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PROCESSING AND VALIDATION OF INTERMEDIATE ENERGY EVALUATED DATA FILES

A report by the Working Party on International Evaluation Co-operation of the NEA Nuclear Science Committee

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NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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FOREWORD

A Working Party on International Evaluation Co-operation was established under the sponsorship of the OECD/NEA Nuclear Science Committee (NSC) to promote the exchange of information on nuclear data evaluations, validation, and related topics. Its aim is also to provide a framework for co-operative activities between members of the major nuclear data evaluation projects. This includes the possible exchange of scientists in order to encourage co-operation. Requirements for experimental data resulting from this activity are compiled. The working party determines common criteria for evaluated nuclear data files with a view to assessing and improving the quality and completeness of evaluated data.

The parties to the project are: ENDF (United States), JEF/EFF (NEA Data Bank Member countries), and JENDL (Japan). Co-operation with evaluation projects of non-OECD countries, specifically the Russian BROND and Chinese CENDL projects, are organised through the Nuclear Data Section of the International Atomic Energy Agency (IAEA).

Subgroup 14 of the working party was set up with the objective of assessing the quality and practical use of intermediate energy evaluated data files. The current collection of intermediate energy data files was established, with the criterion being the processability of the data files for current transport codes. The quality of the pointwise data for neutrons and protons on several isotopes up to 150 MeV was reviewed. This was done by means of the data files themselves, associated cross-section plots and outputs of checking codes. In the process, the LA150 library was recommended for inclusion in ENDF/B-VI. An integral transport calculation with MCNPX was performed to validate the files against a neutron transmission experiment.

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SUMMARY

Current accelerator-driven and other intermediate energy technologies require accurate nuclear data to model the performance of the target/blanket assembly, neutron production, activation, heating and damage. In a previous WPEC subgroup, SG13 on intermediate energy nuclear data, various aspects of intermediate energy data, such as nuclear data needs, experiments, model calculations and file formatting issues were investigated and categorised to come to a joint evaluation effort. The successor of SG13, SG14 on the processing and validation of intermediate energy evaluated data files, goes one step further. The nuclear data files that have been created with the aforementioned information need to be processed and validated in order to be applicable in realistic intermediate energy simulations. We emphasise that the work of SG14 excludes the 0-20 MeV data part of the neutron evaluations, which is supposed to be covered elsewhere. This final report contains the following sections:

- *Section 2*: A survey of the data files above 20 MeV that have been considered for validation in SG14.

- *Section 3*: A summary of the review of the 150 MeV intermediate energy data files for ENDF/B-VI and, more briefly, the other libraries.

- *Section 4*: Validation of the data library against an integral experiment with MCNPX.

- *Section 5*: Conclusions.

PROCESSING AND VALIDATION OF INTERMEDIATE ENERGY EVALUATED DATA FILES

1. Data files above 20 MeV

The various intermediate energy files that have been created have several things in common:

- They are usually created for both incident neutrons and protons.
- They are stored in the ENDF-6 format.
- The usual upper energy limit is 150 MeV, though some files up to 50 MeV (for fusion) exist.
- The part below 20 MeV is usually left untouched, whereas the part above 20 MeV is primarily based on new model calculations, which are guided by the few existing experimental data sets.

Table 1 gives the entire collection of intermediate energy data files that is presently known to SG14. The criterion of being included in this table is that the data file has been, or will be in the near future, successfully used in a transport code (in practice, at the moment this means either MCNP-4A/B/C or MCNPX). The following (partial) libraries were considered:

- Los Alamos LA150 [1]. This is a neutron and proton library up to 150 MeV for a suite of isotopes. The library has been tested against both microscopic and integral experiments. The LA150 library was produced in collaboration with JAERI, Japan and NRG, Petten.
- NRG/CEA [2]. This presently consists of 150 MeV neutron and proton files for the main iron and nickel isotopes. The library is the result of a collaboration between NRG, Petten and CEA, Bruyères-le-Châtel.
- JENDL/HE [3]. This is a 50 MeV neutron data library for isotopes relevant for fusion. The library is produced at JAERI.

- IPPE/FZK [4]. This is also a 50 MeV neutron data library for isotopes relevant for fusion. The library was produced by IPPE Obninsk and FZK Karlsruhe.

- IPPE/KTH [5]. This consists of 150 MeV neutron and proton files for the main thorium and uranium isotopes. This library was produced by IPPE Obninsk and KTH Stockholm for the IABAT project of the EU.

2. Review of the basic data

As argued in several papers [1,2,6], below 150 MeV the predictive power of several pre-equilibrium/statistical model codes is superior to intranuclear cascade codes for continuum reactions. Also, individual reaction mechanisms (giant resonances, direct collective reactions, etc.) constitute a relatively larger fraction of the reaction spectrum and require an individual, more sophisticated treatment. When results from such detailed reaction mechanisms are collected and included in a data file, they form a data source that in quality can never be matched by one single computer code. All the physical models that are utilised in the LA150 and NRG/BRC libraries are described in [1] and [2] respectively. Most of the data have been generated with the GNASH and ECIS codes. Refs. [1,2] contain a large collection of comparisons of the calculated data (which are stored in the file) and the existing experiments. The comparisons include total and reaction cross-sections, elastic scattering angular distributions, double differential data and residual production cross-section above 20 MeV. The agreement with experimental data ranges from excellent to very reasonable, as can be seen from the figures in the aforementioned references.

2.1 LA150 library

Subgroup 14 has been asked to review the LA150 library, and to make recommendations concerning inclusion of LA150 in ENDF/B-VI. In the meantime, the adoption of LA150 into ENDF/B-VI has taken place. The CSWEG request came from the Evaluation Committee of ENDF/B-VI, which only concerns itself with "Phase 1" reviews. This means that the present review does not involve integral data testing, but rather is concerned with:

- The correct format of the evaluations.

- Errorless passing of the checking codes.

- Continuous data varying smoothly with energy, angle, etc.

- Agreement with existing measurements.

The two principal authors of the LA150 library, M.B. Chadwick and P.G. Young, have provided Subgroup 14 with the following information:

- Documentation:

  – A recent publication in *Nuclear Science and Engineering* [1], containing extensive comparisons of the model-based data with measurements.

  – A collection of summary file-1 documentation and benchmark figures (some of them three-dimensional) depicting the data in the libraries [7].

- Data in electronic form:

  – All the evaluated files of LA150.n and LA150.p.

  – Outputs of the BNL checking codes CHECKR, FIZCON, PSYCHE and STANEF.

  – Various postscript plots depicting the data.

  – Summary files of cross-sections.

The review has been performed by two parties, JAERI (T. Fukahori) and NRG Petten (A. Koning). Both concluded that LA150 passed the several tests of the "Phase 1" review and that, with some minor modifications, it could be adopted. A few of the findings follow below.

2.1.1 Cross-section plots

An extensive collection of figures of total, differential and double differential data for the LA150 library has been provided in [7]. These figures clearly reveal the overall smooth behaviour of the data as a function of mass, energy and angle. In general, for incident energies between 20 and 50 MeV, the evaporation peak seems to be very pronounced for some (*n,xd*) data. In particular, there are some, maybe anomalous, spikes in the (*n,xd*) spectra for ^{30}Si, ^{31}P, Ca, ^{60,62,64}Ni, ^{63}Cu (but not in ^{65}Cu) and ^{93}Nb. It is not immediately clear why these peaks appear for these nuclei and this particular channel, whereas they are not present in the (n,xt) and (n,$x\alpha$) cross-sections. Similar spikes appear in ^{28}Si(p,xt) and ^{29}Si(p,$x\gamma$). The fact that the magnitude of these cross-sections is relatively small and that this appears only in a very small energy region means that this is certainly no reason to reject the data files. Of course, the effect may actually be physical. Consult [7] for further details.

2.1.2 BNL checking codes

The output files of the checking codes CHECKR, FIZCON and PSYCHE report several warnings. However these apply almost all at the part below 20 MeV. The only high-energy warning concerns a new feature of the ENDF-6 format, namely the switch from Legendre coefficients to tabular distributions at 20 MeV. The CHECKR code wants this point to be at exactly 20 MeV. The LA150 library gives 20.00001 as the first energy point with tabulated data (and thereby avoids a double point, which seems to be better). Perhaps CHECKR requires a little change for this. This warning seems to be a minor detail. Table 1 shows the data files which are known to have been checked this way.

2.2 NRG/CEA library

For this library essentially the same working methods were used as for LA150. The main difference lies in the use of new optical models throughout the calculation. The checking procedure described for LA150 is also applied here. As an example of the contents of the file Figure 1 shows double differential data for protons on ^{58}Ni.

2.3 JENDL HE library

A comparison of the JENDL HE library with the LA150 and NRG/CEA libraries has been provided by Lee and Fukahori [10]. The conclusions were that JENDL HE generally describes the data well up to 50 MeV, but that improvements in optical models are required for the most basic cross-sections. Also for some materials (notably iron) the double differential cross-sections of LA150 and NRG/CEA seem to do somewhat better than the JENDL HE results. A lot of added value in the JENDL HE library is provided by covering materials that were not (yet) considered in the 150 MeV libraries.

2.4 *Processing*

Table 1 shows that most data files have proven to be processable by NJOY into an MCNP library. In another WPEC document [8], a set of special rules and recommendations for an evaluated nuclear data file are given, such that the above processing conditions are obeyed. Recommendations resulting from that work are:

- Use double-points in the MF3 section of the evaluation for the transition of the low-energy range (E_n < 20 MeV) to the high-energy range (E_n > 20 MeV).

- Double-points should not be used in the MF6 section of the evaluation.

- Use a representation with MT2 (elastic cross-section), MT5 ((*n*,*x*) cross-section), MT18 (fission cross-section) and possibly MT101 (neutron disappearance cross-section) in the high-energy region.

- Use the redundant production cross-sections MT201 to MT207 for the ease of the user: It enables the calculation of production rates in MCNP.

- Specify distributions of reaction products in the MF6 section of the evaluation for MT5.

- If MT18 is used, the MT456 section in MF1 is required.

If these recommendations are applied, high-energy neutron evaluated nuclear data files can be produced which can be used without problems in MCNP(X).

3. Validation on an integral experiment with MCNPX

A number of neutron transmission experiments have been performed [11-13] at the Azimuthally Varying Field Cyclotron facility (TIARA) at the JAERI Takashi site. Incident 43- or 68-MeV protons impinged on converters consisting of 99.9% enriched ^{7}Li. The ^{7}Li(p,n) reaction produced nearly monoenergetic neutrons, which were then collimated and allowed to strike iron or concrete targets of various thickness. The neutron transmission was measured at several positions relative to the transmission target. Although the neutrons were initially almost monoenergetic in all cases, their actual spectra were measured in order to allow for a more realistic comparison with neutron transport calculations. Details about the experimental arrangement and the geometry can be found in the aforementioned references.

This experiment forms an ideal case to validate some of the intermediate energy libraries. The iron isotopes of the Los Alamos 150 MeV library have already been used in an analysis [1] of the 68 MeV experiment. Within SG14, this analysis has been repeated, as an independent check, and extended to other cases. We confirm the overall excellent agreement between the measurements and the data (see Figures 2-4) that was already reported in [1]. The alternative libraries from NRG/BRC (Figures 5-7) give an equally good agreement.

It is obvious from Figures 8-10 that the predictions by LAHET do not have the quality of those using the data libraries. One reason for the deviation from the data is the quality of the elastic scattering model used in LAHET. This is currently under development.

The main reason that we include this comparison with experiment is that we use MCNPX, with the geometrical set-up of this experiment, to see whether the other isotopes of the LA150 library show any undesired irregularities. This does give a valuable indication of the presence of problems in the evaluations. In Figures 11-14 the neutron flux at centreline behind a 40 cm slab of pure material is shown. The atomic density at room temperature for all the elements are used. The figures demonstrate that, for this simple experiment, the data files do not exhibit any misbehaviour.

An analysis similar to the one described here has been performed by Konno, *et al*. [14-16]. In addition, these authors have performed multi-group analyses with the LA150 library (see Table 1) using the DORT code and P9 expanded multi-group libraries. The authors claim that LA150 may have some problems since their MCNP calculations tend to overestimate the neutron flux above 10 MeV with an increasing thickness of the assembly. This is an important point for future research. For completeness, we mention that this experiment has also been used to test some of the other libraries [17,18].

As an alternative manifestation of the impact of the 150 MeV data evaluations, we present a calculated result from the TIERCE code system [19], which comprises among others HETC and MCNP-4A, with the 150 MeV file for ^{58}Ni from NRG/CEA. Figure 15 displays the neutron flux resulting from a 200 MeV proton beam incident on a 50 cm long ^{58}Ni-cylinder. Two calculations were performed: One with HETC and MCNP + 20 MeV data file and one with MCNP + 150 MeV data file. Besides the expected discontinuity at 20 MeV for the case with the conventional 20 MeV cut-off, one can observe an overall difference of up to 40% in the high-energy region.

4. Conclusions

In line with the “Phase 1” review of ENDF/B-VI, we have checked that the LA150 data show a smooth behaviour, where this is expected, by means of cross-section plots. The comparison of the contents of the data files with experimental data reveals that the data files seem to be superior to anything else existing at the moment (e.g. the intranuclear cascade codes), at least consistently over such a large range of mass, energy and reaction channels. The checking codes do not complain about the contents of the files above 20 MeV, and the files can be processed by NJOY into MCNP libraries.

The quality of several of the libraries is tightly connected with the quality of the nuclear model codes GNASH and ALICE, which are known to perform better or at least as good as its competitors [6]. In other words, they are relatively safe tools when so little experimental data is available as in the intermediate energy region. It should however be mentioned, and the authors of the various libraries are aware of that, that a lot can still be gained by improving nuclear models, of which the optical model, level density and pre-equilibrium models seem to be the most crucial. To this end, a new WPEC subgroup on nuclear model codes will be formed. Hence, the present intermediate energy libraries represent a challenge to other methods that claim to do even better in the future.

Within SG14, the LA150 and NRG/BRC data files have been tested, with the transport code MCNPX, against an iron benchmark experiment. A similar validation has been simultaneously performed by others. For nuclear applications with nucleon energies below 150 MeV, the calculations with neutron data files suggest a drastic improvement of the description of macroscopic experiments, when compared with the intranuclear cascade code LAHET. This confirms the findings that were reported in [1]. For this simple benchmark experiment, there seems to be no clear quality argument in favour of either the LA150 or the NRG/BRC neutron data files for iron. Some discontinuities can still be observed at energies around 20 MeV, although they are no longer as large as in the LAHET + 20 MeV data file calculations. This suggests that for a continuous description the data below and above 20 MeV should preferably be re-evaluated in one and the same working process. Also, the findings by Konno, *et al.* mentioned in the previous section need to be taken into account. Finally, we have checked that the other materials present in the LA150 data library show no strange irregularities that result from the extension to 150 MeV. For several of the data files of Table 1 this still needs to be done. The conclusion of SG14 is, however, that there should in principle be no problem to achieve this, provided the format procedures of the LA150 and NRG/BRC libraries are followed.

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TABLES

Table 1. Intermediate energy data files, May 2000

Nuclide	Library	Origin	Particle	Energy	Checked	MCNP	Multi-group
^{1}H	ENDF/B-VI	LANL	p,n	150 MeV	yes	yes	yes
	JENDL HE	JAERI	n	50 MeV			
^{2}H	ENDF/B-VI	LANL	p,n	150 MeV	yes	yes	
C	ENDF/B-VI	LANL	p,n	150 MeV	yes	yes	
^{12}C		IPPE/FZK	n	50 MeV		yes	
	JENDL HE	JAERI	n	50 MeV			
^{14}N	ENDF/B-VI	LANL	p,n	150 MeV	yes	yes	
^{16}O	ENDF/B-VI	LANL	p,n	150 MeV	yes	yes	yes
		IPPE/FZK	n	50 MeV		yes	
^{23}Na		IPPE/FZK	n	50 MeV		yes	
	JENDL HE	JAERI	n	50 MeV			
^{24}Mg	JENDL HE	JAERI	n	50 MeV		yes	
^{25}Mg	JENDL HE	JAERI	n	50 MeV		yes	
^{26}Mg	JENDL HE	JAERI	n	50 MeV		yes	
^{27}Al	ENDF/B-VI	LANL	p,n	150 MeV	yes	yes	yes
	JENDL HE	JAERI	n	50 MeV		yes	
^{28}Si	ENDF/B-VI	LANL	p,n	150 MeV	yes	yes	yes
		IPPE/FZK	n	50 MeV		yes	
	JENDL HE	JAERI	n	50 MeV		yes	
^{29}Si	ENDF/B-VI	LANL	p,n	150 MeV	yes	yes	yes
	JENDL HE	JAERI	n	50 MeV		yes	
^{30}Si	ENDF/B-VI	LANL	p,n	150 MeV	yes	yes	yes
	JENDL HE	JAERI	n	50 MeV		yes	
^{31}P	ENDF/B-VI	LANL	p,n	150 MeV	yes	yes	
^{35}Cl	JENDL HE	JAERI	n	50 MeV			
^{37}Cl	JENDL HE	JAERI	n	50 MeV			
^{39}K		IPPE/FZK	n	50 MeV		yes	
	JENDL HE	JAERI	n	50 MeV		yes	
^{41}K	JENDL HE	JAERI	n	50 MeV		yes	
Ca	ENDF/B-VI	LANL	p,n	150 MeV	yes	yes	yes
^{40}Ca	JENDL HE	JAERI	n	50 MeV		yes	
^{42}Ca	JENDL HE	JAERI	n	50 MeV		yes	
^{43}Ca	JENDL HE	JAERI	n	50 MeV		yes	
^{44}Ca	JENDL HE	JAERI	n	50 MeV		yes	
^{46}Ca	JENDL HE	JAERI	n	50 MeV		yes	
^{48}Ca	JENDL HE	JAERI	n	50 MeV		yes	
^{46}Ti	JENDL HE	JAERI	n	50 MeV		yes	
^{47}Ti	JENDL HE	JAERI	n	50 MeV		yes	
^{48}Ti	JENDL HE	JAERI	n	50 MeV		yes	
^{49}Ti	JENDL HE	JAERI	n	50 MeV		yes	
^{50}Ti	JENDL HE	JAERI	n	50 MeV		yes	

Yes. The action has been successfully performed.
No. The action has not been successfully performed.
Blank. It is not known whether the action has taken place.

Table 1. Intermediate energy data files, May 2000 (*cont.*)

Nuclide	Library	Origin	Particle	Energy	Checked	MCNP	Multi-group
^{50}V	JENDL HE	JAERI	n	50 MeV		yes	
^{51}V		IPPE/FZK	n	50 MeV		yes	
	JENDL HE	JAERI	n	50 MeV		yes	
^{50}Cr	ENDF/B-VI	LANL/JAERI	p,n	150 MeV	yes	yes	
	JENDL HE	JAERI	n	50 MeV		yes	
^{52}Cr	ENDF/B-VI	LANL/JAERI	p,n	150 MeV	yes	yes	
		IPPE/FZK	n	50 MeV		yes	
	JENDL HE	JAERI	n	50 MeV			
^{53}Cr	ENDF/B-VI	LANL/JAERI	p,n	150 MeV	yes	yes	
	JENDL HE	JAERI	n	50 MeV			
^{54}Cr	ENDF/B-VI	LANL/JAERI	p,n	150 MeV	yes	yes	
	JENDL HE	JAERI	n	50 MeV			
^{55}Mn	JENDL HE	JAERI	n	50 MeV			
^{54}Fe	ENDF/B-VI	LANL/NRG	p,n	150 MeV	yes	yes	yes
		NRG/CEA	p,n	150 MeV	yes	yes	
	JENDL HE	JAERI	n	50 MeV		yes	
^{56}Fe	ENDF/B-VI	LANL/NRG	p,n	150 MeV	yes	yes	yes
		NRG/CEA	p,n	150 MeV	yes	yes	
		IPPE/FZK	n	50 MeV		yes	
	JENDL HE	JAERI	n	50 MeV		yes	
^{57}Fe	ENDF/B-VI	LANL/NRG	p,n	150 MeV	yes	yes	yes
	JENDL HE	JAERI	n	50 MeV		yes	
^{58}Fe	ENDF/B-VI	LANL/NRG	p,n	150 MeV	yes	yes	yes
	JENDL HE	JAERI	n	50 MeV		yes	
^{58}Ni	ENDF/B-VI	LANL/JAERI	p,n	150 MeV	yes	yes	
		NRG/CEA	p,n	150 MeV	yes	yes	
	JENDL HE	JAERI	n	50 MeV		yes	
^{60}Ni	ENDF/B-VI	LANL/JAERI	p,n	150 MeV	yes	yes	
		NRG/CEA	p,n	150 MeV	yes	yes	
	JENDL HE	JAERI	n	50 MeV		yes	
^{61}Ni	ENDF/B-VI	LANL/JAERI	p,n	150 MeV	yes	yes	
	JENDL HE	JAERI	n	50 MeV		yes	
^{62}Ni	ENDF/B-VI	LANL/JAERI	p,n	150 MeV	yes	yes	
	JENDL HE	JAERI	n	50 MeV		yes	
^{64}Ni	ENDF/B-VI	LANL/JAERI	p,n	150 MeV	yes	yes	
	JENDL HE	JAERI	n	50 MeV		yes	
^{63}Cu	ENDF/B-VI	LANL/NRG	p,n	150 MeV	yes	yes	
	JENDL HE	JAERI	n	50 MeV		yes	
^{65}Cu	ENDF/B-VI	LANL/NRG	p,n	150 MeV	yes	yes	
	JENDL HE	JAERI	n	50 MeV		yes	
^{89}Y	JENDL HE	JAERI	n	50 MeV			

Yes. The action has been successfully performed.
No. The action has not been successfully performed.
Blank. It is not known whether the action has taken place.

Table 1. Intermediate energy data files, May 2000 (*cont.*)

Nuclide	Library	Origin	Particle	Energy	Checked	MCNP	Multi-group
^{90}Zr	JENDL HE	JAERI	n	50 MeV			
^{91}Zr	JENDL HE	JAERI	n	50 MeV			
^{92}Zr	JENDL HE	JAERI	n	50 MeV			
^{94}Zr	JENDL HE	JAERI	n	50 MeV			
^{96}Zr	JENDL HE	JAERI	n	50 MeV			
^{93}Nb	ENDF/B-VI	LANL	p,n	150 MeV	yes	yes	
	JENDL HE	JAERI	n	50 MeV			
^{92}Mo	JENDL HE	JAERI	n	50 MeV			
^{94}Mo	JENDL HE	JAERI	n	50 MeV			
^{95}Mo	JENDL HE	JAERI	n	50 MeV			
^{96}Mo	JENDL HE	JAERI	n	50 MeV			
^{97}Mo	JENDL HE	JAERI	n	50 MeV			
^{98}Mo	JENDL HE	JAERI	n	50 MeV			
^{100}Mo	JENDL HE	JAERI	n	50 MeV			
^{180}W	JENDL HE	JAERI	n	50 MeV			
^{182}W	ENDF/B-VI	LANL	p,n	150 MeV	yes	yes	
	JENDL HE	JAERI	n	50 MeV			
^{183}W	ENDF/B-VI	LANL	p,n	150 MeV	yes	yes	
	JENDL HE	JAERI	n	50 MeV			
^{184}W	ENDF/B-VI	LANL	p,n	150 MeV	yes	yes	
	JENDL HE	JAERI	n	50 MeV			
^{186}W	ENDF/B-VI	LANL	p,n	150 MeV	yes	yes	
	JENDL HE	JAERI	n	50 MeV			
^{196}Hg	ENDF/B-VI	LANL/JAERI	p,n	150 MeV	yes	yes	
^{198}Hg	ENDF/B-VI	LANL/JAERI	p,n	150 MeV	yes	yes	
^{200}Hg	ENDF/B-VI	LANL/JAERI	p,n	150 MeV	yes	yes	
^{201}Hg	ENDF/B-VI	LANL/JAERI	p,n	150 MeV	yes	yes	
^{202}Hg	ENDF/B-VI	LANL/JAERI	p,n	150 MeV	yes	yes	
^{204}Hg	ENDF/B-VI	LANL/JAERI	p,n	150 MeV	yes	yes	
^{206}Pb	ENDF/B-VI	LANL/NRG	p,n	150 MeV	yes	yes	
^{207}Pb	ENDF/B-VI	LANL/NRG	p,n	150 MeV	yes	yes	
^{208}Pb	ENDF/B-VI	LANL/NRG	p,n	150 MeV	yes	yes	
^{209}Bi	ENDF/B-VI	LANL	p,n	150 MeV			
^{232}Th		IPPE	p,n	150 MeV	no	yes	
^{238}U		IPPE	p,n	150 MeV		yes	

Yes. The action has been successfully performed.
No. The action has not been successfully performed.
Blank. It is not known whether the action has taken place.

FIGURES

Figure 1. (p,xp) on ^{58}Ni: Comparison between NRG/CEA data file and experimental data [9] for incident energies of (a) 150 MeV (b) 120 MeV, (c) 100 MeV at several outgoing energies

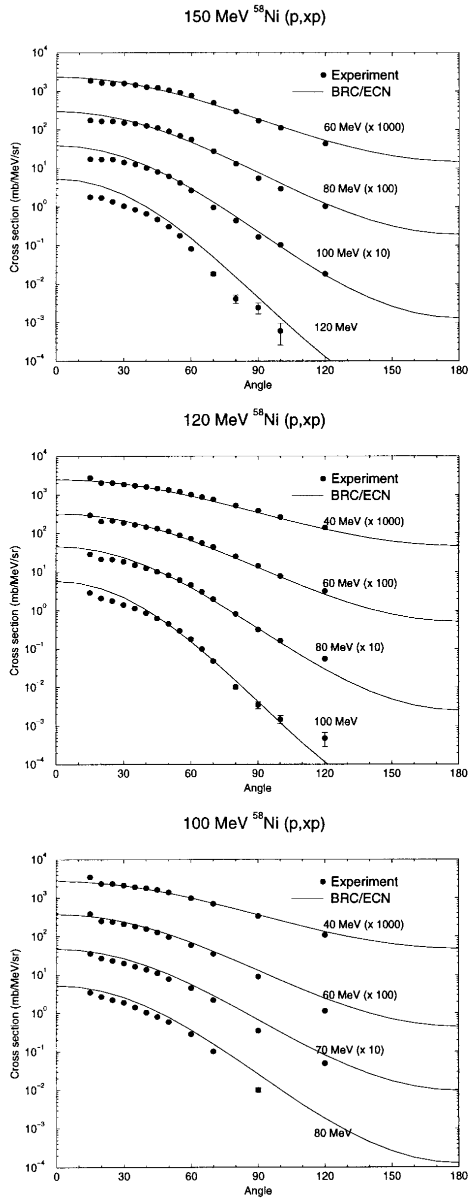

Figure 2. 68 MeV neutrons on 40 cm of iron, detector at centreline

Comparison between experimental data and MCNPX + LA150 data libraries

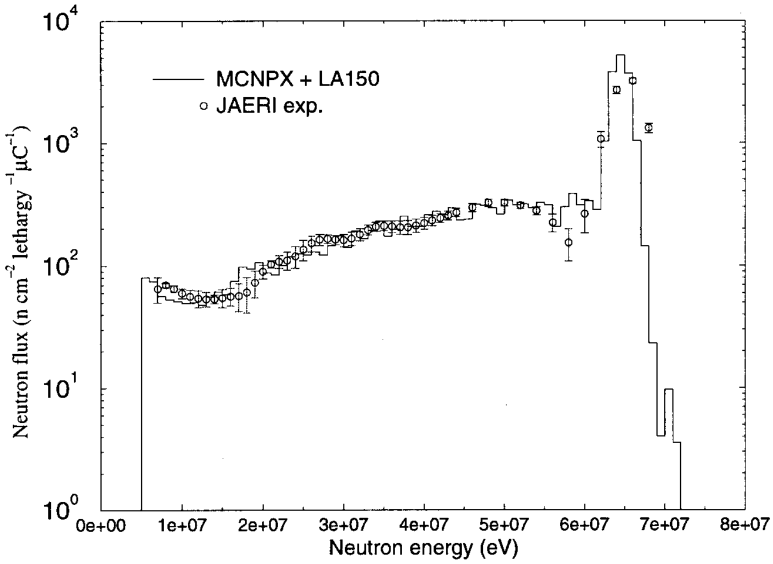

Figure 3. 68 MeV neutrons on 40 cm of iron, detector at 20 cm

Comparison between experimental data and MCNPX + LA150 data libraries

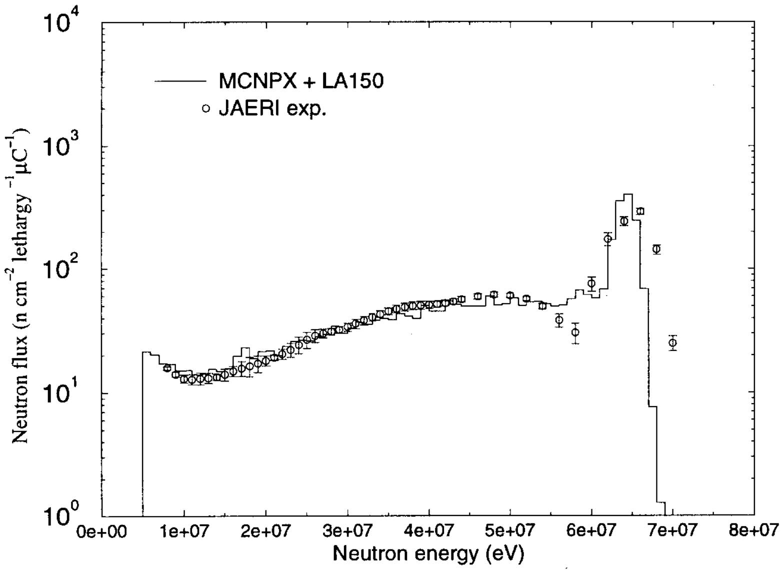

Figure 4. 68 MeV neutrons on 40 cm of iron, detector at 40 cm

Comparison between experimental data and MCNPX + LA150 data libraries

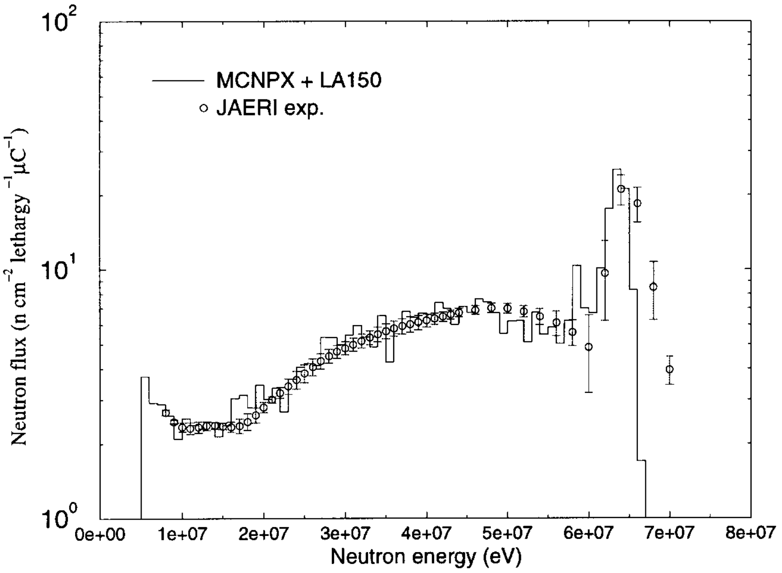

Figure 5. 68 MeV neutrons on 40 cm of iron, detector at centreline

Comparison between experimental data and MCNPX + ECN/BRC data libraries

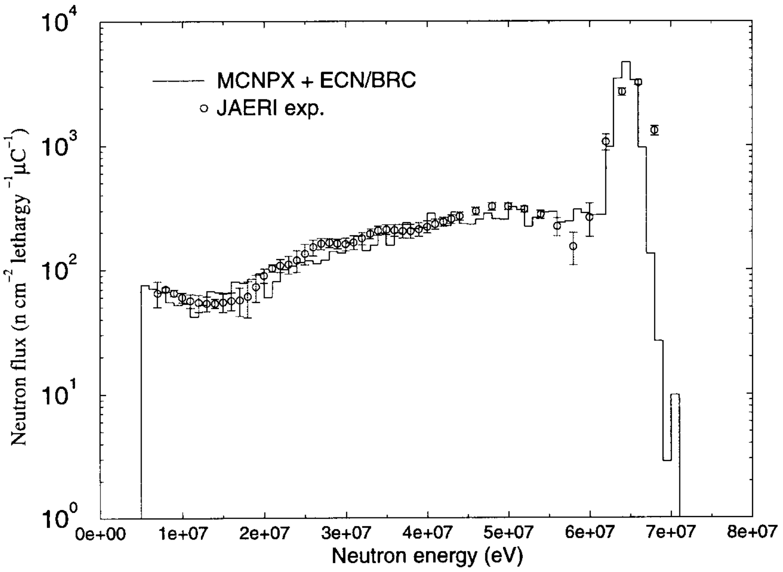

Figure 6. 68 MeV neutrons on 40 cm of iron, detector at 20 cm

Comparison between experimental data and MCNPX + ECN/BRC data libraries

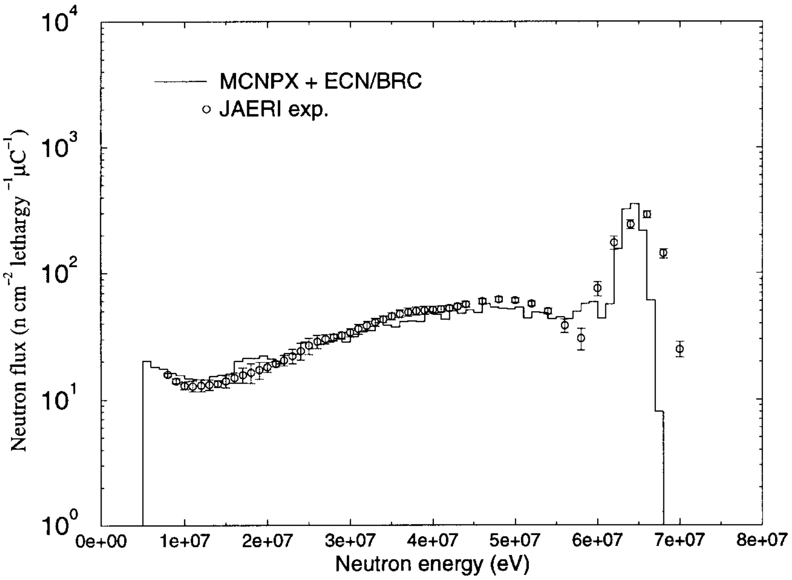

Figure 7. 68 MeV neutrons on 40 cm of iron, detector at 40 cm

Comparison between experimental data and MCNPX + ECN/BRC data libraries

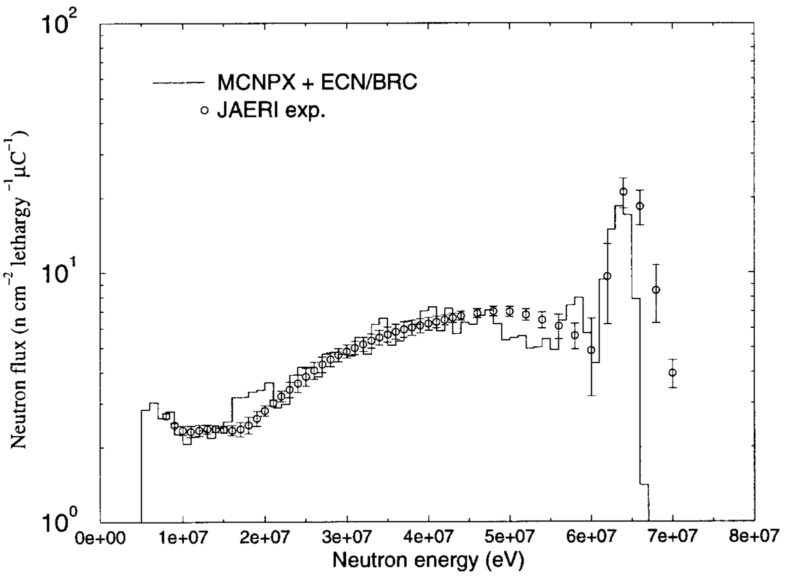

Figure 8. 68 MeV neutrons on 40 cm of iron, detector at centreline

Comparison between experimental data and MCNPX + LAHET above 20 MeV

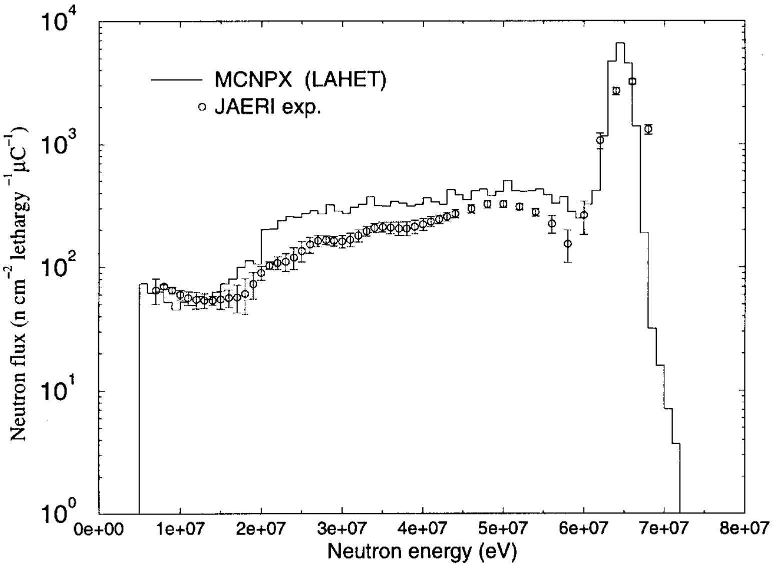

Figure 9. 68 MeV neutrons on 40 cm of iron, detector at 20 cm

Comparison between experimental data and MCNPX + LAHET above 20 MeV

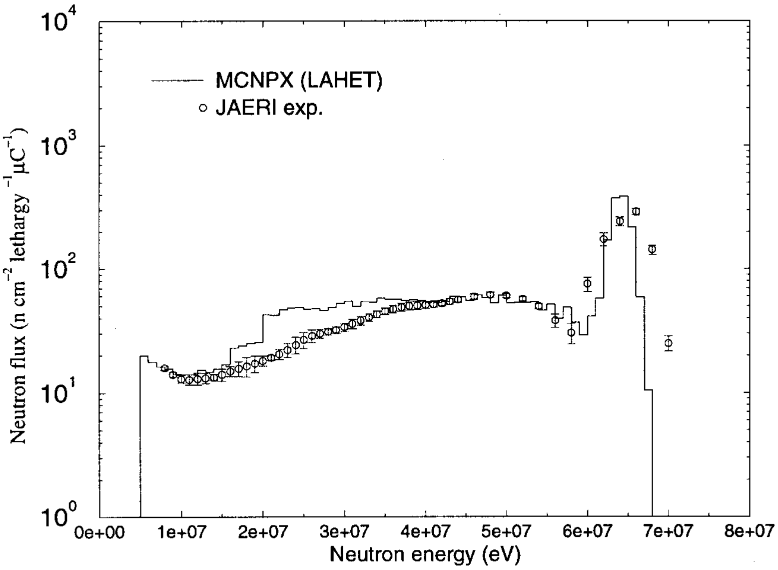

Figure 10. 68 MeV neutrons on 40 cm of iron, detector at 40 cm

Comparison between experimental data and MCNPX + LAHET above 20 MeV

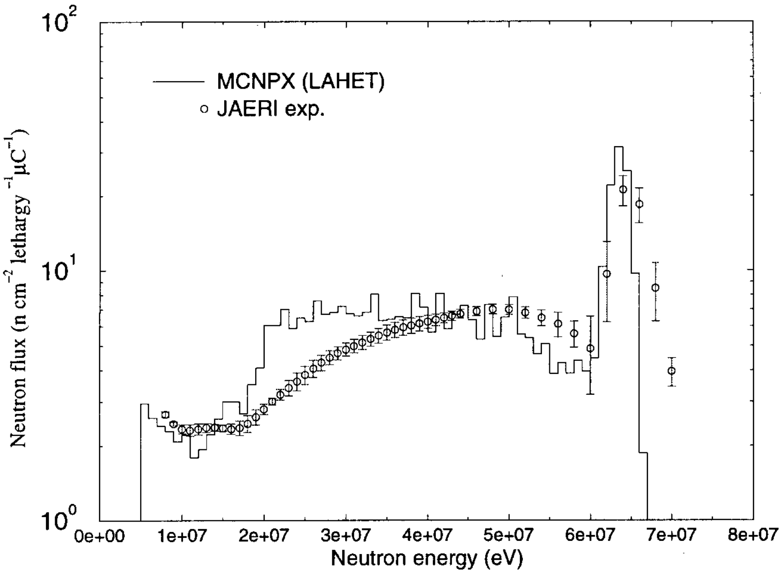

Figure 11. 68 MeV neutrons on 40 cm of carbon, nitrogen and oxygen, detector at centreline

Calculated result of MCNPX + LA150 data libraries

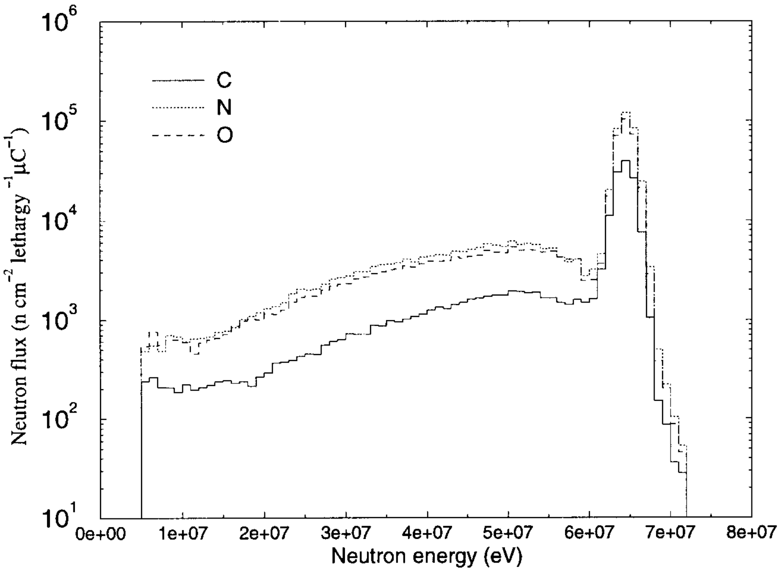

Figure 12. 68 MeV neutrons on 40 cm of aluminium, silicon and calcium, detector at centreline

Calculated result of MCNPX + LA150 data libraries

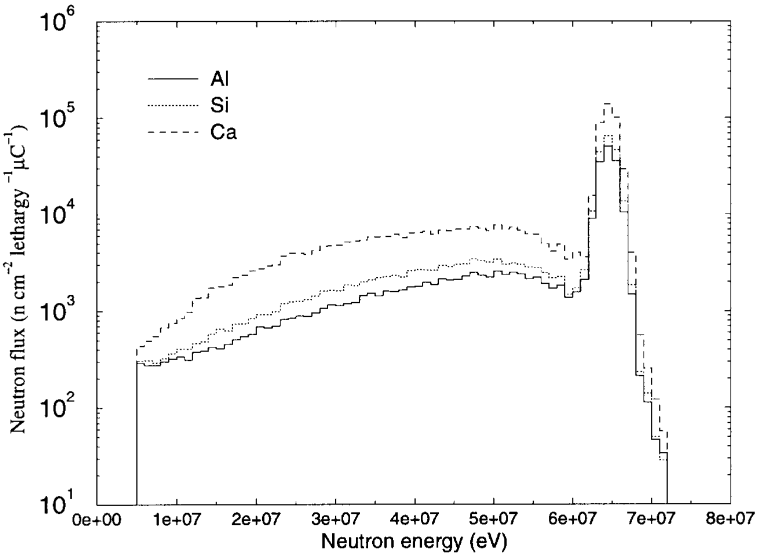

Figure 13. 68 MeV neutrons on 40 cm of chromium, iron and nickel, detector at centreline

Calculated result of MCNPX + LA150 data libraries

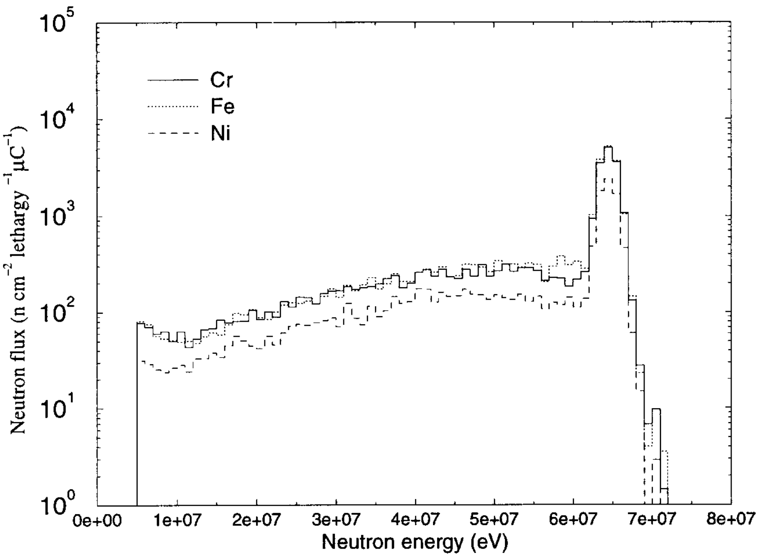

Figure 14. 68 MeV neutrons on 40 cm of tungsten and lead, detector at centreline

Calculated result of MCNPX + LA150 data libraries

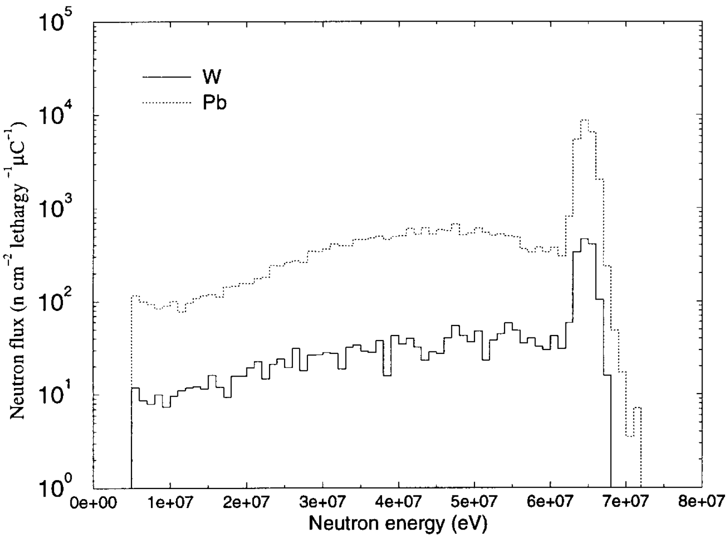

Figure 15. HETC-MCNP4A calculation for 200 MeV protons incident on a ^{58}Ni cylinder with the neutron data file cut-off at 20 vs. 150 MeV

The cylinder is 50 cm long and has a radius of 20 cm.
The mean neutron flux is calculated between 10 and 20 cm.