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NEUTRON TOTAL CROSS SECTION MEASUREMENTS ON OXYGEN, ALUMINUM AND CARBON BELOW 930 KEV

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Neutron Total Cross Section Measurements on Oxygen, Aluminum and Carbon below 930 keV

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Neutron transmission measurements were made on aluminum, aluminum oxide and carbon using a TOF spectrometer of the Japan Atomic Energy Research Institute (JAERI) linac. Total cross sections of oxygen, aluminum and carbon were deduced below 930 keV.

Keywords: Neutron Total Cross Section, Oxygen, Aluminum, Carbon, KeV Range 0.1 - 1000, TOF Spectrometer

酸素，アルミニウム，炭素の930 keVまでの中性子全断面積の測定

日本原子力研究所東海研究所物理部
大久保牧夫

（1986年12月26日受理）

アルミニウム，酸化アルミニウムおよび炭素について，原研リニアックの飛行時間スペクトロメータを用いて，中性子透過率の測定を行った。その結果，酸素，アルミニウム，および炭素の930 keV までの中性子全断面積を得た。

東海研究所：〒319－11　茨城県那珂郡東海村白方字白根2－4

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1. Introduction

In the course of the neutron cross section measurements, we often encounter the cases where the available samples of nuclides aimed at are in chemical forms of oxide. In such cases, accurate cross section of oxygen is needed to correct the effects of oxygen in experimental data acquired.

Neutron cross section of oxygen is accurately known in thermal energy and in MeV energy region, and an evaluated file is available in JENDL3-PR2. However the experimental data are unexpectedly poor in the energy region from 0.1 keV to 300 keV.

We planned to determine experimentally the total cross section of oxygen below 1 MeV by measuring the transmission of aluminum metal and aluminum oxide, and by subtracting between the observed total cross sections of these materials.

Transmission measurements on carbon were also made in the same experimental conditions to check the measuring system.

2. Measurements

Transmission measurements on these samples were carried out at a 47 m TOF station of the JAERI electron linac.[1,2] The electron beam energy was 120 MeV, peak current ~5 A; pulse width 25 ns and the repetition rate 600 pps. Pulsed neutrons were produced by the electron beam bombarding on a water cooled tantalum target, and were moderated by a moderator surrounding the target. The target-moderator system are described in reference 3. The neutrons were traversed to the 47-m station through an evacuated flight tube. In the 47-m station, a B_4C filter to eliminate slow neutrons which overlap to the subsequent bursts, a ^{6}Li-glass neutron flux monitor, a 70 mmϕ collimator, a 35 mmϕ collimator, evacuated flight tube, a detector shielding, and a ^{6}Li-glass neutron detector (1 1/2" x1/2" NE912) were placed. The neutron detector was placed in the boron parafine shielding with B_4C liner, and was separated ~1.5 m from the sample position by the evacuated flight tube.

Neutron detection signals from the detector were analyzed with a 4096 channel time analyzer with the minimum channel width of 31.25 ns. Neutron pulses from the flux monitor were counted in the time region corresponding to 1.1~ 0.3 keV region. The accumulated data in the time analyzer were transfered to a FACOM U-200 computer, and were edited on magnetic tapes.

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The data on the tapes were stored on a disk memory of a large computer FACOM M380 at the JAERI computing center, and the data processing were made through a remote terminal at the linac laboratory.

Aluminum samples to be measured were metallic plates with 7 mm (0.043 atoms/barn), 32mm(0.198a/b), and a lod of 105.5 mm(0.637a/b) thicknesses. Aluminum oxide to be measured was fine powder of 99.9 % purity, heated to 160°C in air for ~3 hrs to eliminate moisture. It was packed into aluminum cylindrical cases of 40φx 30 mmt(Al:0.0436a/b, O:0.0654a/b), and 65φx 128.5 mm (Al:0.178a/b, O:0.267 a/b) thicknesses. These samples were kept in a desiccator. Carbon sample was 50 x50 x24 mm^3t(0.176 a/b), IG-11 delivered from the Toyo-Tanso Co.

Neutron transmission T and its error ΔT are defined as

$$T = \frac{I - B_i}{O - B_0} ,$$

$$\Delta T = T \left(\frac{1}{I} + \frac{1}{O} \right)^{1/2} ,$$

where O and I are open and sample-in beam counts per channel after the correction of the dead time (2.5μsec) of the system. B_i, B_0 are the background for the sample-in beam and the open-beam respectively. Energy scale of the TOF system was calibrated by the aluminum resonances at 5.9035 and 119.75 keV. The backgrounds were estimated from the counts at saturated resonances of 2.3 keV(Mn), 35 keV(Al) and 88 keV(Al), where the backgrounds to open beam ratios were less than 0.5 %. The total cross section and its error are

$$\sigma_t = - \frac{1}{n} \ln T ,$$

$$\Delta \sigma_t = \frac{1}{n} \left(\left(\frac{\Delta T}{T}\right)^2 + \sigma_t^2 (\Delta n)^2 \right)^{1/2} ,$$

where n and Δn are the sample thickness and its error in atoms/barn. For thick samples, the ratio $\Delta n/n$ were less than 0.5 %, which were smaller than the statistical errors.

3. Results

1) aluminum

The observed total cross sections of aluminum from 0 to 250 keV are shown in Fig.1, and from 250 to 930 keV in Fig.2, which are deduced from the high resolution measurements(31.25ns channel width) on the 32 mm thick sample. For lower energy region σ_t are shown in an insert in Fig.1 which are deduced from a low resolution (125ns channel width) measurement on the

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105.5 mm sample. At $E_n \sim 1eV$ where crystalline effects are not significant, total cross section of Al was deduced to be 1.41 ± 0.05 barn. No small resonances were observed from 10 to 20 keV region, which are included in JENDL2.[4] On the average, the total cross sections deduced are in good agreement with that by Singh et al.[5] below 110 keV. However, the present energy resolution became insufficient to resolve the fine resonances above 150 keV.

2) oxygen

The observed total cross sections of oxygen are deduced by subtracting σ_t of Al from that of Al_2O_3, and are shown in Fig.3 up to 930 keV. The energy of the lowest resonance of ^{16}O is obtained to be 432 ± 3 keV, and the peak cross section to be about 14.2 barn for thick sample measurement, and to be 15.6 barn for the thin sample measurement. From the peak cross section value, l and J value of this resonance are confirmed to be l=1, and J=3/2. Resonance width Γ is deduced to be 46 ± 4 keV. The energy at resonance peak is about 10 keV lower than the evaluated value in JENDL3-PR1[6], which depend mostly on the data of Okazaki at Wisconsin 1955.[7] The curve of the resonance wing deduced is in good agreement with that by Perey et al.[8] In the energy region between 100 and 300 keV, no fine structure resonance was observed. Below 200 keV, σ_t can be approximated by a linear function

$$\sigma_t(E) = 3.85 - 0.002\,E \quad \text{(barn)} \qquad (E < 200 \text{ keV})$$

where E is in a unit of keV. Total cross sections of oxygen up to 250 keV are shown in Fig.4, which are smoothed for low energy region. The errors in the cross sections are rather large at the strong resonances of aluminum (35, 88 and 150 keV) because of poor statistical accuracy.

At very low energy ($E_n \simeq 0$), σ_t is obtained to be 3.85 ± 0.06 barn in the present measurements. This value is 2.6 % higher than the value 3.761 ± 0.006(barn) measured by Koester et al.[9] at thermal neutron energy.* It is concluded that the contamination with moisture of the Al_2O_3 sample must be carefully estimated. Because of large neutron cross section of hydrogen (~20 barn at $E_n \simeq 0$), inclusion of 1 mg of H_2O in 1 gram of Al_2O_3 is sufficient to rise the apparent oxygen cross section by 0.1 barn.

3) Carbon

Observed total cross sections of carbon are shown in Fig.5 up to 930 keV. On the average, the observed total cross sections of carbon are in good agreement with the values in the evaluated data files. This ensures the accuracy of the present mesuring system.

Observed total cross sections of oxygen and aluminum were sent to the NEA data bank in 1984.

* Koester et al. dried the powder samples very carefully in vacuum oven, and handled and kept them under dry atmosphare of nitrogen or argon.

References

1) Takekoshi,H.,ed ; JAERI-Report 1238(1975)
2) Ohkubo,M.,Mizumoto,M.,and Kawarasaki,Y.: Nucl.Sci.Technol.21,254(1984)
3) Ohkubo,M.: Nucl.Instr.Methods A253,43(1986)
4) Japan Nuclear Data Commity (1978)
5) Singh,U.N., Rainwater,J., Liou,H.I., Hacken, G. and Garg,J.B.: Phys.Rev. C 11, 1117(1975)
6) Japan Nuclear Data Commity (1986)
7) Okazaki,A. : Phys.Rev. 99, 55(1955)
8) Perey,F.G., Love,T.A. and Kinney, W.E. : ORNL-4823(1972)
9) Koester,L., Knopf,K. and Waschkowsky,W. : Zeit.Phys. A292, 95(1979)

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3) Ohkubo,M.: Nucl.Instr.Methods A253,43(1986)

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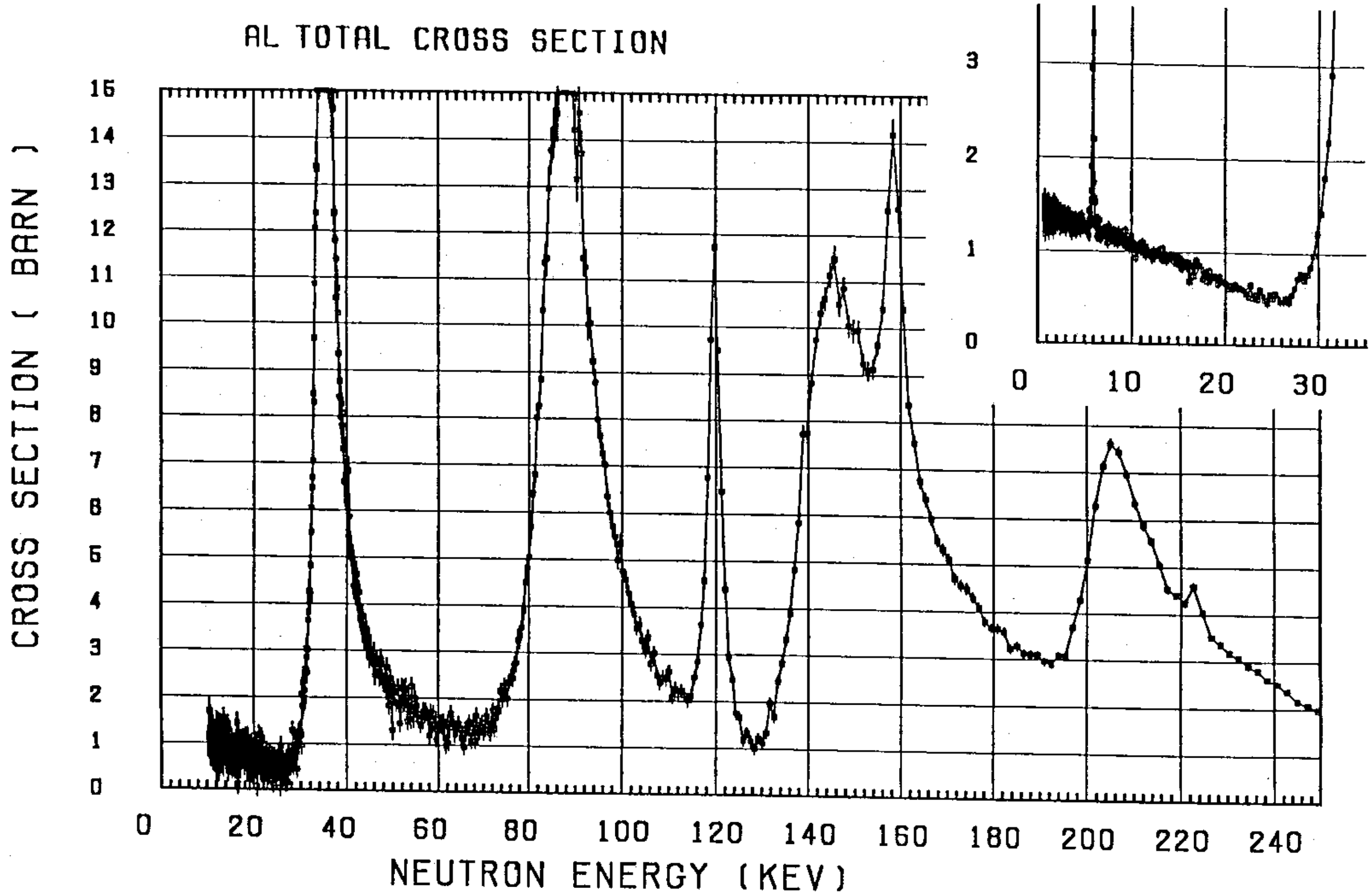

Fig. 1 Observed total cross sections of aluminum up to 250 keV, measured on 32 mm thick sample. TOF channel width was 31.25 ns.
The insert in low energy region below 32 keV, measured on the 105.5 mm sample with TOF channel width of 125 ns.

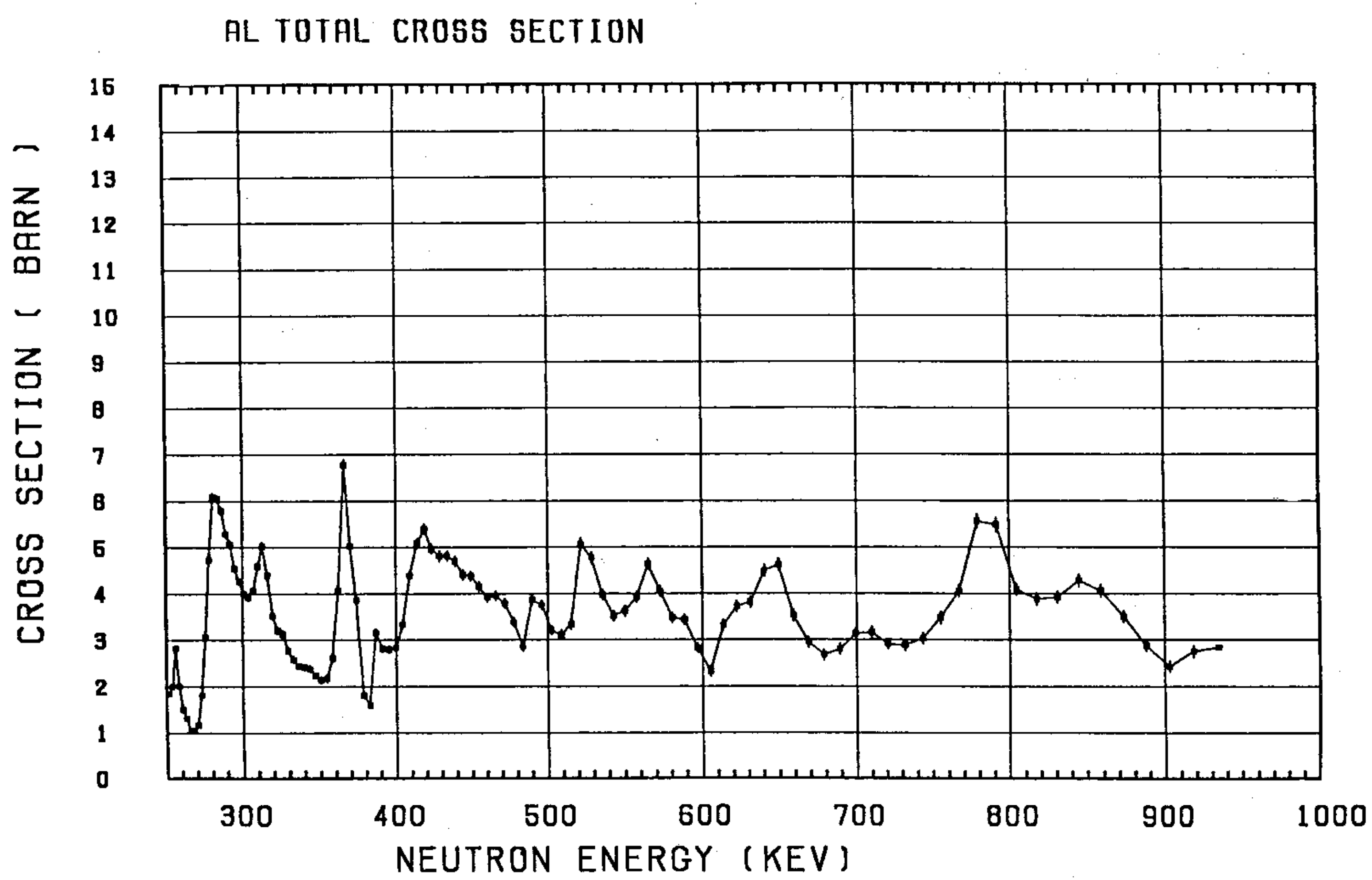

Fig. 2 Observed total cross sections of aluminum from 250 to 930 keV. Energy resolution was insufficient to resolve the resonance structures in this region.

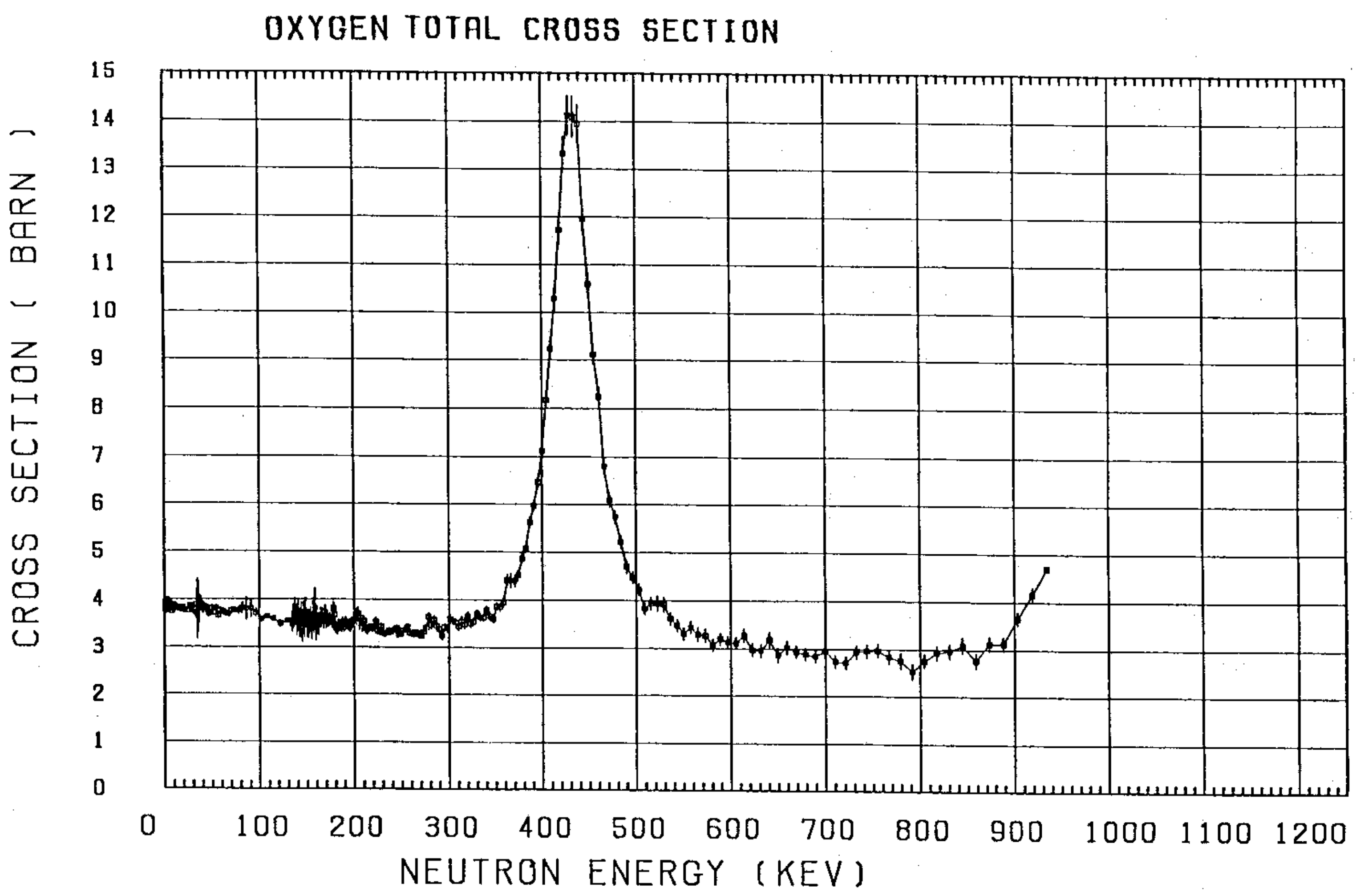

Fig. 3 Observed total cross sections of oxygen up to 930 keV, deduced by the subtraction method. The errors are large at the strong resonances of aluminum because of poor statistical accuracy in the raw data.

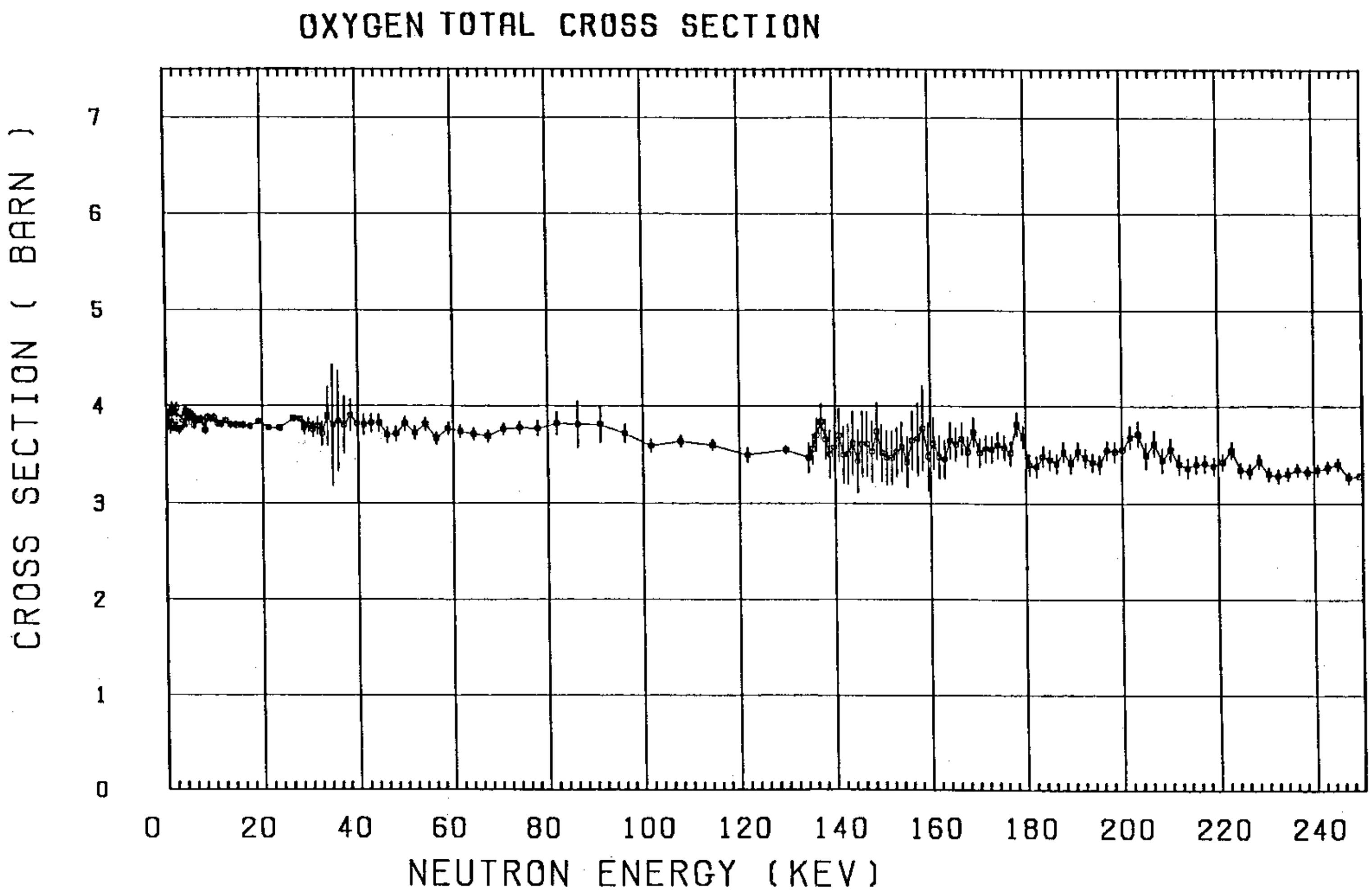

Fig. 4 Observed total cross sections of oxygen up to 250 keV. In the region below 130 keV, smoothing are made over 10 points.

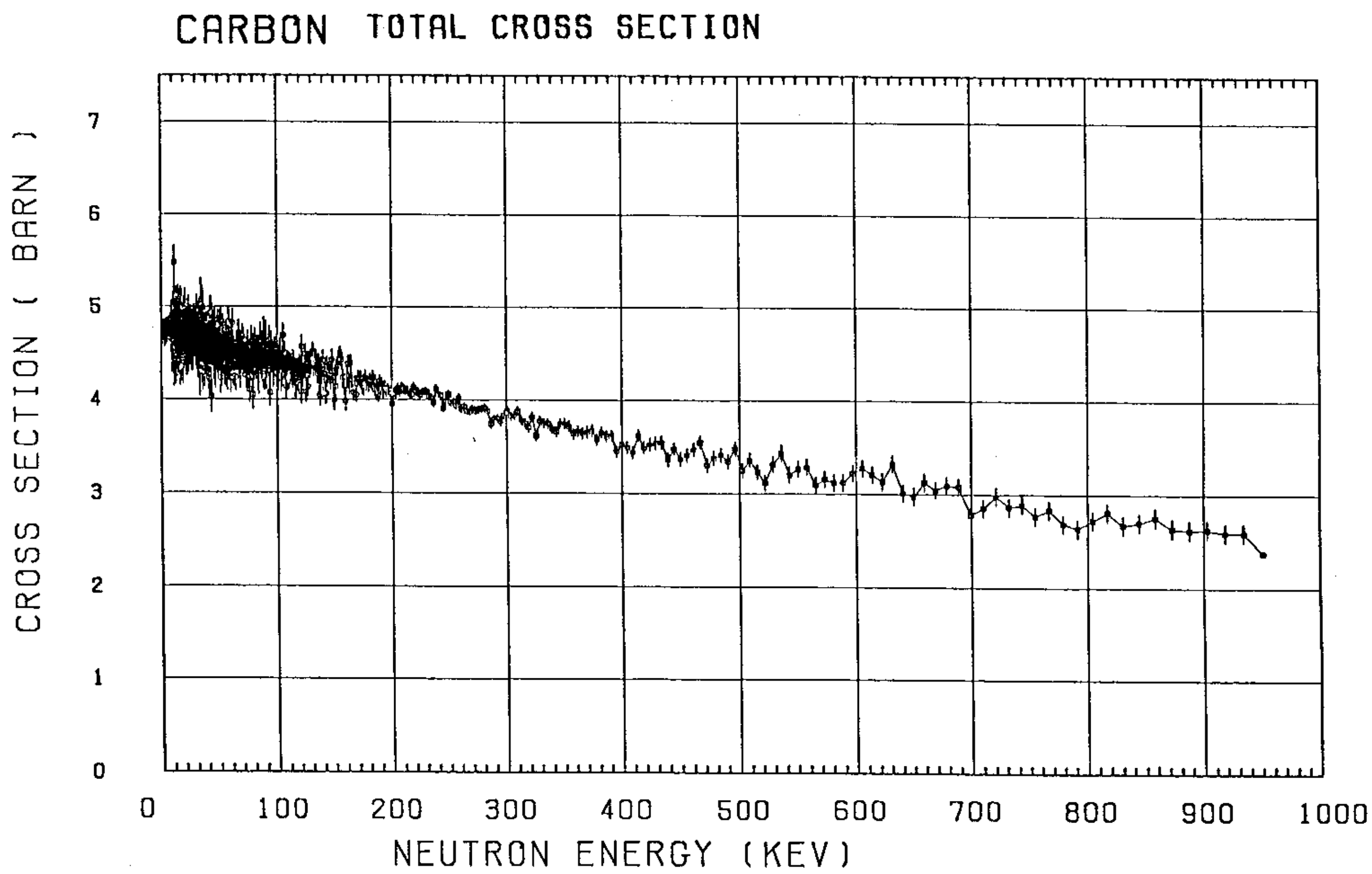

Fig. 5 Observed total cross sections of carbon below 930 keV, which are in good agreement with the evaluated data file.