Recent Experimental Data

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Recent experimental data were reviewed for the neutron reaction cross sections of fission products. Some of our recent results on keV-neutron capture cross sections were compared with other experiments and the quality of recent experimental data was discussed.

1. Introduction

New experimental data are important for the re-evaluation of neutron reaction cross sections of fission products because the accuracy of calculations with nuclear reaction models is not enough at present. Therefore, it is valuable to investigate the new experimental data before starting the re-evaluation work. From this viewpoint, first, we reviewed the quantitative status of recent experimental data for the neutron cross sections of fission products, using the **C**omputer **I**ndex of **N**eutron **Da**ta (CINDA)[1]. Secondly, we reviewed the experimental procedures of main laboratories. Finally, we compared some of our recent results on keV-neutron capture cross sections with other experiments and discussed the quality of recent experimental data.

2. Quantitative Review of Recent Experimental Data

The experimental data reported on and after 1994 were retrieved for the nuclides with the mass number from 66 to 172. **Table 1** shows statistics for the total, capture, and inelastic-scattering cross section data. The number of nuclides for the capture cross section data is 2 to 10 times larger than the others, which is thought to reflect the importance of capture cross sections for many research fields such as nuclear engineering and nuclear astrophysics. However, the number (107) is only 60 % of that of fission products contained in JENDL-3.3[2]. Main laboratories which provided the capture cross section data are shown in **Fig. 1**, where the laboratory codes in CINDA are adopted. The activities of KFK and FEI are excellent. The total activity of Japanese laboratories is comparable to that of US laboratories. Similarly, the laboratories that provided the total and inelastic-scattering cross section data are shown in **Figs. 2 and 3**, respectively. As for the total cross sections, the activities of KFK, ORL, and IJI are excellent.

Table 1 Statistics for the total, capture, and inelastic scattering cross section data

Cross sections	Number of nuclides	Number of data sets	Number of references
Total	43	102	174
Capture	107	290	580
Inelastic scat.	10	18	45

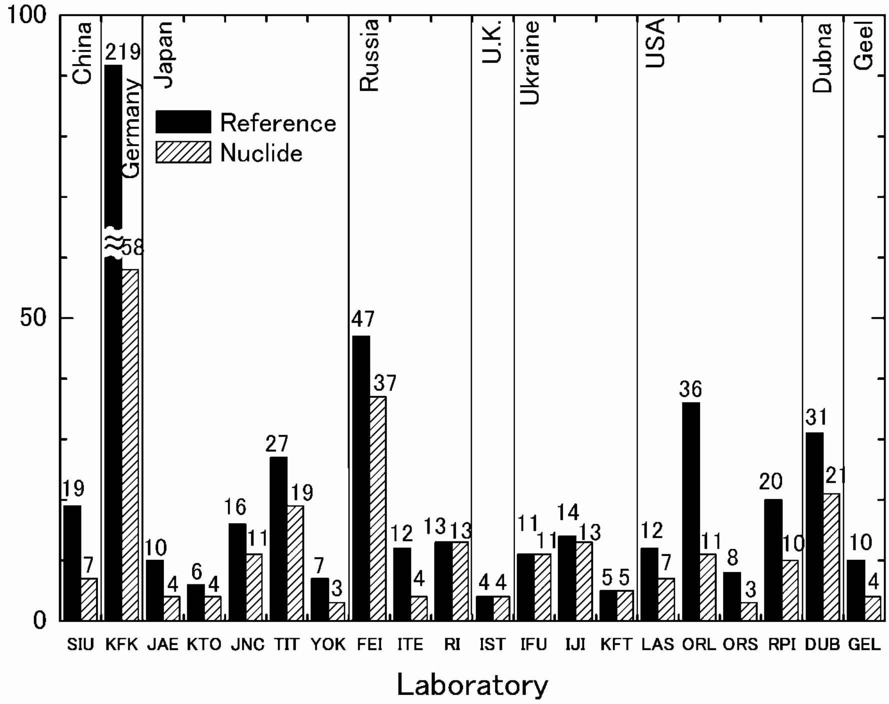


Fig. 1 Main laboratories which provided the capture cross section data

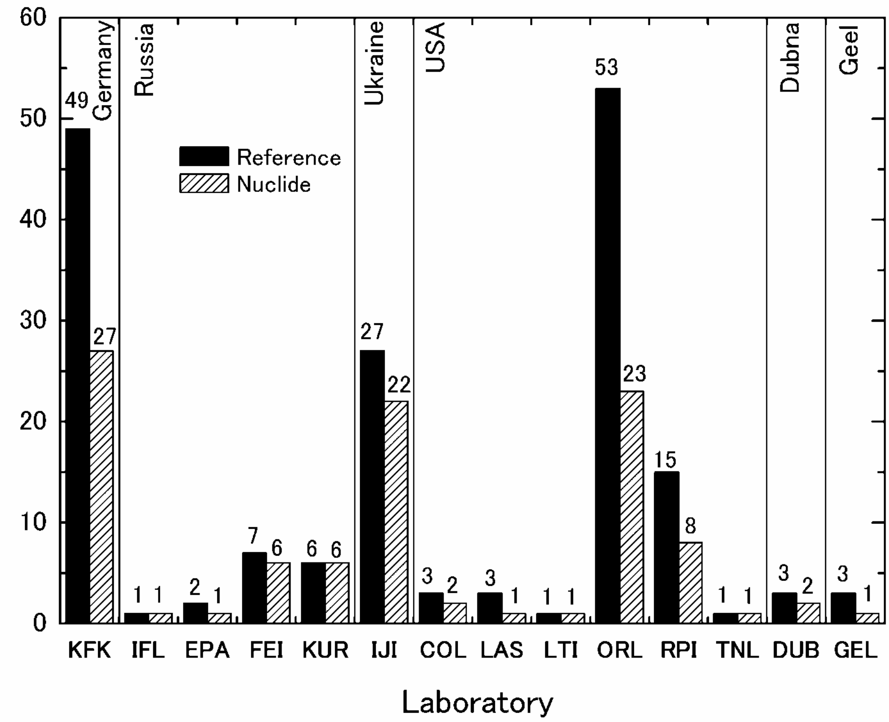


Fig. 2 Laboratories that provided the total cross section data

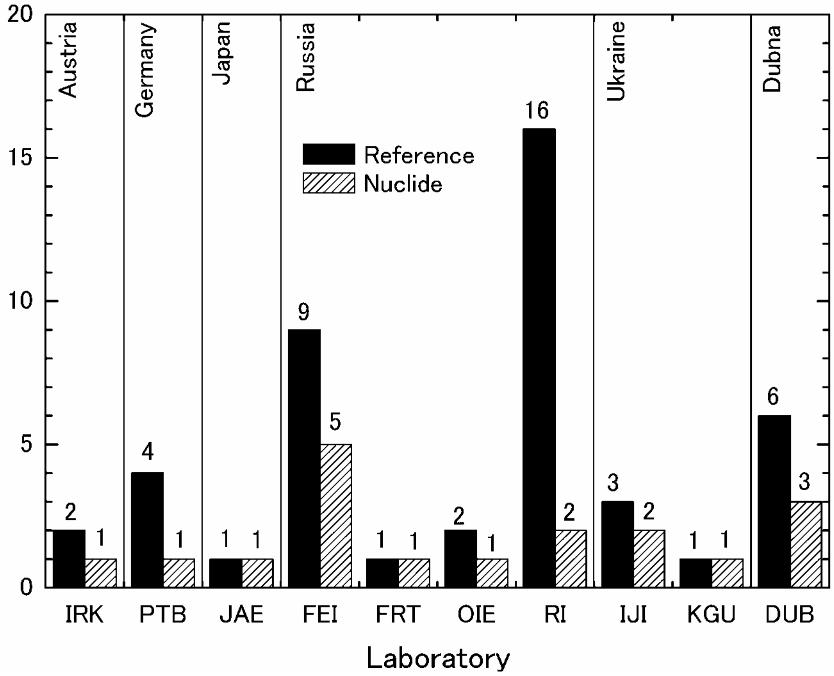


Fig. 3 Laboratories that provided the inelastic scattering cross section data

3. Experimental Procedures of Main Laboratories

The experimental procedures of main laboratories are summarized in **Table 2**, where the laboratories are categorized by their neutron sources. In the capture experiment, KFK, RPI, and KTO employed a segmented 4π-spectrometer, and ORL, GEL, and KTO employed a pair of C_6D_6 scintillation detectors. On the other hand, TIT employed an anti-Compton NaI(Tl) spectrometer together with a very-short neutron flight path (FP). JNC, JAE, and YOK adopted an activation method and provided the thermal capture cross sections and resonance integrals of radioactive fission products. As for the total experiment, all laboratories except for IJI employed a ^{6}Li-glass scintillation detector.

4. Comparisons of keV-Neutron Capture Cross Section Data

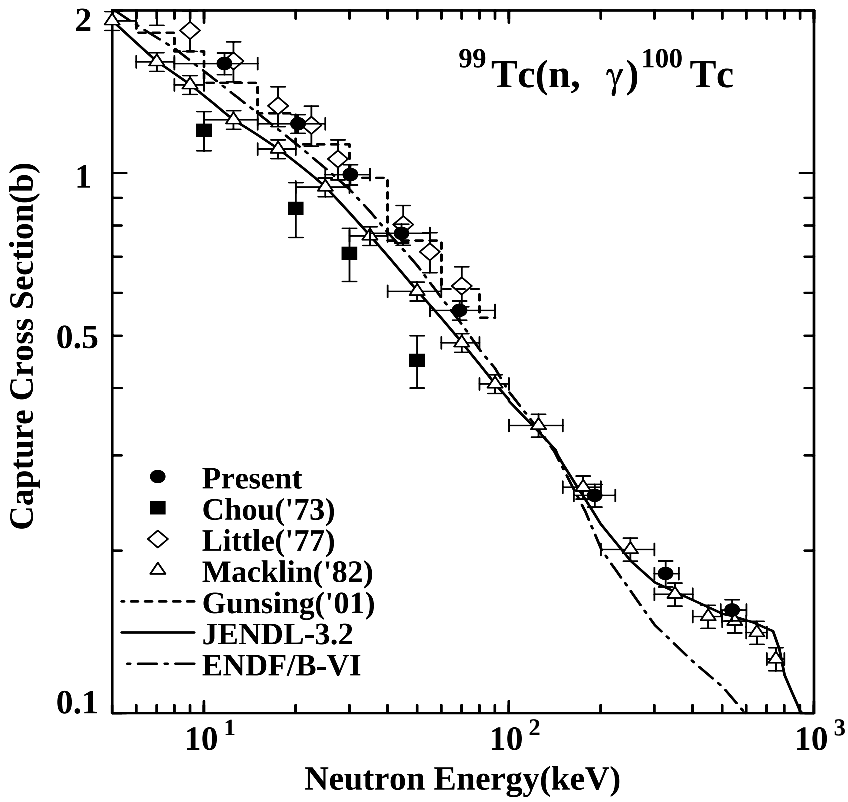
In order to investigate the qualitative status of recent experimental data on keV-neutron capture cross sections, the comparisons of data sets were made for some fission products. The comparisons for ^{99}Tc, ^{140}Ce, and ^{146}Nd are shown in **Figs. 4-6**, respectively, where "Present" means the results of TIT.

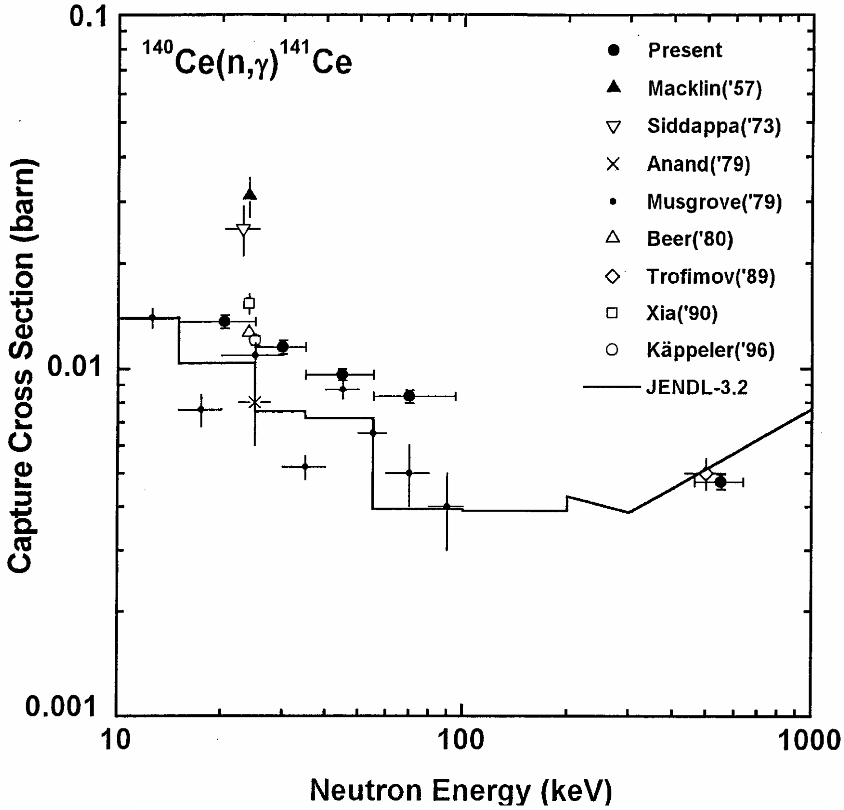
The recent results of TIT[3] and Gunsing *et al.* (GEL)[4] for the long-lived radioactive nuclide of ^{99}Tc agree with each other, as shown in Fig. 4, though they did not give the experimental errors. Below 100 keV, the recent results support the old results of Little and Block[5] rather than the results of Macklin[6]. However, above 200 keV, the results of TIT support those of Macklin.

Table 2 Experimental procedure of main laboratories

Group 1: Time-of-flight method with the ^{7}Li(p,n)^{7}Be neutron source
KFK: En=3-230 keV; Capture: 0.79 m FP + 4πBaF$_2$; Total: 2.6 m FP + ^{6}Li-galss
FEI: En=20-450, 1400 keV; Capture: 2.4 m FP + 17 l tank; Total: 2.1 m FP + ^{6}Li-glass
TIT: En=10-600 keV; Capture: 0.12-0.20 m FP + Anti-Compton NaI(Tl)
Group 2: Time-of-flight method with the photo-neutron source
ORL: En=eV-700 keV; Capture: 40 m FP + 2 C$_6$D$_6$; Total: 80 or 200 m FP + ^{6}Li-glass
RPI: En=thermal-3 keV; Capture: 26 m FP + 16 NaI(Tl); Total: 26 m FP + ^{6}Li-glass
GEL: En=eV-200 keV; Capture: 28 m FP + 2 C$_6$D$_6$; Total: 49 m FP + ^{6}Li-glass
KTO: En=thermal-40 keV; Capture 1: 12 m FP + 2 C$_6$D$_6$ or 12 BGO; Capture 2: Pb slowing-down spectrometer
Group 3: Reactor neutron source
IJI: En=thermal-600 keV; Time-of-flight method with a chopper, or Filtered beam; Total: ^{3}He or ^{1}H counter
JNC, JAE, YOK: En=thermal, resonance integral; Capture: Activation method

FP: Flight Path





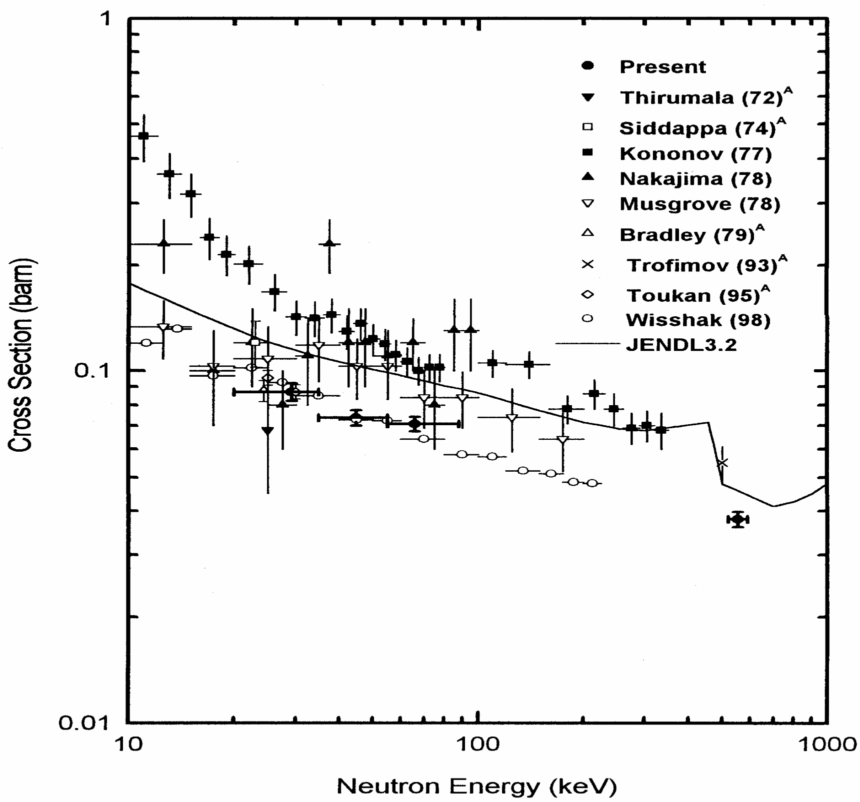


Fig. 6 keV-neutron capture cross sections of ^{146}Nd

As for ^{140}Ce that has very small capture cross sections in the fission product region, an activation method was adopted in all previous measurements except for that of Musgrove *et al.*[7]. The recent activation result of Kaeppeler *et al.* (KFK)[8] at 24 keV is in good agreement with those of TIT[9]. Musgrove *et al.*[7] performed their experiment at ORL, using a pair of C_6F_6 scintillation detectors, not C_6D_6. Their results are smaller than those of TIT by about 40 %.

As for ^{146}Nd that has rather small capture cross sections, both of activation and prompt γ-ray detection methods were adopted in the previous measurements, as shown in Fig. 6, where the superscript "A" on the references indicates the activation results. The recent results of Wisshak *et al.* (KFK)[10] and TIT[11] agree with each other within the experimental errors. Moreover, the recent activation result of Toukan *et al.* (KFK)[12] at 24 keV is in good agreement with those of Wisshak *et al.* and TIT.

From the above comparisons, no serious discrepancy was found among the recent experimental data on the keV-neutron capture cross sections of fission products.

5. Conclusion

After the evaluation work for JENDL-3.2 released in April 1994, new experimental data on capture cross sections were reported for about 60 % of fission product nuclides contained in JENDL-3.3. As for total and inelastic-scattering cross sections, however, new data were poor in comparison with the capture cross section data. The comparisons of recent experimental data showed that the quality of keV-neutron capture cross section data was good.

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