Measurement of fission cross sections

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A review is presented on the recent progress in the experiment of fission cross section measurement, including recent activity in Japan being carried out under the project of nuclear data measurement.

1. Introduction

Fission plays an essential role in nuclear energy through regeneration of neutrons. For the reason, fission cross section has been a critical issue in the development of nuclear energy and still be of a key parameter for the development of new reactor system like ADS (Accelerator driven transmutation system), low moderation reactors and high burn up reactors and so on. For the reasons, cross section requirement is extending to high energy regions, proton-induced reactions and minor actinide elements (MA). However, the data accuracy is not good enough in particular for MA and high energy or proton induced reactions as shown in Fig.1 [1].

In reply to the requirement, world–wide effort is undertaken for the improvement of fission cross section data through the development of new facilities and experimental techniques. It should be noted that, in the case of fission cross sections, experimental data are of special importance for data improvement because the data accuracy required is far beyond that which can be reached by the present nuclear reaction theories.

This report summarizes recent progress in fission cross section measurement including activities in Japan conducted under the project of nuclear data measurement.

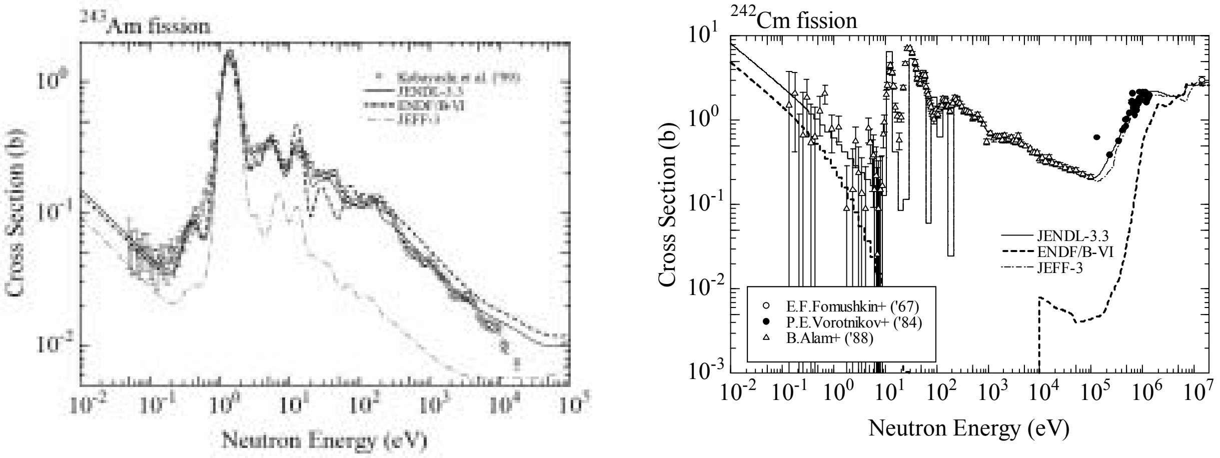

Fig.1 Present status of fission cross section data [1]

2. Problems in fission cross section measurement

Usually, fission cross sections are measured by detection of fission fragments with appropriate detectors because of high accuracies reached by the technique [2]. Parallel plate ionization chambers are most popular ones owing to their almost 100 % detection efficiency. In the fission cross section measurement, there are two big problems: One is very high α-activities of fissionable nuclides, in particular higher actinides elements, and the other one is the difficulty to obtain high pure samples for experiments. For some nuclides, only very little sample is available, and chemical and/or isotopic purification is indispensable.

The α-activities introduce serious backgrounds in fission fragment detection. For nuclides with high α-activity, the number of sample nuclides is also limited. Therefore, suppression of α-particle events have been undertaken by taking into consideration the difference of stopping power [2]. A typical one is a parallel plate ionization chamber employing sample-electrode distances shorter than α-particle range as shown in Fig.2. Some one adopts collimation for efficient suppression [2].

An essential solution to the problems is the employment of high neutron flux and fragment detectors with α-particle suppression for fission cross section measurement. It should be noted that recent development in digital signal processing (DSP) provides a powerful tool to obtain reliable data under high neutron flux and/or unfavorable experimental condition such as signal pile ups because it enables detailed analysis of signal wave forms.

For the second problem, a "surrogate technique" is also developed to obtain the cross sections for neutron induced reactions of unstable nuclides or nuclides for which appropriate sample is not available.

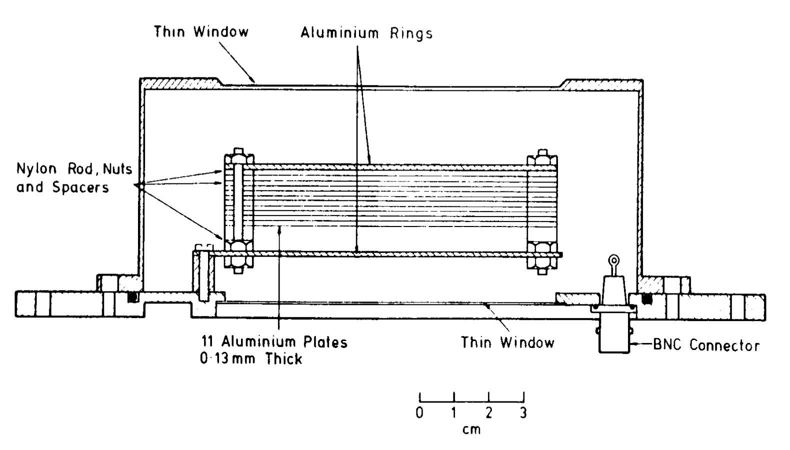

Fig.2: A multiple-plates parallel plate ionization chamber with electrode separation narrower than the α-particle range [2].

3. Recent progress in fission cross section studies

3-1 Utilization of intense neutron source

To obtain higher neutron flux, development has been continued for high power electron linacs like ORELA (Oak Ridge Electron Linear Accelerator) and GELINA (Geel Electron Linear Accelerator) and so on. A lead slowing down neutron spectrometer was also developed and achieved great success. It utilizes the relation between neutron slowing down time and average neutron energy inside a lead assembly around 1.5 cubic meter [3]. The neutron flux reached inside the assembly is higher than that in TOF spectrometer by more than three decades or more, although energy resolution is limited to 30-40 % as shown in Fig.2. It enabled discovery of sub-threshold fission of ^{238}U and great progress in minor actinide cross sections via much higher neutron flux in Rensselaer polytechnique institute (RPI) and Kyoto University Research Reactor Laboratory (KUR; Fig.3) [4].

A spallation neutron source has also been used for nuclear data measurement. A spallation source at LANSCE/WNR (Los Alamos National Laboratory) driven by a 800 MeV proton beam with very short duration (< 1ns) was used effectively for fission cross section measurement in the neutron energy region from 20 MeV to 400 MeV on ^{235,238}U, ^{239}Pu, ^{237}Np and so on [5]. Recently, a lead slowing down spectrometer was also assembled combined with the spallation source and enable fission cross section measurement of elements as little as ~10 ng [6]. The spallation sources in Russia have also been used for fission studies.

Recently, new high power neutron spectrometer was installed at CERN (Fig.4) [7]. Neutrons are produced by the spallation reaction of 20 GeV protons (6 ns duration) and a neutron flight path around 200 m is available. Using the facility, a "n-TOF" project is in progress through collaboration in EC and other countries. Experiments on fission cross sections are in progress on ^{209}Bi, ^{nat}Pb, ^{232}Th, ^{233,234,236}U, ^{237}Np, ^{242,243}Am, ^{245}Cm for eV ~ 200 MeV energy region using a parallel-plate-avalanche-counter (PPAC) as well as fission ionization chambers to achieve higher timing resolution.

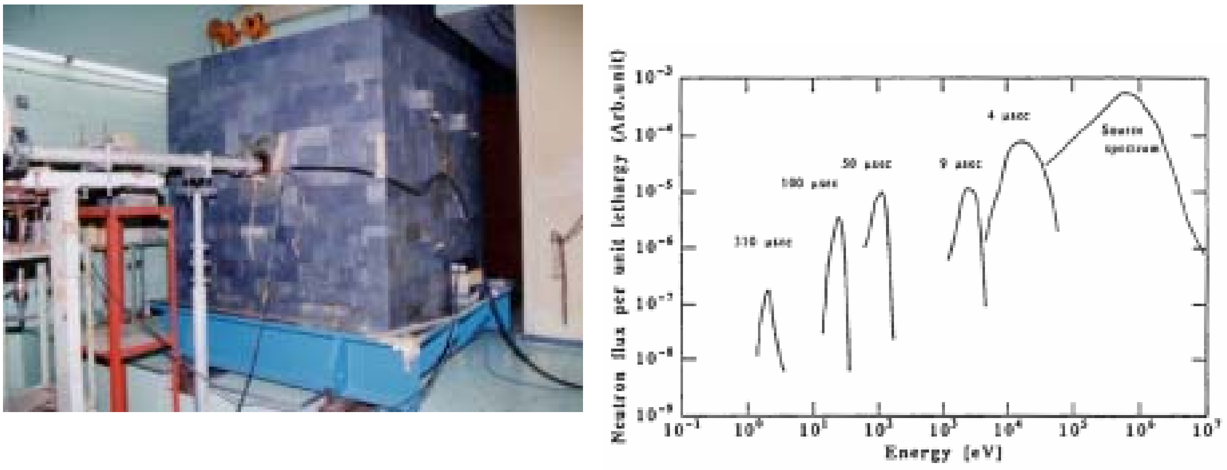

Fig.3; The lead slowing down spectrometer ate Kyoto Univ. (left) and its energy vs time (right) [4].

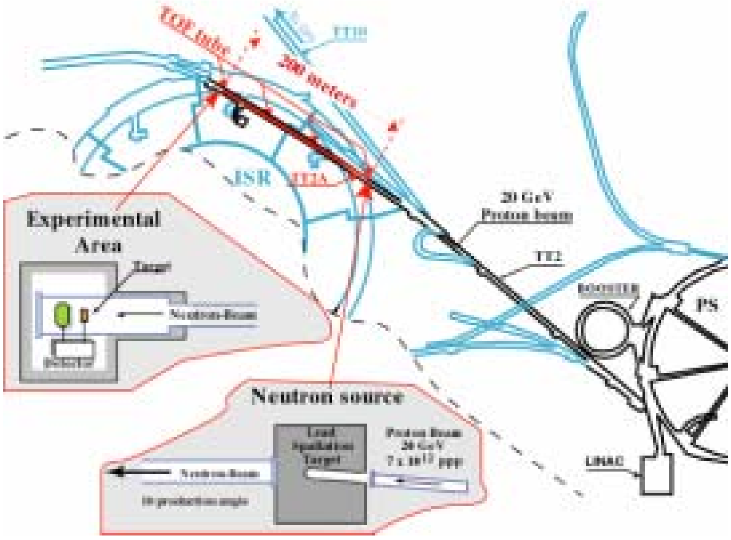

Fig.4; CERN neutron TOF spectrometer for n_TOF project.

3.2 Surrogate reaction technique [8]

Nuclear data are required also for nuclei with very short life time or with very little amount of samples for practical application like nuclear transmutation and studies on nuclear synthesis. ^{233}Pa and ^{238}Np are typical examples. In these cases, surrogate transfer reactions such as (d,pf), (t,pf) etc on stable nuclei are used effectively in place of direct neutron induced-reaction on unstable elements.

The neutron cross section is obtained by the following relation:

$\sigma_{nf} = \sigma_{in} \cdot P_f$, of neutron induced reaction, σ_{in} = cross section of the surrogate reaction, P_f = fission probability of the states e $P_f = \Gamma_f / (\Gamma_f + \Gamma n)$,

where σ_{nf} =fission cross section of states excited by the surrogate reaction, Γ_f and Γn are, respectively, the fission width and neutron width of the state excited by the surrogate reaction. The fission probability should be obtained by the calculation using appropriate model parameters. Younes and Brit of LLNL have applied this model to many cases to obtain neutron induced fission cross sections of ^{231,232}Th, ^{234,235,235m,236,237,239}U, ^{240,241,243}Pu using the data of (t,pf), (^{3}He,df), (^{3}He,tf) reactions on the stable nuclei [8]. Figure 5 shows an example of comparison of the surrogate technique with direct reaction of ^{233}Pa [9].

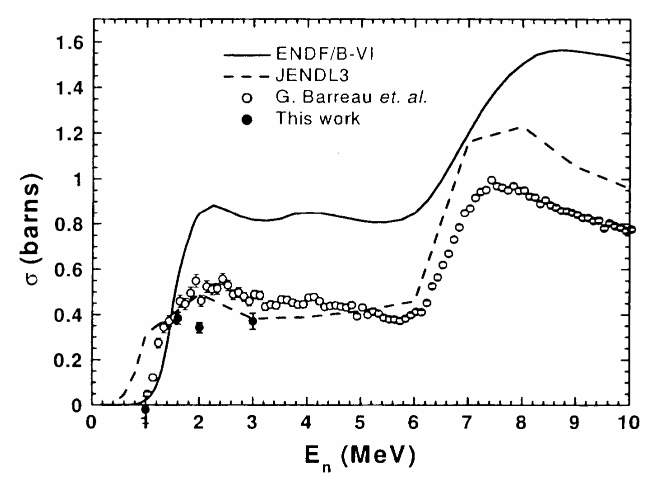

Fig.5: ^{233}Pa(n,f) cross sections

"This work" (closed circle) shows direct results by neutron induced reaction while

"G. Barreau et al" (open circle) shows results by surrogate technique

3.3 Activities in proton induced reactions

Studies on proton induced reactions are also in progress in Uppsalla university [10] and Russian institutes. Figure 6 shows an example of the results for (p,f) cross sections of light actinides. Smirnov et al deduced the relation of fission probability in proton induced reaction and neutron induced reaction as shown in Fig.6. using the fissility parameter Z^2/A [10]. The relation may be used to estimate cross section of neutron induced reaction on the basis of proton induced data.

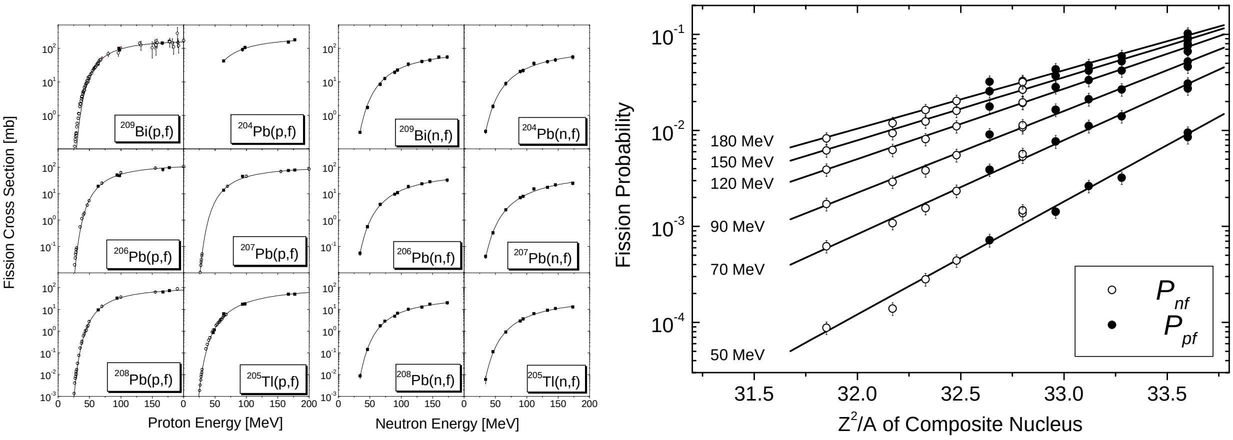

Fig.6; Proton induced fission cross sections (left) and the relation between fission probability and Z^2/A (right) [10].

4. Fission cross section studies in nuclear data project

We[1] are now promoting fission cross section studies under the nuclear data project on minor actinide data which is lead by Dr. Igashira (TIT) [11]. The aim of the projects is to obtain advanced experimental data and provide data base of MA for advanced reactors through development of advanced experimental techniques.

The program covers the following subjects:

1] Neutron induced fission cross sections
  1) Low energy region up to hundred of keV using Kyoto Univ. Lead Spectrometer (KULS)
  2) High energy region 20-80 MeV region using a AVF cyclotron at the Cyclotron and Radioisotope Center Tohoku Univ, (CYRIC) [12] and intense ^{7}Li(p,n) source recently installed there
  3) Medium energy region (hundred of keV to 20 MeV) using Tohoku Univ., Dynamitron accelerator
2] Proton induced fission：Tohoku Univ., AVF cyclotron
  1) Fission cross sections
  2) Fission yields by activation, radio-chemical methods, counter technique
3] Development of experimental techniques for fission
  Parallel plate avalanche counter (PPAC) for fragment detection,
  Fast response/ recovery detection system, digital signal processing,

As mentioned in sect.3.1, a lead spectrometer is a powerful neutron source and useful for fission cross section measurement of MAs. For major MAs, experimental data have been reported for by Kobayashi and Yamamoto using KULS [4]. Nevertheless, the data was limited in the energy region lower than around 10 keV because of the effect of intense "γ-flash". In the present program, therefore, the experiment is being extended to higher energies by providing electromagnetic shielding for detector-preamp lines, and employing fast recovery electronics and digital signal processing technique. In Fig.7, the extension of neutron energy range is illustrated achieved by the above mentioned means (^{237}Np fission cross section). Digital signal processing technique is also effective and reaches to similar results.

Recently, a new ^{7}Li(p,n) neutron source is under development at Tohoku University CYRIC to obtain intense quasi-monoenegy neutrons by employing a geometry shown in Fig.8. In this design, the sample or fission counters can be set around 70 cm from the source, then the neutron intensity will be as high as around 10^6/cm^2・sec for 1 μA beam current that is the highest value in the world. The neutron source is now under test and adjustment for licensing. It will be opened for utilization soon.

In the Dynamitron laboratories, many fission cross section data were obtained and still can be used for the experiment from hundreds of keV to 18 MeV neutron energy region, if there is need.

For proton induced reaction studies, the beam line of Tohoku Univ. Cyclotron was upgraded to enable irradiation of fissile elements and actinide elements, and now applied to fission yield experiments using activation technique.

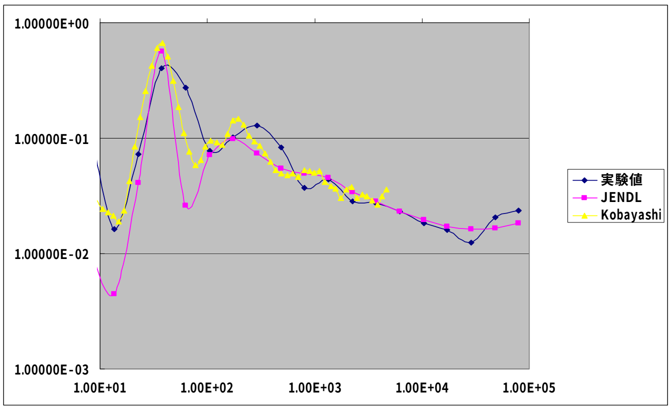

Fig.7: Extension of cross sections measurement to higher energy at KULS.

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[1] The members are as follows: M. Baba, T. Yamauti, T.Oishi, M.Hagiwara (Tohoku Univ., CYRIC), T.Ohtsuki, H. Yuki (Tohoku Univ., Linear Accelerator Lab.,), J Hori, H.Yamana, K.Nakajima, M.Takamiya (Kyoto Univ,, , Research Reactor Institute)

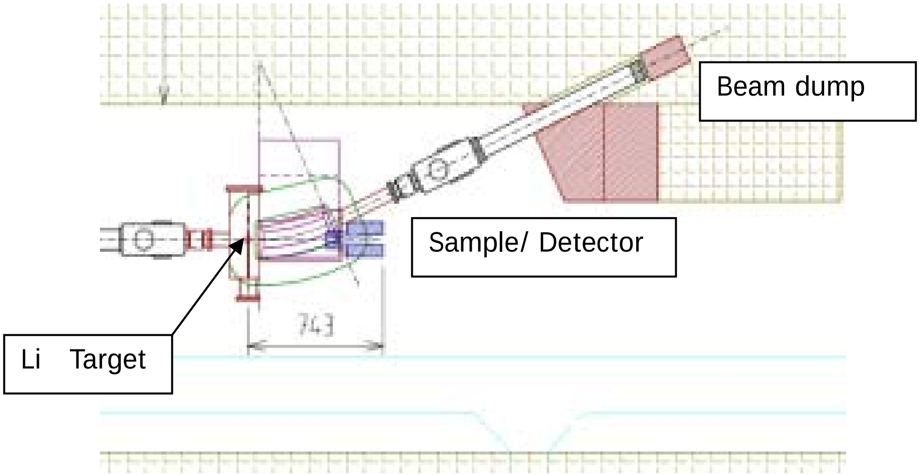

Fig.8: A new ^{7}Li(p,n) neutron source at Tohoku Univ., CYRIC

ACKOWLEDGEMEBNT:

The author wishes to thank Drs. K. Kobayashi and S. Yamamoto for collaboration and useful information on experiments at KULS. He also expresses his thanks to Prof. H. Okamura and Mrs. S. Chiba, Y. Omiya, N. Takahashi for collaboration to installation of new Li(p,n) neutron source at CYRIC.

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