Nuclear Data for Science and Technology (1988 MITO), 1233-1235, Copyright © 1988 JAERI.

# Session 1. Fission Neutron Yield and Related Topics

by

John W Boldeman

Australian Nuclear Science and Technology Organisation
Private Mail Bag 1, Menai, NSW, 2234, Australia

A consultants' meeting on the Physics of Neutron Emission in Fission was held in Mito City, Japan, 24-27 May, 1988, under the sponsorship of the International Atomic Energy Agency. The primary objective of the meeting was to review recent experiments, developments of theory and the conclusions from evaluations on all aspects of this process. The proceedings of the meeting will be published in due course. The meeting was organised into two sessions, the first dealing with fission neutron yield and related topics and the second with aspects of the energy spectrum of fission neutrons. For each session a working party was set up to summarise the status of knowledge. This was then presented to a plenary session of the meeting for consideration and endorsement. This paper presents the summary and recommendations from the meeting for the first session subject. Membership of the sub committee is listed below.

## Topic 1. Energy Dependence of $\bar{\nu}_p$

1. The $\bar{\nu}_p$ value for the reference standard, $^{252}$Cf, is known to high accuracy. The recommended value is 3.7661 ± 0.0054 from the review by Axton. The accuracy of the value for this standard is adequate for all current applications of $\bar{\nu}_p$ data. However, the internal consistency of the data suggests that there may be a systematic difference between the average value derived by $MnSO_4$ bath experiments and the average of the values derived from large liquid scintillator tank determinations. Since the liquid scintillator average is dominated by the value from the recent measurement by Spencer (ORNL), the systematic difference is essentially one between this measurement and the $MnSO_4$ bath determinations. The other scintillator measurements are consistent with the average of the $MnSO_4$ bath measurements.

2. The values of $\bar{\nu}_p$ for thermal neutron fission determined from a comprehensive analysis of all 2200 ms$^{-1}$ and Maxwellian averaged thermal data and the $\bar{\nu}_p$ value for $^{252}$Cf are adequate for all current applications. The recommended values are also those of Axton. There are however, minor inconsistencies in the data which compensate in the overall averaging process. A comprehensive experimental program to resolve all such matters would be very extensive and is difficult to justify at the present time.

Axton in his evaluation drew attention to the need to improve fission neutron spectra because corrections are required in $\bar{\nu}_p$ measurements for differences in the efficiencies of the neutron detector for the fission neutron spectrum of the measured fission process and that of the standard $^{252}$Cf. Although the data for $^{252}$Cf have improved, those for other important fission processes have not. Some further measurements (for neutron fission of $^{235}$U for example), especially comparative measurements with $^{252}$Cf, would be valuable.

The recent evaluation of the neutron resonance fission cross section data for $^{239}$Pu carried out by Fort et al. leads to some modifications to the values of $\bar{\nu}_p$ for $^{239}$Pu in the thermal region. It should be investigated if this affects the evaluation of Axton. It should also be investigated if smaller statistical fluctuations known to occur for the resonances of $^{235}$U affect the evaluated data.

3. Although the data for the energy dependence of $\bar{\nu}_p$ for neutron fission of $^{233}$U, $^{235}$U and $^{239}$Pu are satisfactory for nuclear reactor applications, a discrepancy of 0.5% exists between the data obtained by ORNL and the combined data obtained by the French and Australian groups for all three cases. It is conceivable that this discrepancy is also that in the absolute values of $\bar{\nu}_p$ for $^{252}$Cf. Possible sources of error were discussed in detail, but no solutions were obtained. Resolution of this discrepancy should be given priority.

4. Minor structures have been observed in the energy dependence of $\bar{\nu}_p$ for neutron fission of the three most important fissile nuclei $^{233}$U, $^{235}$U and $^{239}$Pu. The magnitudes of such structures have always been small, and the consistency between different determination has not been exact. The following comments summarise discussion on this topic:

(a) The structure in $\bar{\nu}_p(E_n)$ for $^{233}$U (at 200 keV) recommended in evaluations of the data was not observed in the recent measurement by Gwin et al. and probably does not exist.

(b) The recent measurement of $\bar{\nu}_p(E_n)$ for $^{235}$U by Gwin found a minimum at 40 keV. There are no comparable $\bar{\nu}_p(E_n)$ or $\bar{E}_K(E_n)$ data at this energy. It was noted that the fission fragment anisotropy has a minimum at approximately this energy.

(c) There appears to be no complementarity of fine structures observed in $\bar{\nu}_p(E_n)$ and $\bar{E}_K(E_n)$. This is not surprising in view of the complexity of the fission process.

(d) The energy dependence of $\bar{\nu}_p$ for neutron fission of $^{237}$Np has been measured by three groups. The two measurements from Kuzminov and Vesser differ from the third measurement (Fréhaut) by 3 percent. An independent measurement is required.

(e) There exists some variation in the linear dependence of $\bar{\nu}_p$ due to multiple chance fission. This has been observed in some nuclei e.g. $^{232}$Th, but not all nuclei. This behaviour was explained in the framework of a two spheroid model combined with the generalised Madland-Nix Model.

(f) Most recent data for $\bar{\nu}_p(E_n)$ have not been included in the readily available data files and this matter should be addressed urgently.

Topic 2. Multiplicity Distribution and Variances

1. Neutron multiplicity data are extremely accurately known for thermal neutron fission and for the spontaneous fission of $^{252}$Cf, $^{240}$Pu and $^{242}$Pu. There have been several recent measurements of high precision plus several evaluations of the experimental data.

2. The trends in the variation of the multiplicity with energy in neutron emission were reported by Fréhaut and are seen to show consistent behaviour. However, in the specific case of neutron fission of $^{239}$Pu where high precision is required for safeguards applications, much higher precision is requested. The appropriate method of treating experimental multiplicity data to derive accurate assessments of the precision was presented by Perey.

3. An improved method of treating high multiplicity data, particularly eliminating the effect of oscillations which appear in current analyses, is requested.

4. A larger data set on the variation of multiplicity with incident neutron energy is also required. Presently data are available from only one experiment. Experimental data from Gwin et al. and Boldeman and Walsh should be analysed.

Topic 3. Competition Between Neutron and $\gamma$ Ray Emission

1. Data exist on the variation of total gamma ray energy and multiplicity with fragment mass for thermal neutron fission of $^{235}$U (Pleasonton) and spontaneous fission of $^{252}$Cf (Signarbieux). Furthermore the variation in total gamma ray emission with energy in the neutron fission of $^{235}$U, $^{237}$Np and $^{232}$Th has been measured by Fréhaut and co-workers. For all processes a direct correlation has been observed between $\bar{\nu}$ and $\bar{E}\gamma$ (and multiplicities for the first two experiments). A theoretical description is required. Furthermore, more comprehensive data are required. In particular, data on the variation of total $\gamma$ ray energy and spectra as a function of fragment mass for a specific fissioning system (spontaneous fission of $^{252}$Cf for example) would be valuable.

2. The systematics of the (n,$\gamma$f) process are well understood especially for the case of neutron fission of $^{239}$Pu.

Statistical fluctuations of $\bar{\nu}_p$ correlated with the mass distribution and kinetic energy have been observed for resonances in the neutron fission of $^{235}$U. These fluctuations are not correlated with spin and are not related to the (n,$\gamma$f) process which is extremely small in this system.

These statistical fluctuation will probably occur for other fission systems and may therefore influence slightly the analysis of the (n,$\gamma$f) process for neutron resonances in $^{239}$Pu.

Topic 4. Fission Neutron Emission Near Threshold

1. Although measurements of the variation of $\bar{\nu}_p(E_n)$ and $\bar{E}_K(E_n)$ for subthreshold and near threshold fission are extremely difficult the experimental data are generally consistent. Recent data were presented by Kuzminov. Analyses by Fréhaut and Trochon, Kuzminov and Boldeman were discussed.

2. For vibrational resonances in the neutron fission of $^{230}$Th, $^{232}$Th, $^{234}$U, $^{236}$U and $^{238}$U the value of the average fission fragment kinetic energy decreases significantly. Since the fission fragment angular distributions for such resonances show strong non-isotropic behaviour because of the specific value of K associated with each resonance, the dip in the average fission fragment kinetic energy is also reflected in different values of the average kinetic energy at 0° and 90° to the incident neutron direction.

3. Similarly the $\bar{\nu}_p(E_n)$ dependences also in general show a great deal of structure in the vicinity of the vibrational resonances.

4. However, the $\bar{\nu}_p(E_n)$ and $\bar{E}_K(E_n)$ dependences are not complementary in character.

5. Surprisingly, the $\bar{\nu}_p(E_n)$ data for neutron fission of $^{230}$Th show no structure for the vibrational resonance at 715 keV.

6. One analysis of the $\bar{\nu}_p(E_n)$ data for $^{232}$Th shows that $\bar{\nu}_p$ is strongly correlated with the quantum number K of the fission channel.

7. An exact explanation of the structure in $\bar{\nu}_p(E_n)$ and $\bar{E}_K(E_n)$ in the threshold region is required if the fission process is to be fully understood. However, such an explanation cannot be attempted until consistent channel analyses are obtained of the fission cross sections.

Topic 5. $\bar{\nu}$ in Resonances

1. The work of Fort et al. shows that resonance variations of $\bar{\nu}_p$ should be included in data files. The additional data that should be listed include the resonance spin variation of $\bar{\nu}_p$ and data for the (n,$\gamma$f) process.

2. From a general discussion of the (n,$\gamma$f) process, it was noted that the size of the process for neutron resonances of $^{241}$Pu should be similar to that for resonances in $^{239}$Pu. For $^{235}$U on the contrary, the size of the process should be smaller. However, the (n,$\gamma$f) process only significantly affects resonances in which the fission width is small. Therefore, the effect of the (n,$\gamma$f) process on resonances in $^{241}$Pu and $^{235}$U is minimal.

General Recommendation

The rapid development of modern techniques for multi-parameter measurements of the properties of the fission process promises an opportunity to improve substantially the current understanding of this extremely complicated nuclear process. Furthermore, these measurement techniques provide a real method to aid the transfer of technology not only to the developing countries but also between developed ones. It is proposed therefore that a Coordinated Research Program be established to study "Nuclear Data on Neutron Emission in the Fission Process and its Understanding". A number of laboratories have expressed a great deal of interest in this idea.

Sub Committee Membership

J W Boldeman, J Fréhaut, Huang Shengnian, I Kanno, H Knitter, B Kuzminov, H Lemmel, Y Nakagome, F Perey