Extension of the He-4 Evaluation to 60 MeV for FENDL-3

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Introduction

One of the objectives of the IAEA CRP on the FENDL-3 library is to provide evaluated nuclear reaction data for all materials relevant for fusion-related neutronics calculations up to incident neutron energies of 60 MeV. Starter evaluations were selected and in case they did not extend up to the desired incident neutron energies, the Japanese colleagues extended the range to at least 60 MeV using data from the TENDL-2010 library. Unfortunately this was not possible for the light nuclides because TENDL-2010 is based on nuclear model calculations, which are not applicable for the lightest nuclides. The evaluations in the new ENDF/B-VII.1b4 library for ^{1}H and ^{2}H cover the desired energy range, but no evaluation extends beyond 20 MeV for ^{3}H, ^{3}He and ^{4}He. In the present work the extension of the ^{4}He evaluation to 60 MeV is described.

Procedures

The ENDF/B-VII.1b4 evaluation is taken as a starting point. The evaluation was checked against the experimental data in the EXFOR database. Extension to each reaction was made as described below.

Total cross section

The data of Haesner [1], Shamu [2] and Battat [3] were considered. A curve was fitted manually through the data points, applying some ad-hoc smoothing. The data were extrapolated to 60 MeV such that the general trends of the cross section behaviour at lower energies were preserved. The total cross section plot is shown on Figure 1.

Elastic cross section

The competing (n,d) reaction is significant only at the 22.2 MeV peak and the (n,2n) reaction has a threshold at about 25 MeV and is much smaller than the elastic cross section, therefore the elastic cross section is practically equal to the total cross section.

Elastic angular distributions

Above 20 MeV measurements by Shamu [2] are available and they extend up to 23.7 MeV. The plots of the angular differential cross sections are shown on Figures 2 and 3. At 60 MeV the measured data by Arnold [4] are available. Legendre Polynomial expansion was fitted to the data. The fit is shown in Figure 4. The evaluated angular differential cross sections between 20 MeV and 60 MeV were obtained by linear interpolation. The agreement with measured data at 23.7 MeV can be seen on Figure 3.

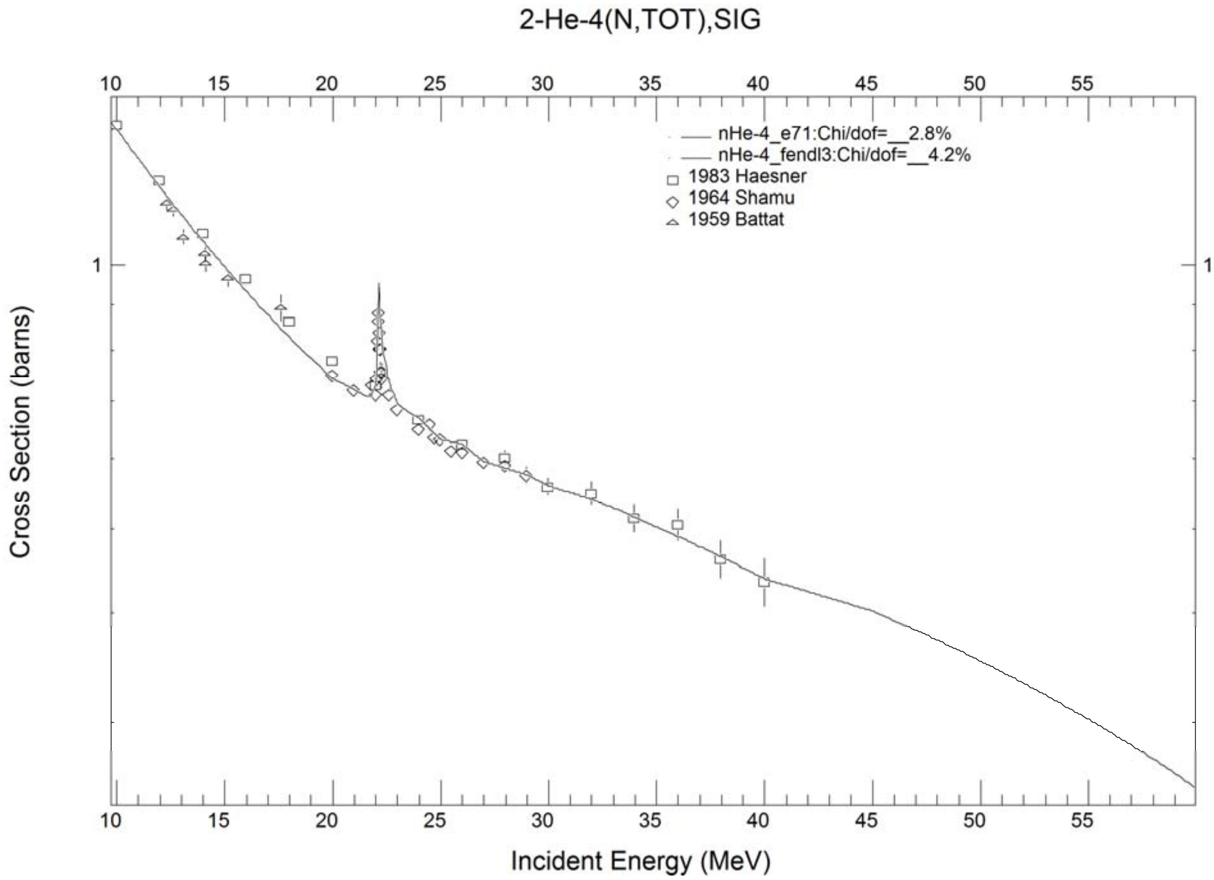

Figure 1: Total cross section of 4He extended to neutron incident energies up to 60 MeV.

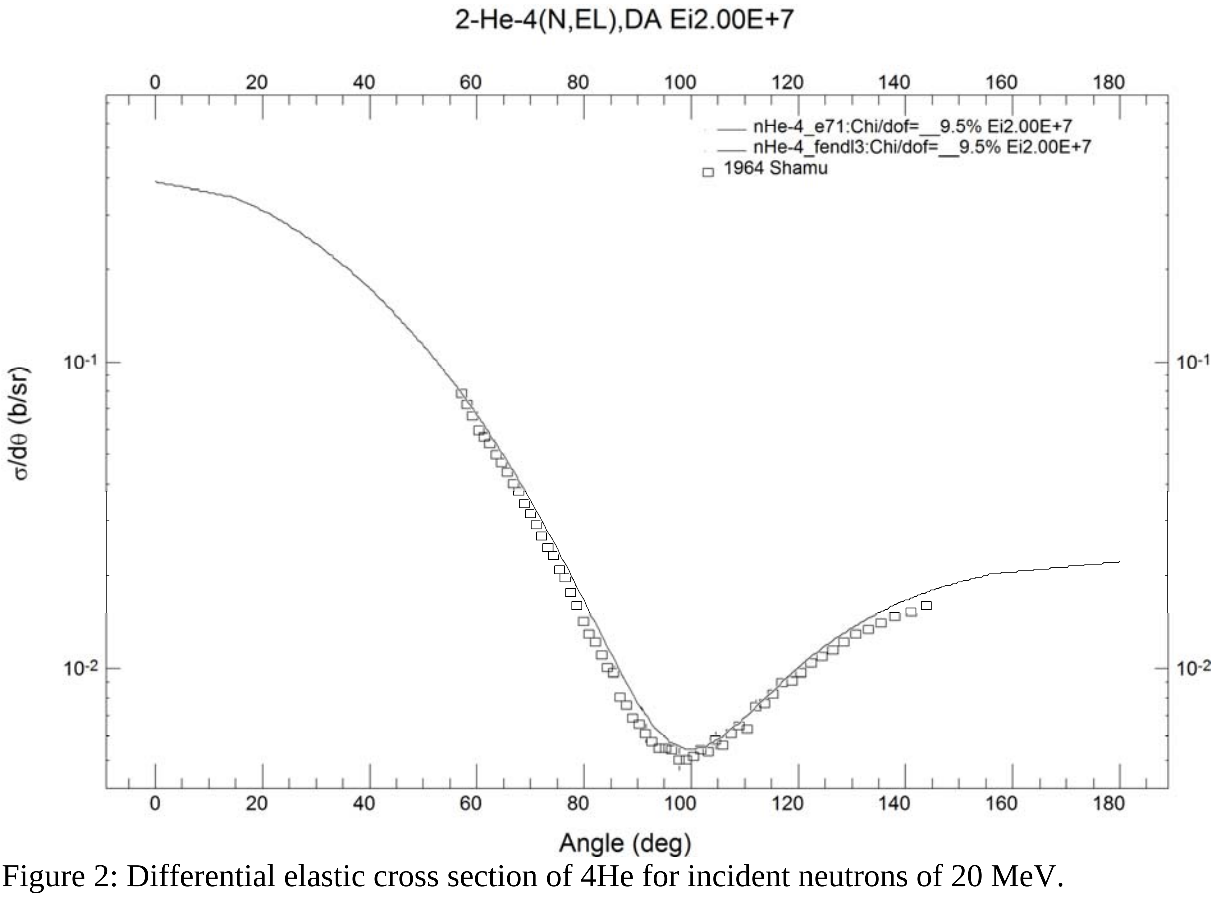

Figure 2: Differential elastic cross section of 4He for incident neutrons of 20 MeV.

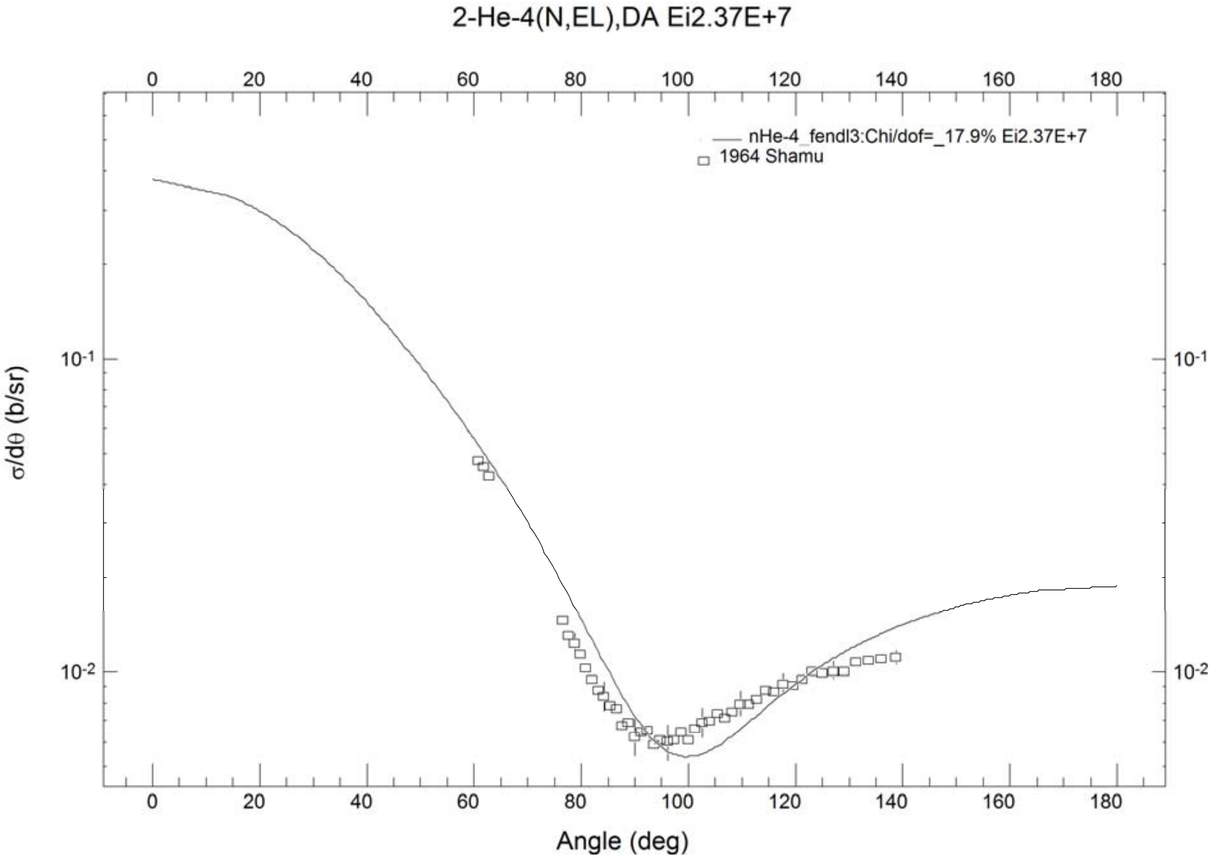

Figure 3: Differential elastic cross section of 4He for incident neutrons of 23.7 MeV.

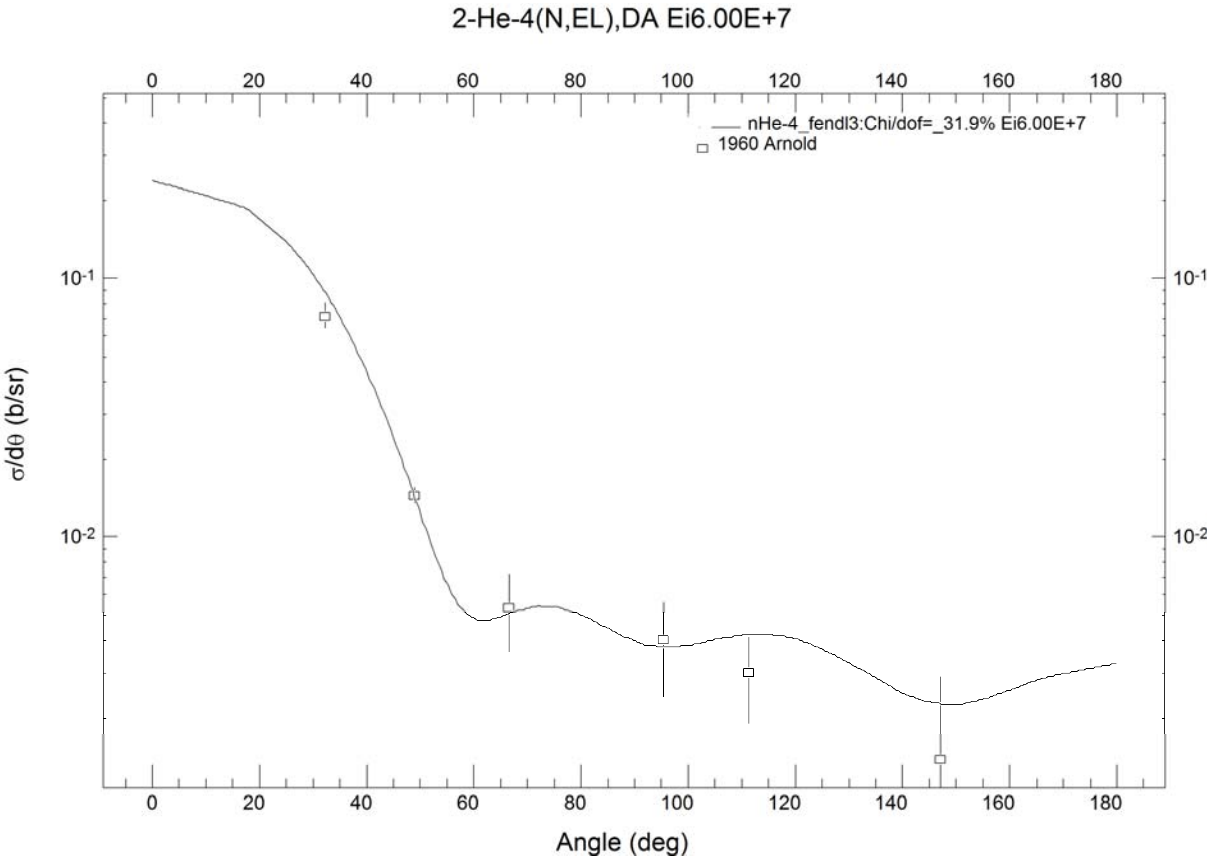

Figure 4: Differential elastic cross section of 4He for incident neutrons of 60 MeV

Two-neutron emission cross section

The two-neutron emission cross section has a threshold of 25.67 MeV and is not present in any of the evaluated nuclear data libraries, except the special library for activation EAF-2010 [5]. The cross sections from this library were adopted, which have a peak of 3.5 mb at around 54 MeV. The angular distributions of the emitted neutrons were assumed isotropic in the laboratory system. The emitted neutrons were assumed to follow the distribution of an evaporation spectrum with an effective temperature of 900 keV.

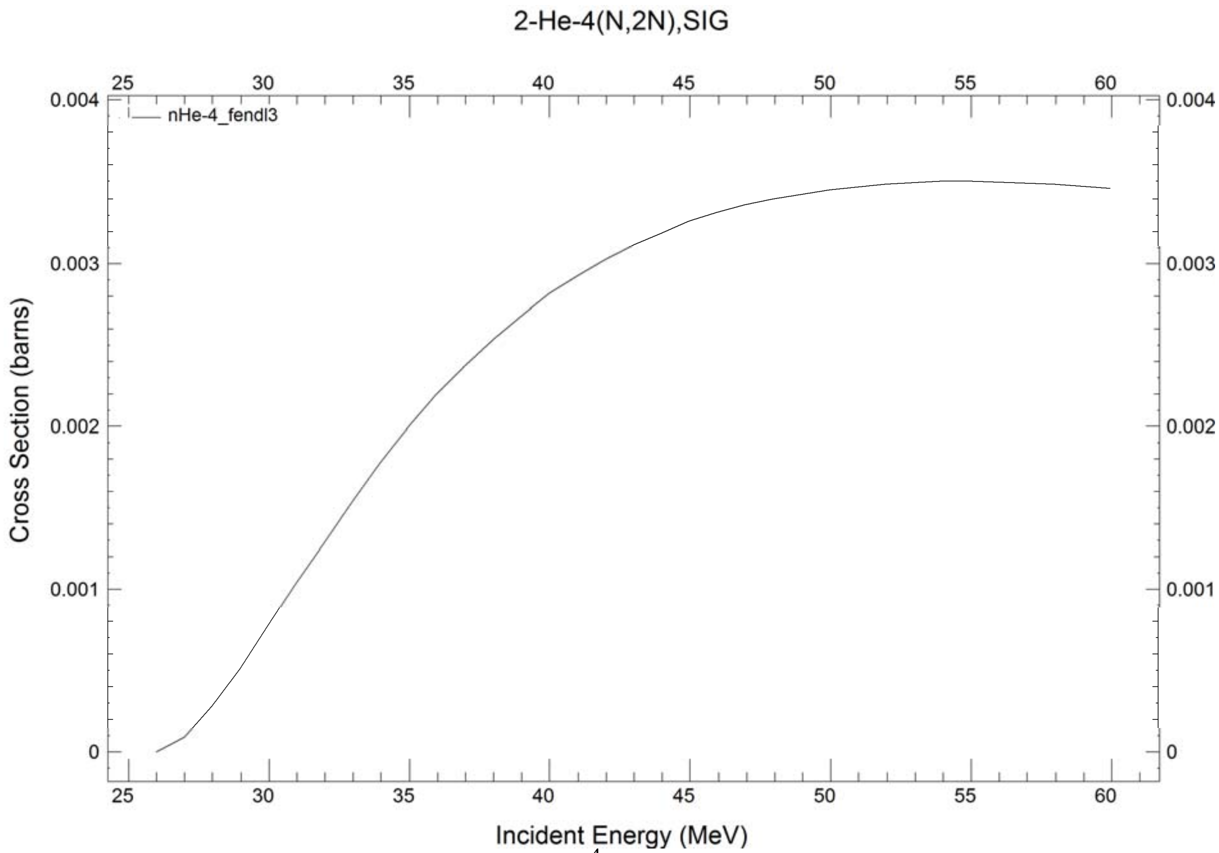

Figure 5: The (n,2n) reaction cross section of ^{4}He.

Deuteron emission cross section

Deuteron emission cross section has a threshold of 22.02 MeV and is not present in any of the evaluated nuclear data libraries, including EAF-2010. However, the experimental data by Shamu [2] include the ^{4}He(n,d)^{3}H reaction in the peak of the resonance at 22.2 MeV. The data were entered into the ENDF file, extrapolating the cross section to 60 MeV by following the trend of the last four measured points on log-log scale. The cross section is shown in Figure 6. No emission spectra and angular distributions of deuterons and tritons are given.

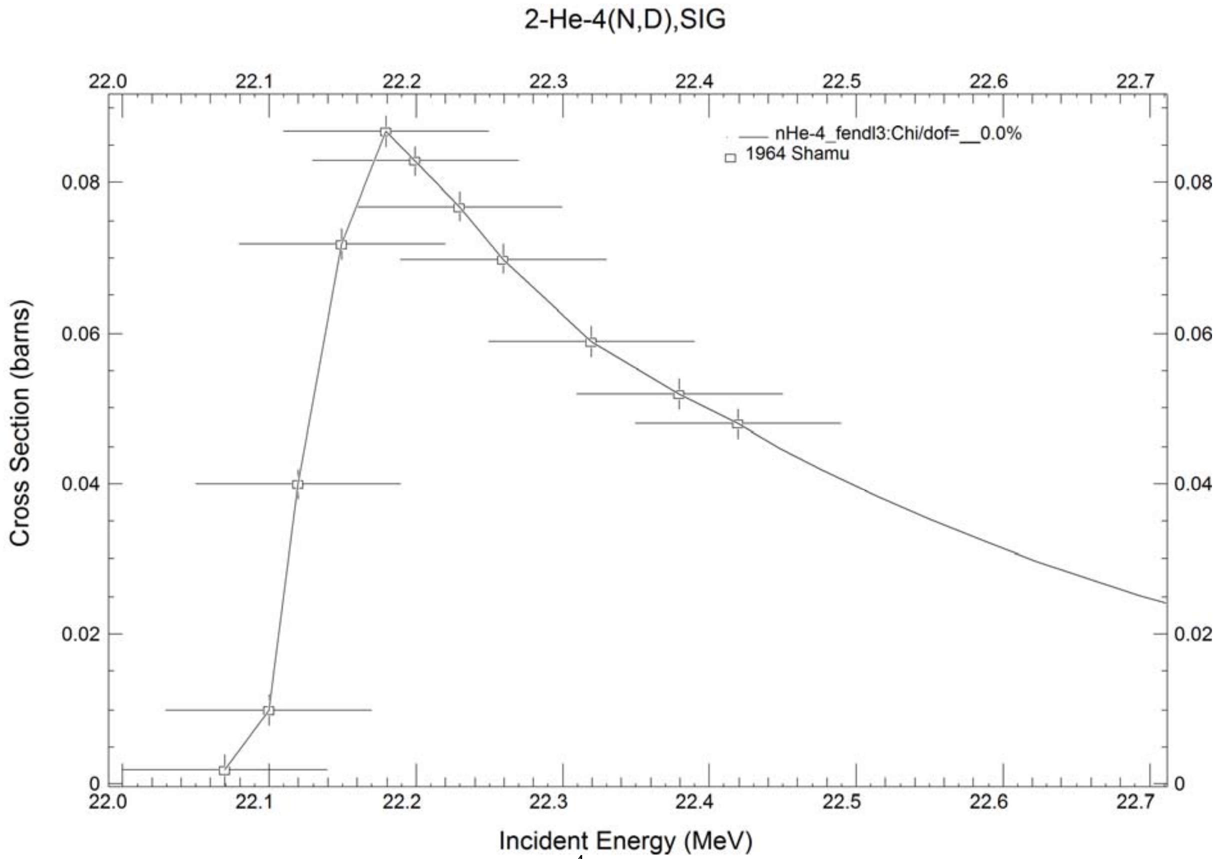

Figure 6: The (n,d) reaction cross section of ^{4}He.

Verification

The CHECKR code reported no problems. Fizcon reports that for MT=15 in MF=5 the value of U is not consistent. It seems likely that this is a false message because FIZCON compares (Q+U)/Q to a tolerance of 10^{-3}, but U is given in the laboratory system while the Q-value is defined in the centre-of-mass system. The PSYCHE code does not report problems either.

Processability of the file is checked by running the codes of the PrePro-2010 series including LINEAR, RECENT, SIGMA1 and FIXUP. Further testing is done by running NJOY to generate an ACE library for Monte Carlo codes like MCNP and a MATXS library for deterministic codes. The heating curve generated by the HEATR module is useful for checking potential energy-balance problems and is shown in Figure 7. The figure did not reveal any problems. The plots produced by the ACER module also showed nothing suspicious and are not presented.

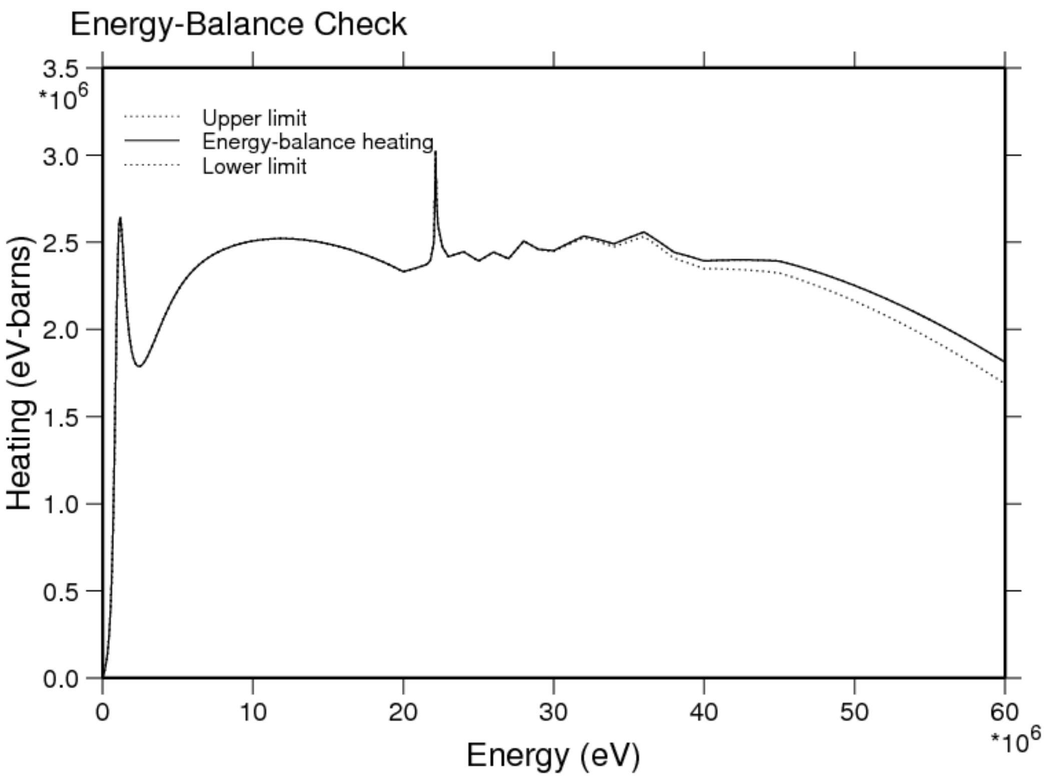

Figure 7: Plot of the heating calculated by the HEATR module of NJOY.

Conclusions

A viable evaluated nuclear data file for ^{4}He for incident neutron energies up to 60 MeV was produced for inclusion in the FENDL-3 library by extending the ENDF/B-VII.1b4 evaluation. The extension is based on ad-hoc methods and can not compete with evaluations based on rigorous R-matrix analysis such as announced by G. Hale from the Los Alamos National Laboratory, but the data from that evaluation above 20 MeV have not been released and are not likely to be available before the release of FENDL-3.

References

[1] B.Haesner, W.Heeringa, H.O.Klages, H.Dobiasch, G.Schmalz, P.Schwarz, J.Wilczynski, B.Zeitnitz, F.Kappeler, Measurement of the 3He and 4He Total Neutron Cross Sections up to 40 MeV, Physical Review, Part C, Nuclear Physics; Vol.28, Issue.3, p.995 (1983), EXFOR: 21883.

[2] R.E.Shamu, J.G.Jenkin, Neutron-alpha scattering in the 20-MeV range, Physical Review; Vol.135, Issue.1, p.B99 (1964), EXFOR: 30405.

[3] M.E.Battat, R.O.Bondelid, J.H.Coon, L.Cranberg, R.B.Day, F.Edeskuty, A.H.Frentrop, R.L.Henkel, R.L.Mills, R.A.Nobles, J.E.Perry, D.D.Phillips, T.R.Roberts, S.G.Sydoriak, Total neutron cross sections of the hydrogen and helium isotopes, Nuclear Physics; Vol.12, p.291 (1959), EXFOR: 11021.

[4] M.Arnold, P.E.Hodgson, D.F.Shaw, D.M.Skyrme, The Interaction of 40-160 MeV Neutrons with Helium Nuclei, Nuclear Physics; Vol.19, p.500 (1960), EXFOR: 21152.

[5] EAF-2010 European Activation Library.