrons emitted by the (n,n'$_{cont}$) reaction of molybdenum at 14 MeV.

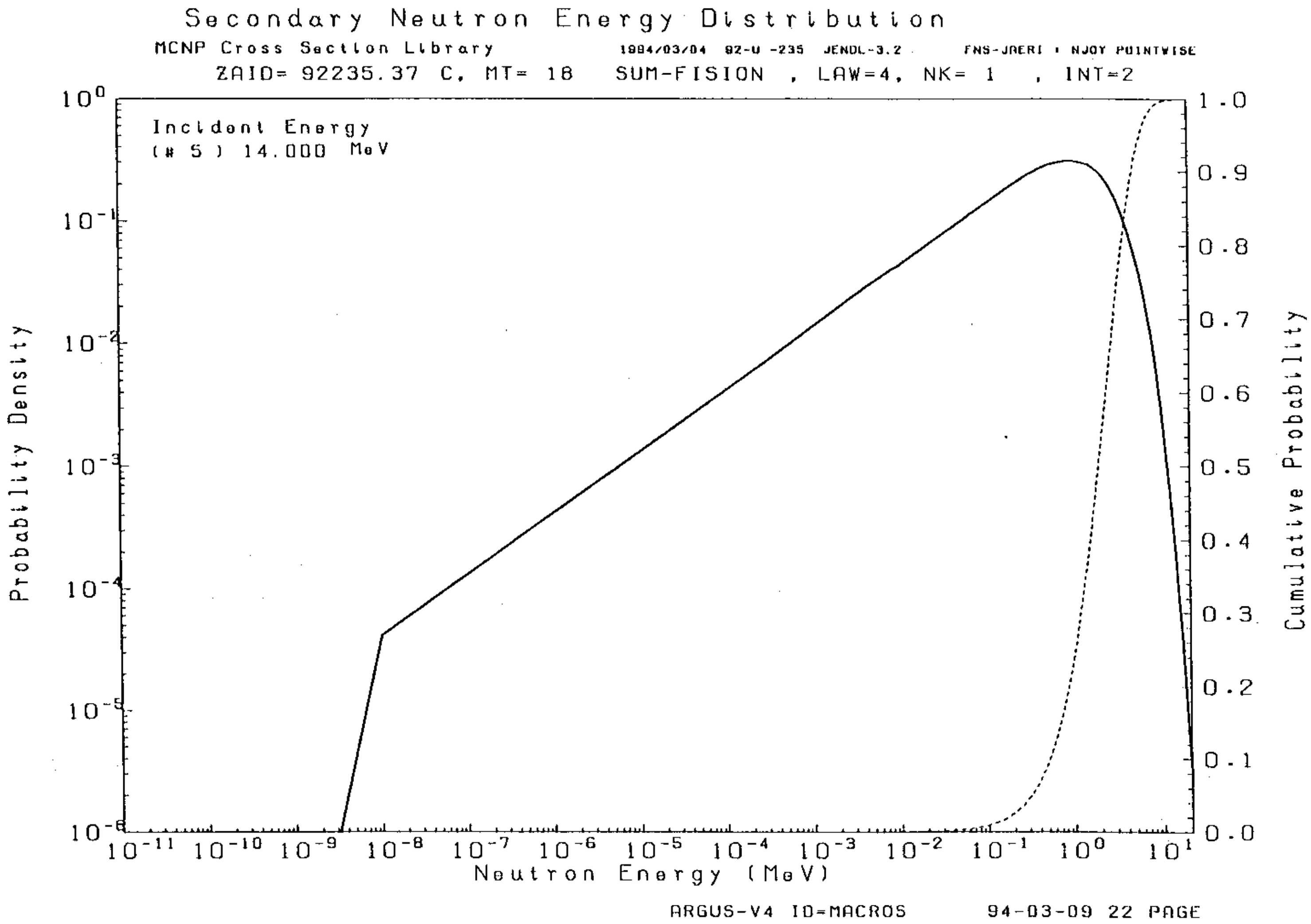

Fig. 3.9 Plot for verification of energy distribution of secondary neutrons emitted by the (n,fission) reaction of uranium-235 at thermal energy.

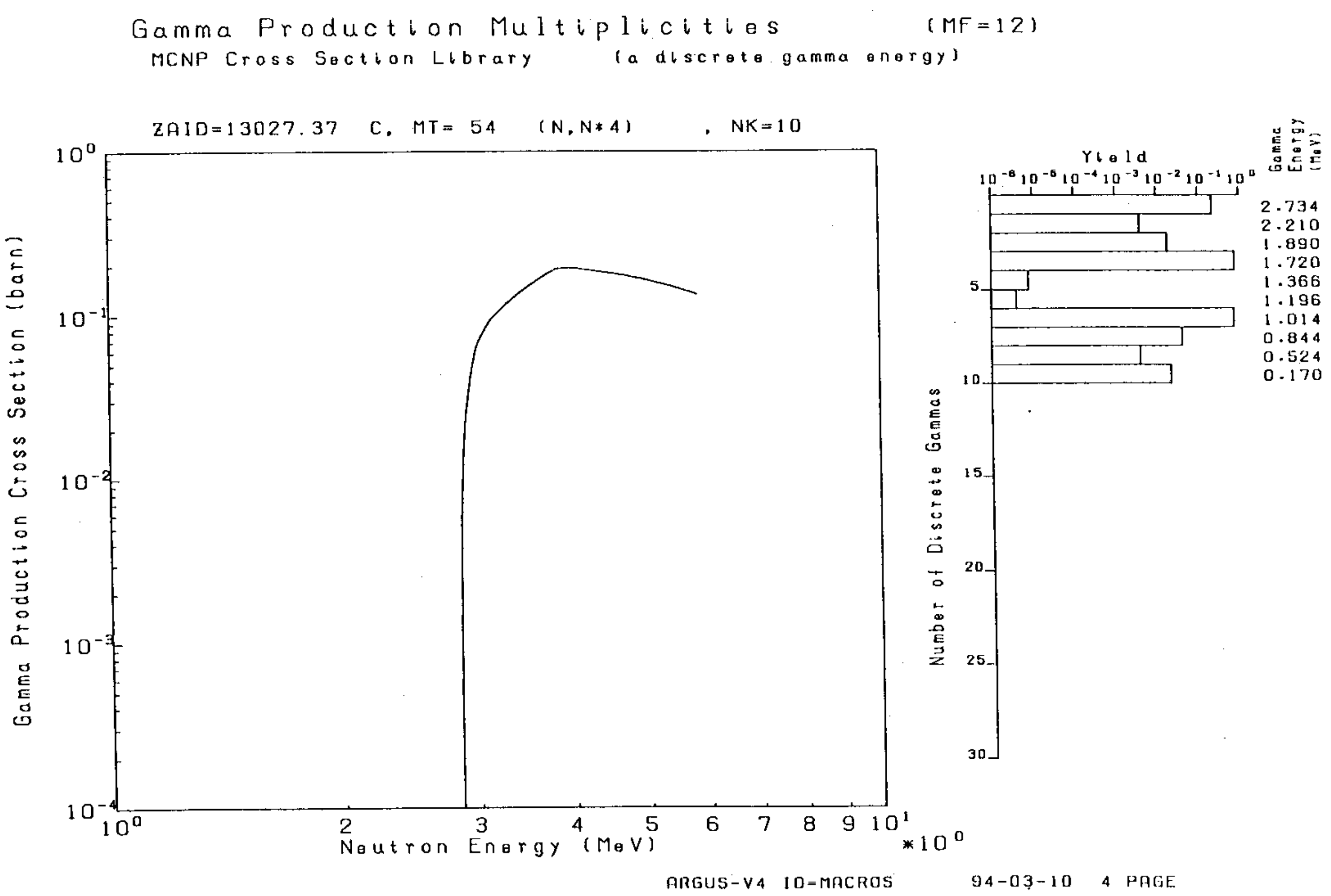

Fig. 3.10　Plot for verification of gamma-ray production data (gamma-ray production cross section for one of the inelastic scattering of aluminum-27).

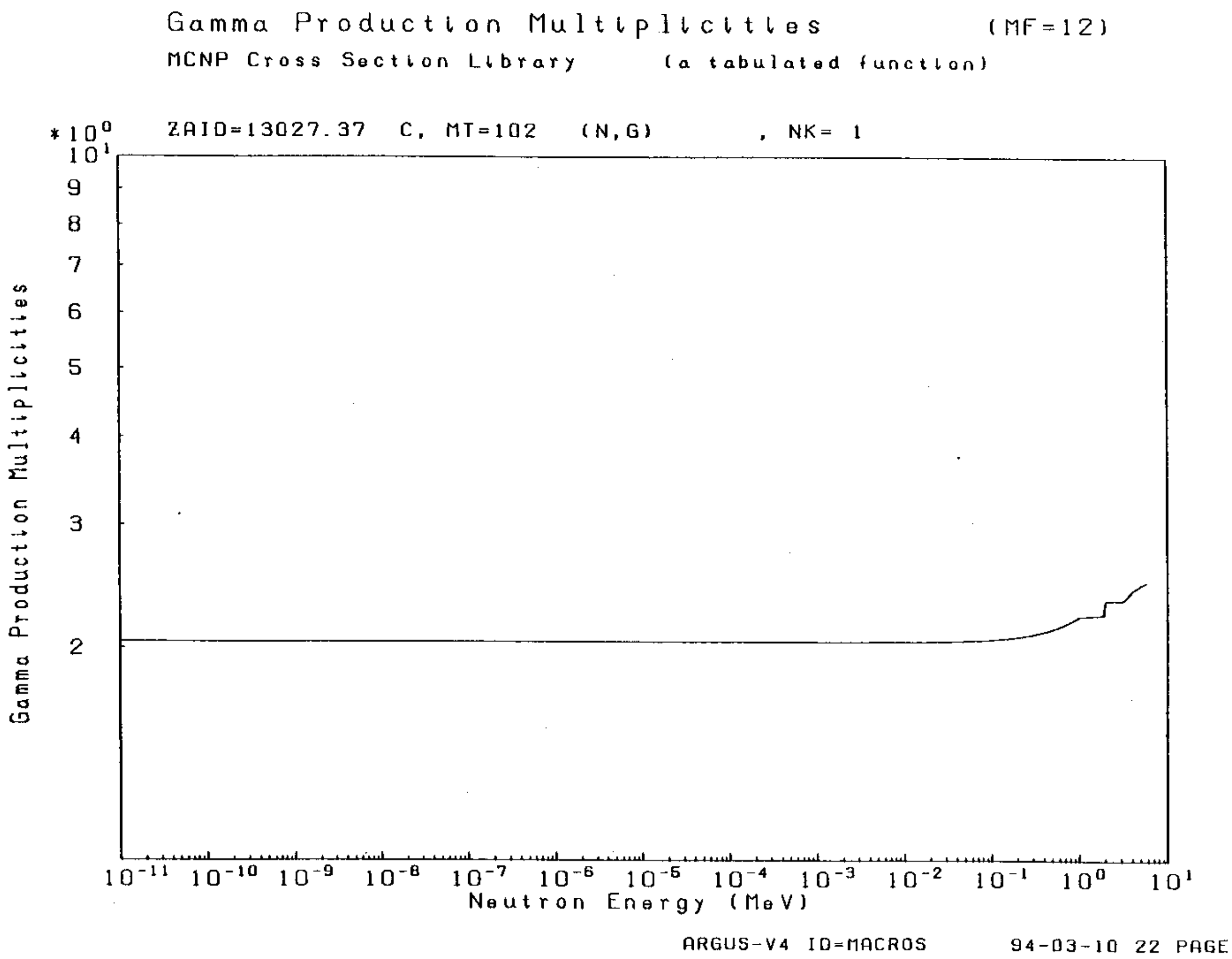

Fig. 3.11 Plot for verification of gamma-ray production data (gamma-ray production multiplicities of the neutron capture reaction of aluminum-27).

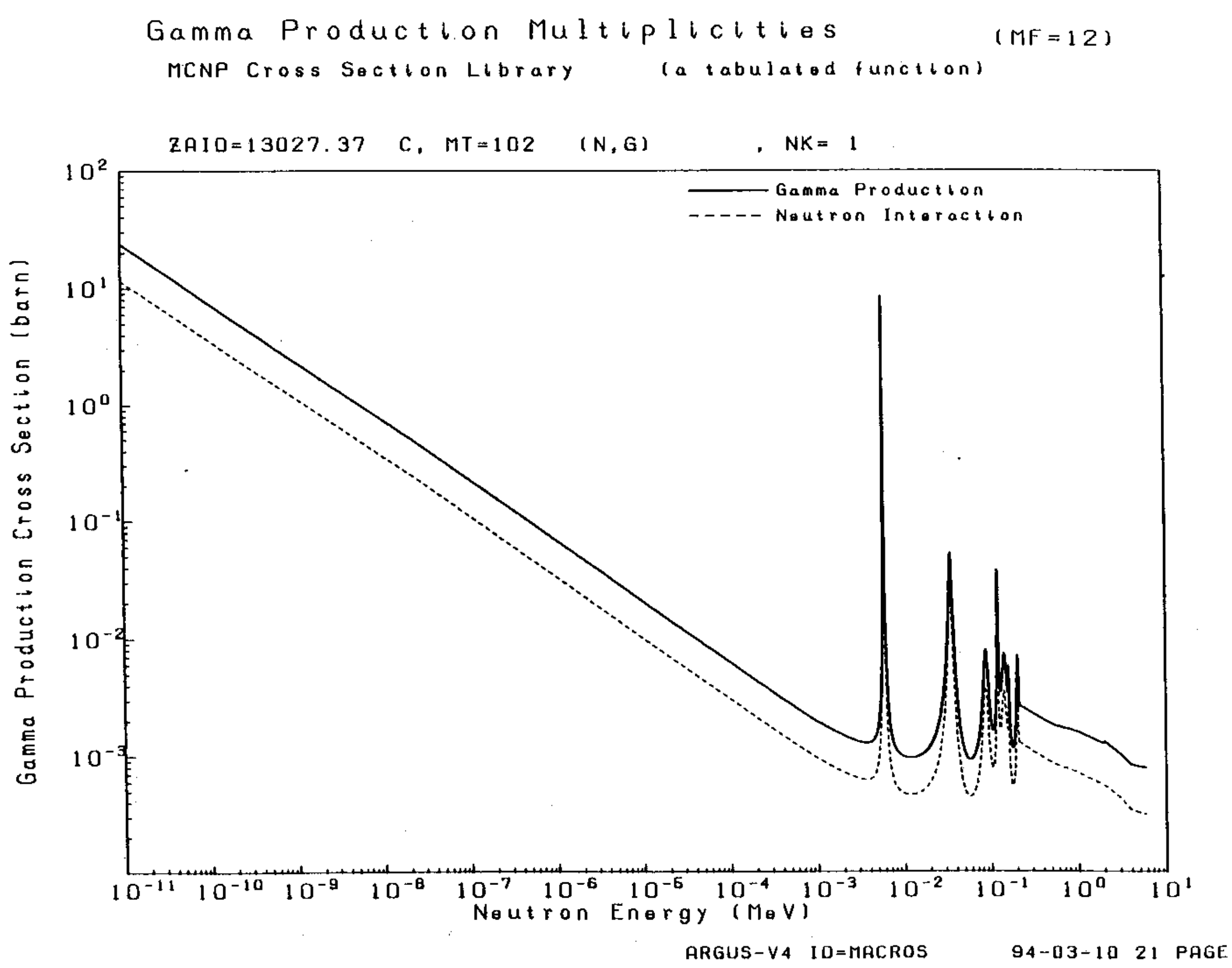

Fig. 3.12 Plot for verification of gamma-ray production data (neutron reaction and gamma-ray production cross sections for the neutron capture reaction of aluminum-27).

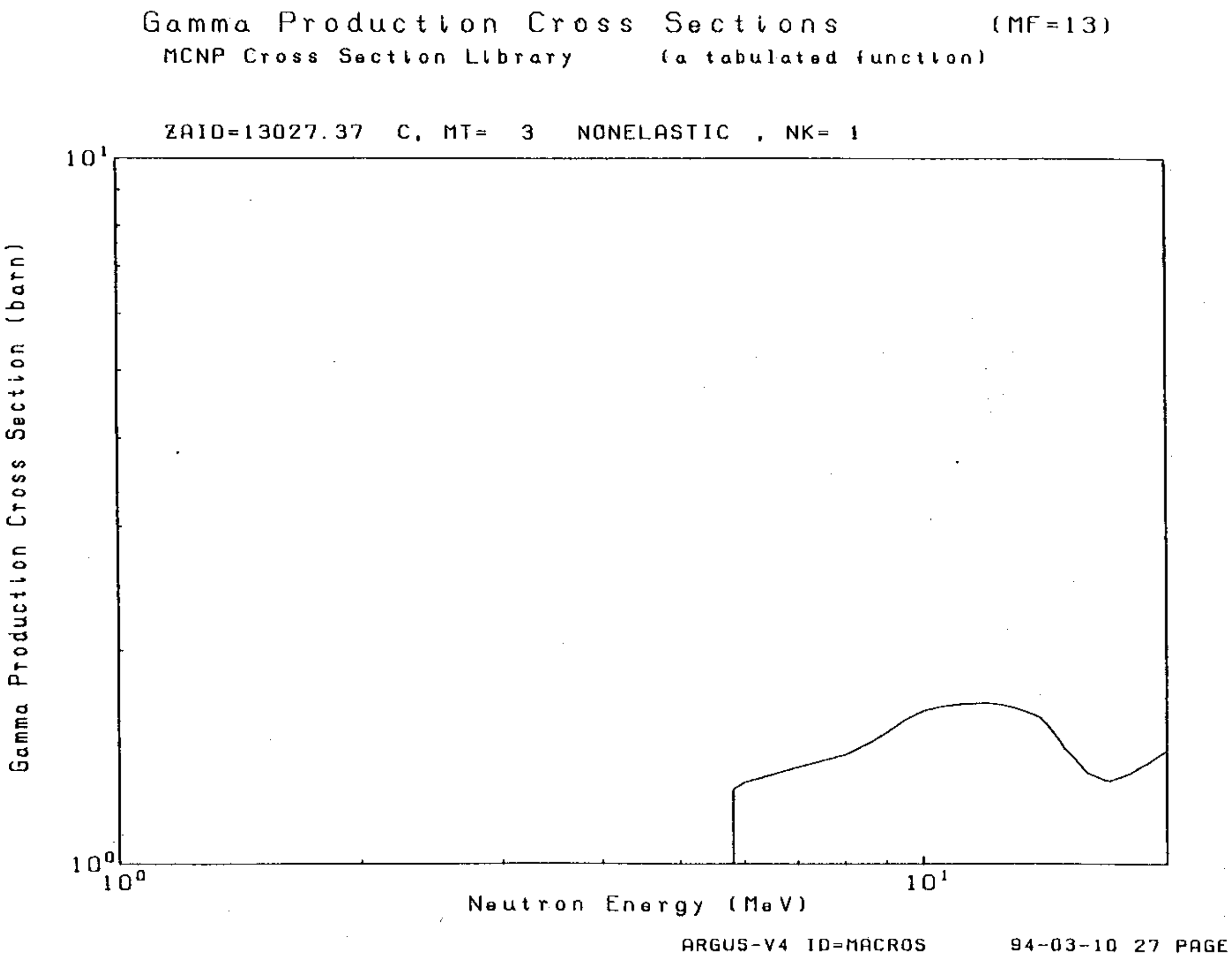

Fig. 3.13 Plot for verification of gamma-ray production data (gamma-ray production cross section of the non-elastic reaction of aluminum-27).

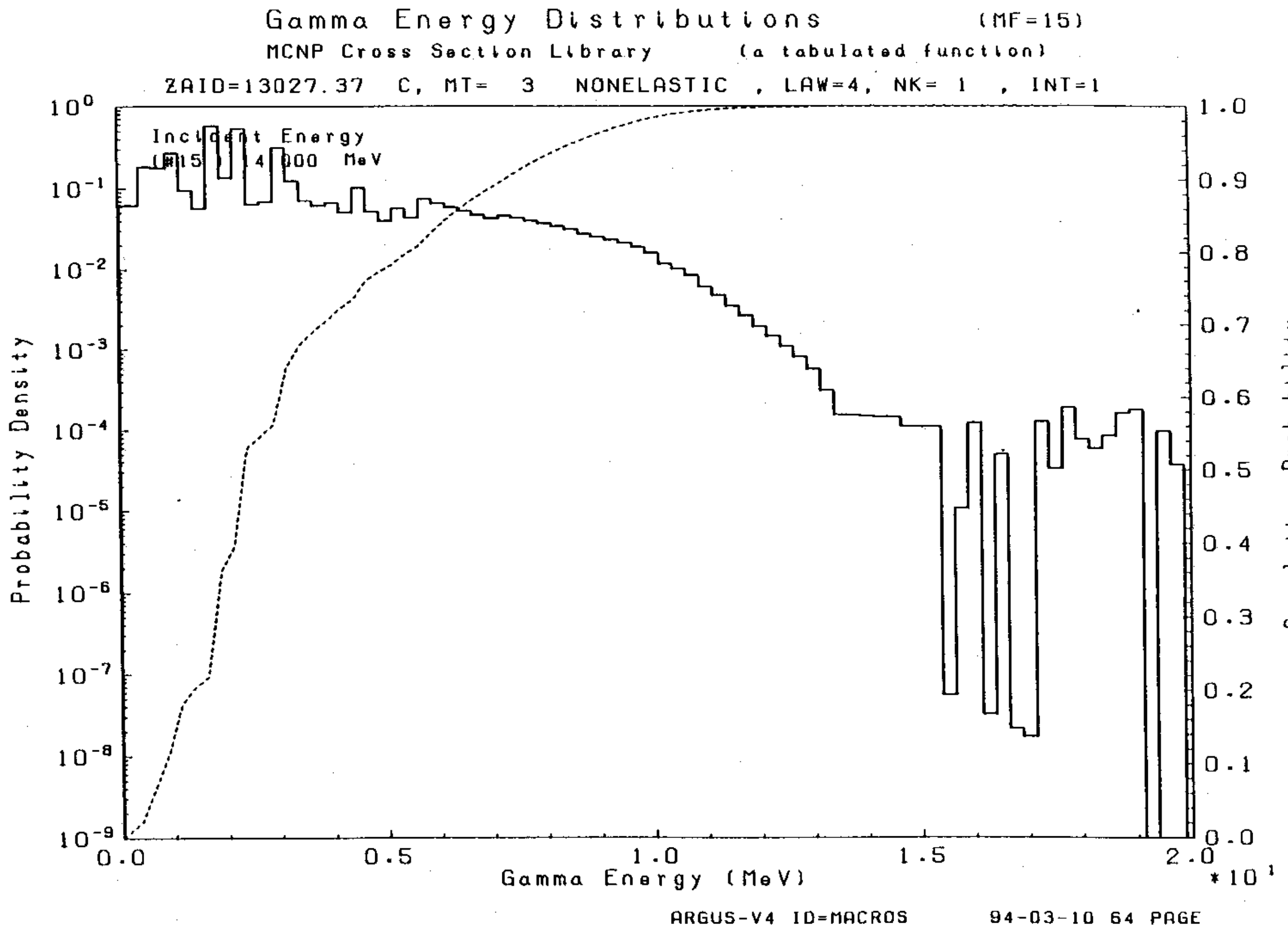

Fig. 3.14 Plot for verification of gamma-ray production data (secondary gamma-ray energy distribution from the non-elastic reaction of aluminum-27 at incident neutron energy of 14 MeV).

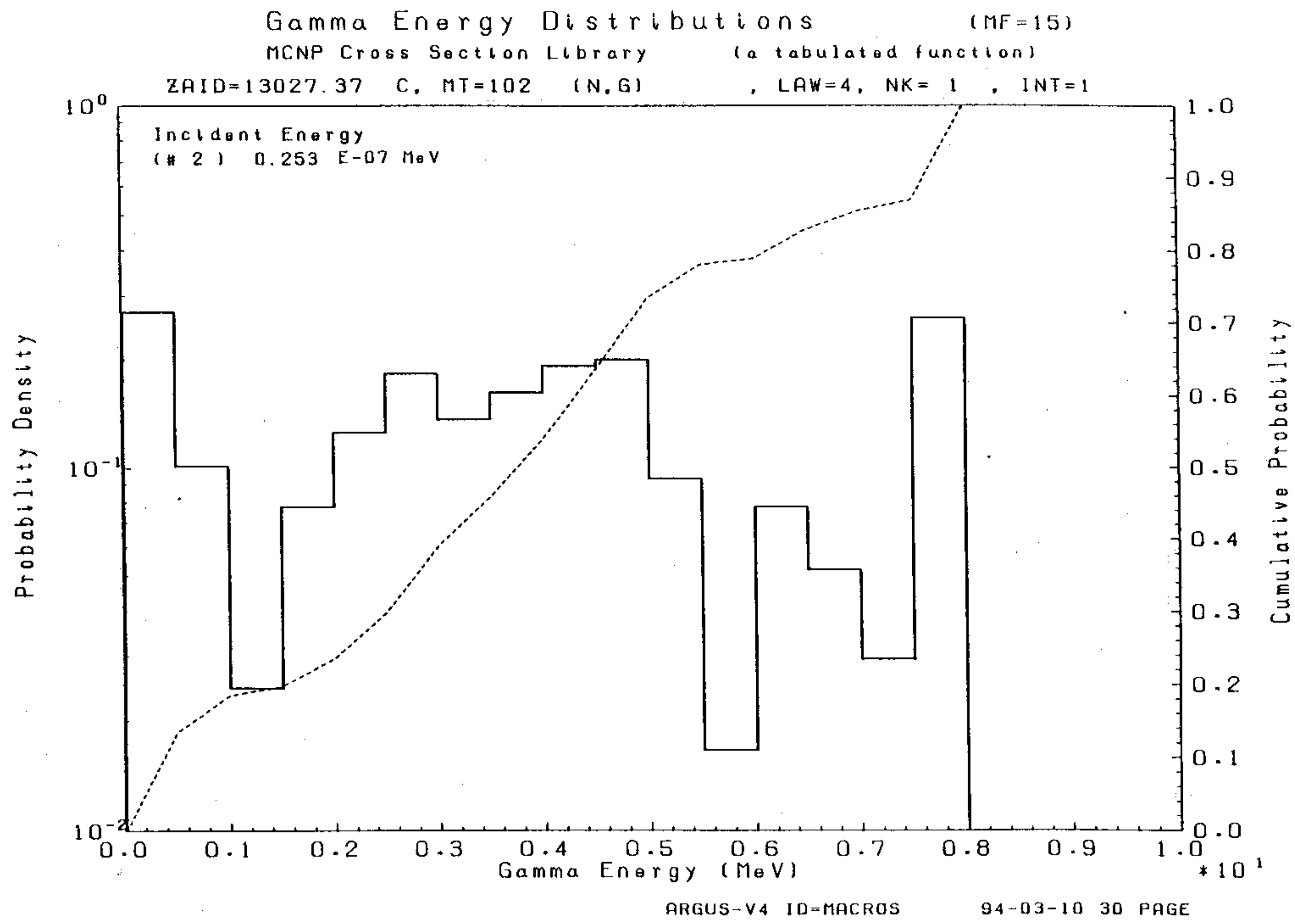

Fig. 3.15 Plot for verification of gamma-ray production data (secondary gamma-ray energy distribution from the neutron capture reaction of aluminum-27 at thermal energy of incident neutrons).

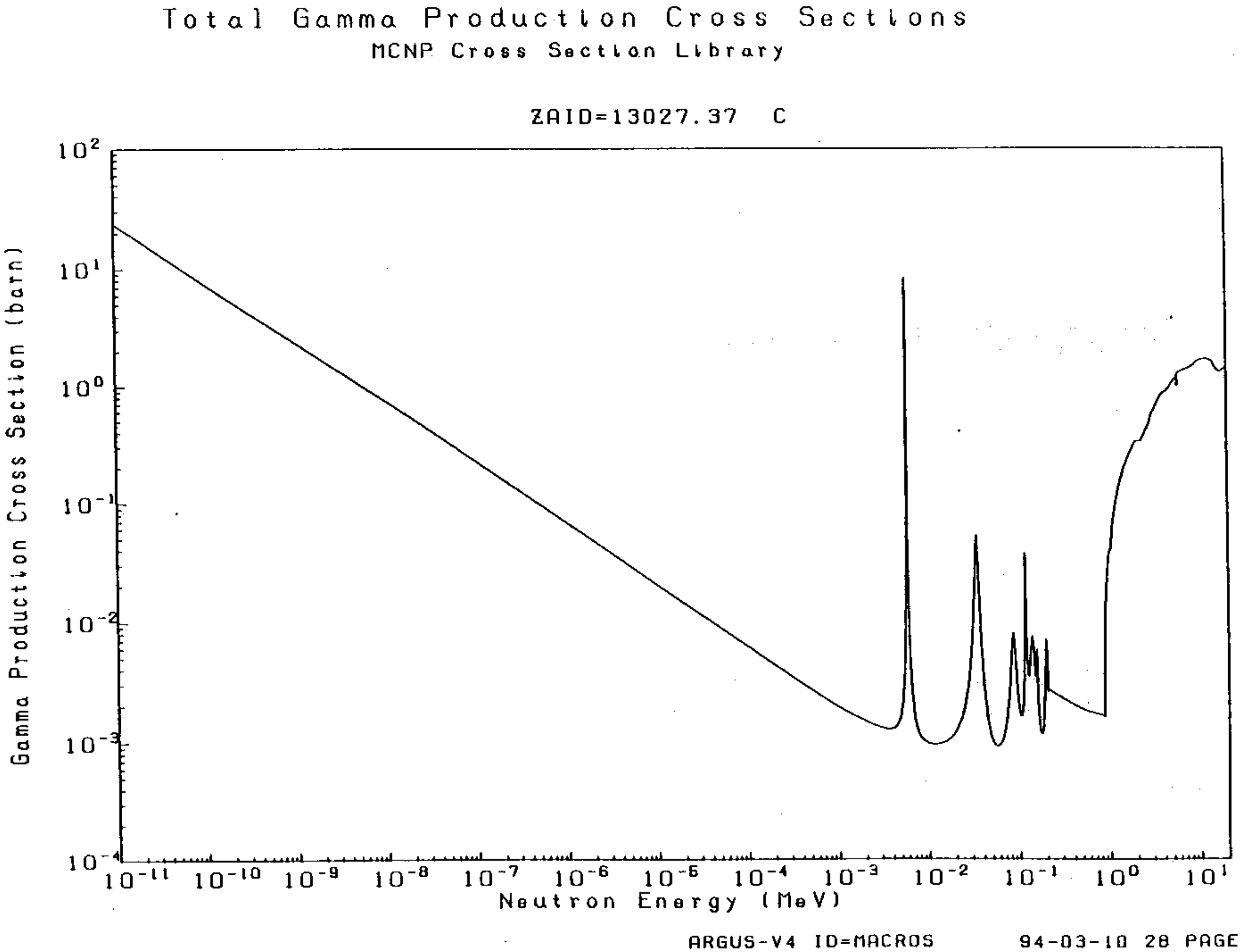

Fig. 3.16 Plot for verification of gamma-ray production data (total gamma-ray production cross section of aluminum-27).

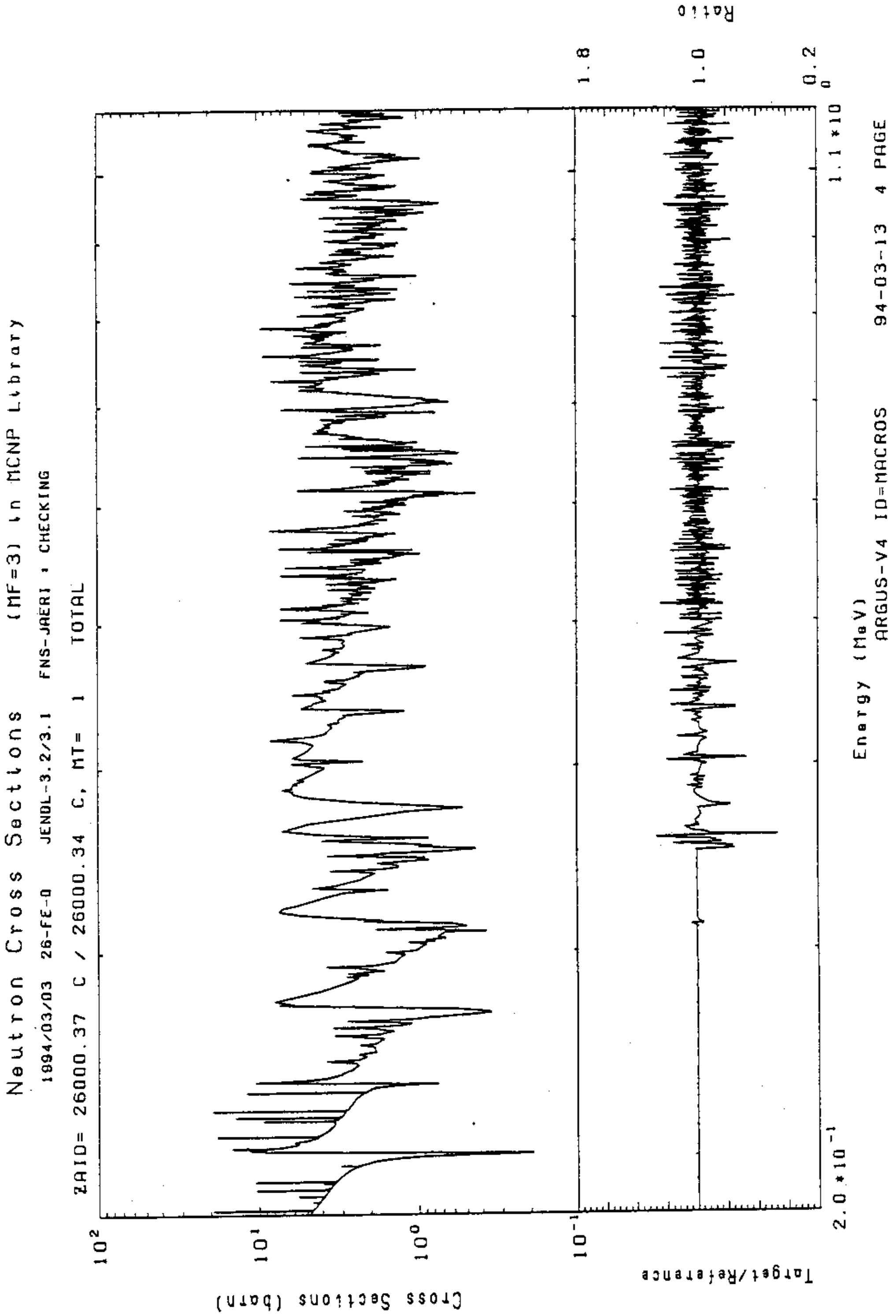

Fig. 3.17 Comparison of the total cross section of iron between FSXLIB-J3R2 and FSXLIB-J3 in an energy range of 0.2 - 1.1 MeV.

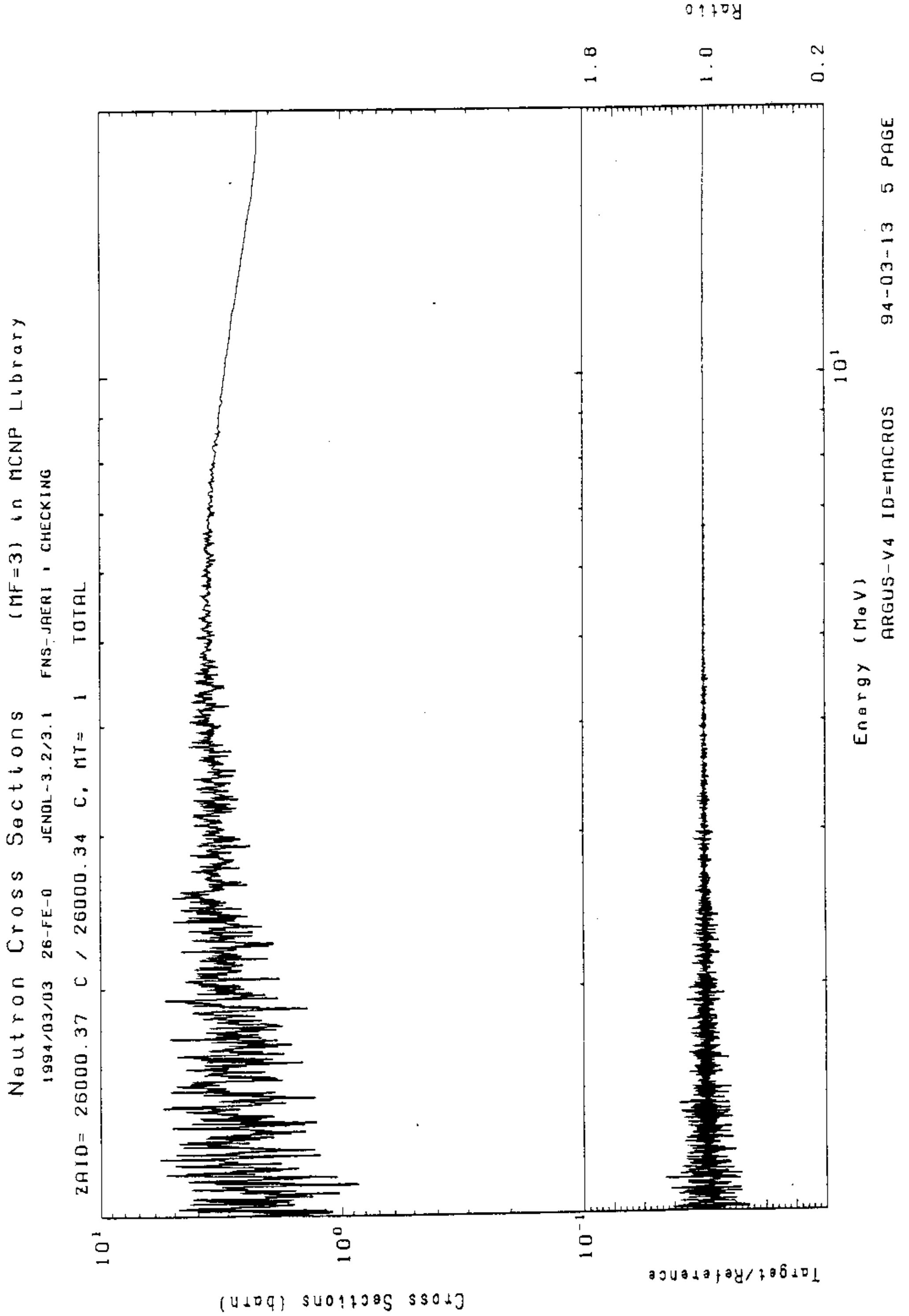

Fig. 3.18 Comparison of the total cross section of iron between FSXLIB-J3R2 and FSXLIB-J3 in an energy range of 1.1 - 20 MeV.

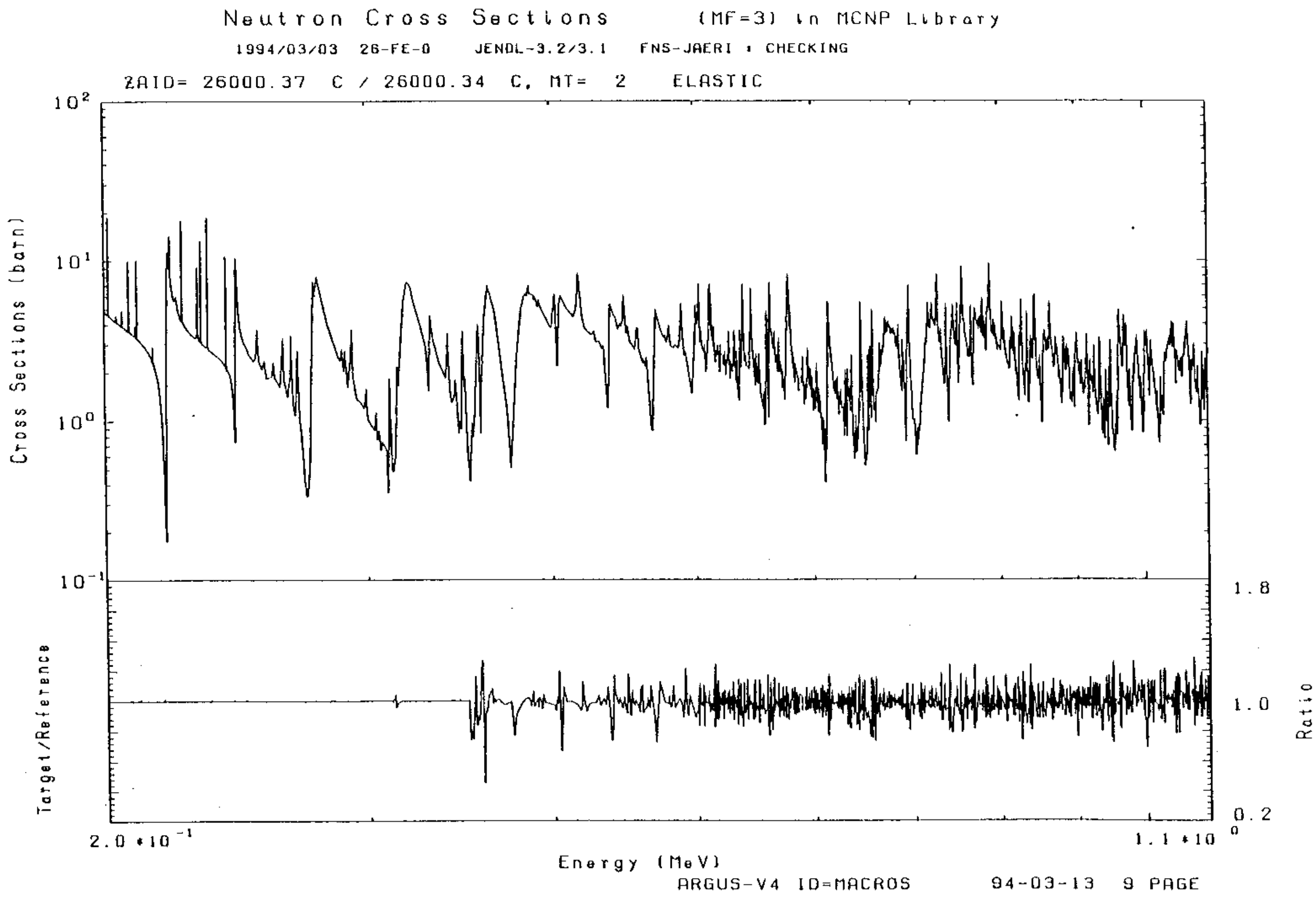

Fig. 3.19 Comparison of the elastic cross section of iron between FSXLIB-J3R2 and FSXLIB-J3 in an energy range of 0.2 - 1.1 MeV.

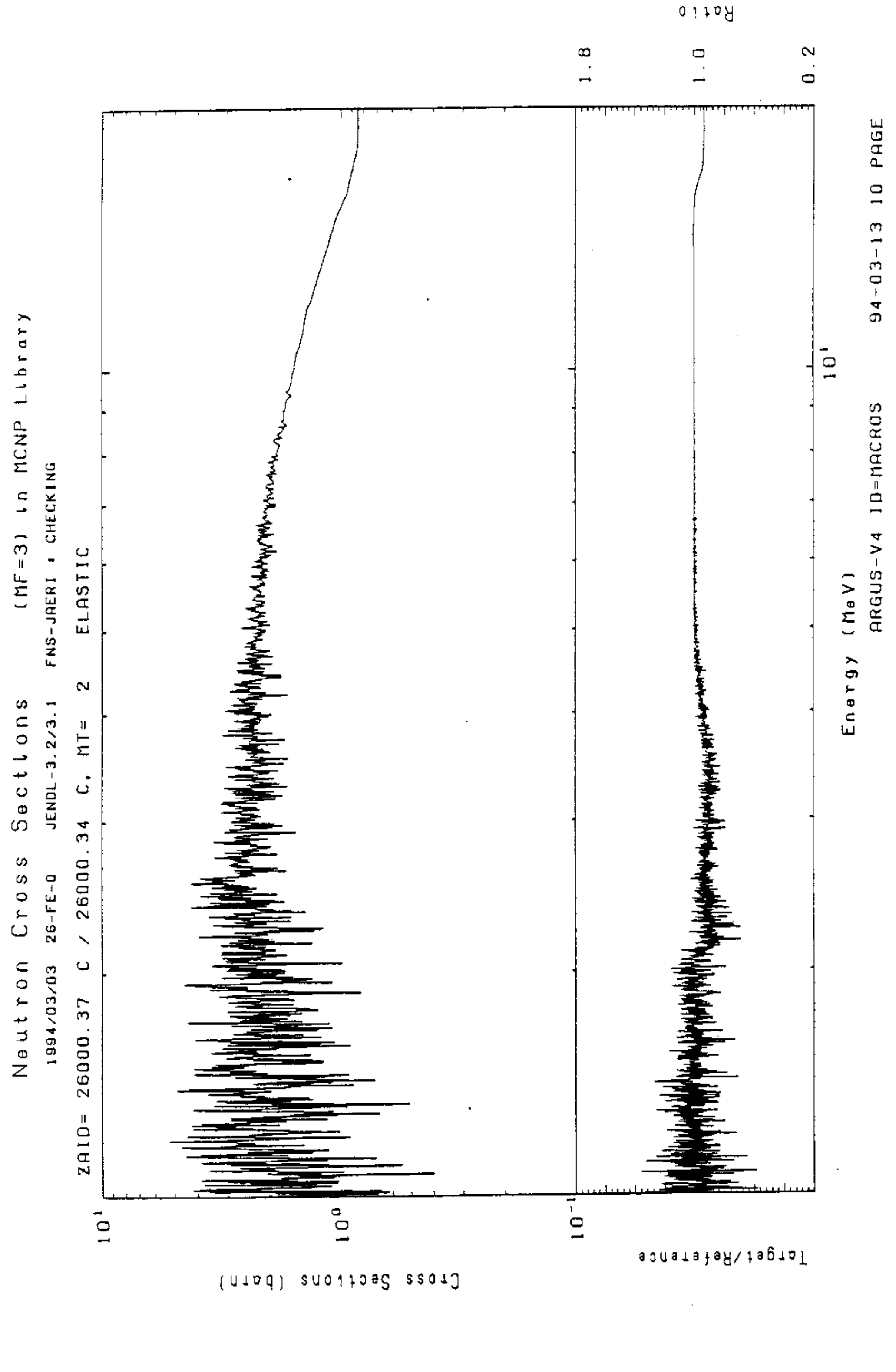

Fig. 3.20 Comparison of the elastic cross section of iron between FSXLIB-J3R2 and FSXLIB-J3 in an energy range of 0.2 - 1.1 MeV.

Appendix Input Data of MACROS

This appendix describes specifications of input data for the MACROS code which treat a continuous energy cross section library for MCNP. All the input data should be entered in a fixed format. Please refer JAERI-M 91-187 for the detailed explanations.

#1 Control Card : format=(5I8)

1) MATNO identification number of nuclide; (atomic number)*1000+(mass number)
2) ITYPE option for functions of MACROS
   - 0 = allocate a new library and register the first nuclide
   - 1 = add a nuclide to the library
     if negative, nuclides are not sorted in the ascending order.
   - 2 = replace a nuclide in the library
     if negative, nuclides are not sorted in the ascending order.
   - 3 = sort the registered nuclides in the ascending order
   - 4 = print out the cross section information of a nuclide with the format same as NJOY
   - 5 = delete a nuclide from the library
     if negative, nuclides are not sorted in the ascending order.
   - 6 = plot neutron cross sections in the library and the nuclear data file for comparisons (using CALCOMP)
   - 7 = combine two directory files
   - 8 = convert an attribution of the directory file
     if positive, from a sequential file to a direct access file
     if negative, from a direct access file to a sequential file
   - 9 = modify a specific data in the directory file of direct access type
   - 10 = plot neutron cross sections in the library (using CALCOMP)
   - 11 = plot angular distributions of secondary neutron in the library and the nuclear data file for simple comparisons (using CALCOMP)
   - 12 = verify and plot neutron energy distributions in the library (using ARGUS-V4)
   - 13 = verify and plot gamma-ray production data (multiplicities, angular distributions and energy distributions) in the library (using ARGUS-V4)
   - 14 = plot angular distributions of secondary neutron in the library and the nuclear data file for detailed comparisons (using ARGUS-V4)
   - 15 = compare and plot neutron cross sections with resonance parameters
     if positive, with data from RESENDD
     if negative, with data by LINEAR-RECENT-SIGMA1
     (using ARGUS-V4)
   - 16 = plot neutron cross sections for detailed comparisons
     if positive, between two nuclides in the library
     if negative, between a nuclide in two different libraries

(using ARGUS-V4)
17 = plot neutron cross sections in the library (using ARGUS-V4)
20 = edit the dosimetry cross section library in direct access type;
if positive, allocate a new dosimetry library and register the first nuclide
if negative, add a nuclide to the dosimetry library

3) LRECD record length of the direct access library (default=2048)
4) LEVELV evaluation identification number (less than 99)
5) MATID material identification number (MAT) of the nuclide in the nuclear data file to be compared with the library; effective in the case of ITYPE=6, 11-15

If ITYPE=0-2, 6, 10-17 or 20, enter #2-card.

#2 Title Card of Nuclide : format=(A70)

BCDA (in the case of ITYPE=0-2, 20) title of nuclide registered in a library or a dosimetry library. It will be used as a comment of the nuclide in the library.
(in case of ITYPE=6, 10-11, 15-17) title plotted in the graph
(in case of ITYPE=12-14) not used; may be blank

If ITYPE=6 or 10, enter #3-card.

#3 Plotting Range of for Neutron Cross Sections : format=(4I8)

LEXPOD(1) lower limit of neutron energy (exponent power in eV)
LEXPOD(2) upper limit of neutron energy (exponent power in eV)
LEXPOD(3) lower value of cross sections (exponent power in barns)
LEXPOD(4) upper value of cross sections (exponent power in barns)
(The default of the plotting range is determined automatically.)

If ITYPE=7, enter #4-card.

#4 Combination Range for Directory files : format=(2I8)

LEXPOD(1) starting record number of another directory file to copy to one file
LEXPOD(2) ending record number of another directory file to copy to one file

If ITYPE=8, enter #5-card.

#5 Conversion of Attribution of Directory File : format=(2I8)

LEXPOD(1) starting record number to convert attribution of directory file
LEXPOD(2) ending record number to convert attribution of directory file
(The default is for all record.)

If ITYPE=9, enter #6-card.

#6 Modification of Directory Information : format=(A72)

BCDA There are three data for modification of an information in a directory file. (each data should be separated by one or more blanks; default is nothing) :
1) NNRECD record number to be modified in the directory file

2) NNPOST position of data on the directory information record to be modified (from 1 to 10)

3) INTESS type of the variable to be modified (character, real or integer data)

If ITYPE=11 or 14, enter #7-card.

#7 Plotting Range of Neutron Angular Distributions : format=(3I8)

LEXPOD(1)	reaction type number (MT) (default=2)
LEXPOD(2)	starting number of incident neutron energy group (default=1)
LEXPOD(3)	ending number of incident neutron energy group (default=last)

If ITYPE=12, enter #8-card.

#8 Plotting Range of Neutron Energy Distributions : format=(5I8)

LEXPOD(1)	reaction type number (MT)
LEXPOD(2)	lower limit of neutron energy (exponent power in MeV)
LEXPOD(3)	upper limit of neutron energy (exponent power in MeV)
LEXPOD(4)	lower value of probabilities (exponent power)
LEXPOD(5)	upper value of probabilities (exponent power)

(The default of the plotting range for all the reactions is determined automatically.)

If ITYPE=15, enter #9-card.

#9 Plotting Range to Compare Resonance Cross Sections with RESENDD of : format=(I8)

LEXPOD(1)	number of the maximum energy point to plot on a graph (default=500)

If ITYPE=16, enter #10-card.

#10 Plotting Range for Comparison of Two Nuclides in the MCNP Library : format=(4I8)

LEXPOD(1)	identification number of nuclide to be compared
LEXPOD(2)	evaluation identification number of a nuclide to be compared
LEXPOD(3)	number of the maximum energy point to plot on a graph (default=700)
LEXPOD(4)	option of treatment of inelastic scattering reactions; 0 = not plotted (default) 1 = plot if Q-values of both inelastic scattering reactions are the same

If ITYPE=17, enter #11-cards.

#11 Plotting Range of Specific Neutron Cross Sections : format=(5I8)

LEXPOD(1)	reaction type number (MT) plotting
LEXPOD(2)	lower limit of neutron energy (exponent power in MeV)
LEXPOD(3)	upper limit of neutron energy (exponent power in MeV)
LEXPOD(4)	lower value of cross sections (exponent power in barns)
LEXPOD(5)	upper value of cross sections (exponent power in barns)

(#11-cards can be repeated as required.)