Nuclear Data for Science and Technology (1988 MITO), 1237-1238, Copyright © 1988 JAERI.

SESSION II : ENERGY SPECTRUM OF FISSION NEUTRONS

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Abstract : Preceding to the International Conference on Nuclear Data for Science and Technology in Mito City there was hold an IAEA Consultants Meeting on the Physics of Neutron Emission in Fission, 24-27 May 1988. One of two sessions of this CM was devoted to the review of the "Energy Spectrum of Fission Neutrons", covering the following topics :
-the Cf-252 spontaneous fission standard spectrum,
-studies of neutron-fragment-correlations for Cf-252 spontaneous fission,
-measurements of neutron induced fission neutron spectra and
-theory of fission neutron spectra.
A brief summary of presentations and Working Group discussions in the frame of this session is presented here.
(fission neutron spectra, fast neutron, Cf-252, U-235, Th-232, U-238, time-of flight, fission chamber)

Evaluation

The status of the present Cf-252 spontaneous fission neutron spectrum evaluation was presented in detail by Mannhart from PTB.

The conclusion of the WG discussion was, that the present evaluation is in a good shape, presenting the spetrum with evaluated uncertainties of $\leq$ 3% between 150 keV and 11 MeV and at least $\leq$ 1.5% between 1 MeV and 5 MeV. Outside of the quoted ranges the uncertainties increase. For the practical use the smooth curve of the data evaluation available in numerical form from the Nuclear Data Centres is recommended.

Between 10 keV and 20 MeV the existing evaluation agree within less than 3% with the Cascade Evaporation Model prediction without parameter fits.

It is recommended to update the evaluation from time to time and especially to include as soon as possible the existing fully documented experimental data.

The WG noticed the attempt by Froehner to approximate the spectrum by a fitted Watt distribution. This parameterization seems to be useful for a fast and simple representation of the spectrum by two paramaters without high requirements concerning the uncertainty.

Neutron-Fragment-Correlations

At the present CM new measurements of double-differential neutron emission $N(E, \theta)$ for Cf-252 s.f. with respect to the FFaxis have been presented by Knitter, Seeliger and Blinov from CBNM Geel, TU Dresden and RI Leningrad, respectively.

By these experiments, which in particular were carried out with new techniques, a very detailed experimental information concerning the neutron emission from specific fission fragments in a wide emission energy range and with high angular resolution was obtained. This tremendeous bulk of new data provides the challenge of detailed studies of the mechanism of neutron emission. The first results of a physical interpretation of the data were presented, showing that this experiments do not give indication for an essential amount of scission neutrons. The upper limit of them, at present, is estimated to be not higher than 5%.

The further exchange of information between all laboratories using this unique sets of data for comparison with theoretical models and physical conclusions is highly recommended by the WG. Beyond the search for neutrons, which are not emitted from fully accelerated fragments, of special interest are investigations of neutron and gamma multiplicities for different fragmentations, but also of the level densities of fission fragments.

The WG stressed, that it should be investigated, whether new experiments of this type could be started also for other spontaneous fissioning nuclei like the Fm-isotopes (in this case the fission would be largely symmetric in opposite to the Californium fission).

It was mentioned also the importance of infomations about the gamma emission from the Cf-252 s.f. for getting improved knowledge about the average gamma energy E_γ, the energy balance of fission and the angular momenta of fission fragments. In particular, it was recommended to analyze carefully in this sense the bulk of data measured during the last years using crystal ball detectors. In future measurements with high resolution detectors could give also useful spectroscopic information about the structure and level schemes of the neutron rich fragment nuclei.

Induced Fission Neutron Spectra

It was stated, that most of the experiments in this field were carried out many years ago, using experimental techniques available at that time. At the present CM new measurements at the Tohoku University and TU Dresden have been presented by Baba and Seeliger for neutron induced prompt fission neutron spectra for Th-232 at 2 MeV and 7.3 MeV, respectively. Blinov informed, that similar experiments are underway at RI Leningrad at 3 MeV and 14 MeV. Simultaneously new measurements of the total neutron emission spectra from U-238 at 14 MeV incidence energy are in progress in a few laboratories. Corresponding reports or short informations have been presented at the CM from Tohoku University, TU Dresden, IAE Beijing and RI Leningrad.

During the discussion in the WG the importance of new, high quality mesurements at a few incident energies was stressed, especially for checking the predictability of new theories for prompt fission neutron spectra. Resulting from the present status of the experiments, the following cases are recommended in particular for careful theoretical analyses and intercomparisons concerning the experimental data as well as the theoretical approaches :
(i) U-235 at thermal neutron energy (as a prompt neutron fission spectrum which was well-investigated in the past);
(ii) Th-232 at 2 MeV incident energy (as a pure fast neutron induced first chance fission neutron spectrum);
(iii) Th-232 at 7.3 MeV incidence energy measured in coincidence with a fission chamber (as a case, where first and second chance fission neutrons are mixed);

(iv) U-238 at 14 MeV incidence energy measured with and without coincidence to a fission chamber (in this case the experimental spectra represent a complicated mixture of direct, pre-equilibrium and equilibrium pre-fission neutrons with prompt fission neutrons up to the third order fission)

Fission neutron models proofed successfully in this cases could further be used for the prediction of unmeasured neutron spectra for primary and secondary actinides, resulting in corresponding improvement of evaluated nuclear data files.

Besides this, also other high quality measurements of neutron induced fission spectra are encouraged by the WG, especially near the energy regions, where new reaction channels open.

Finally, it was pointed out, that during the last years there was no measurement reported concerning neutron-fragment-correlation for neutron induced fission. It might be reasonable to carry out such measurements, f.i. at thermal energies, using for this purpose the new techniques developed in connection with the differential experiments for Cf-252 s.f.

Theory

The WG stated that at present a diversity of terms is used in publications designating prompt fission neutrons. To avoid misunderstandings, the use of following terms is recommended :

(i) pre-fission neutrons
(this include the direct, pre-equilibrium and equilibrium components of neutron emission before fission from reactions like (n,n'f), (n,2nf), (n, pnf) a.s.o.);

(ii) scission neutrons
(these are all neutrons emitted by different possible mechanisms during the descent from saddle to scission point, including the neutron emission at the rupture of fissioning nucleus);

(iii) neutrons from accelerating fragments;

(iv) and neutrons from fully accelerated fragments.

Concerning the development of fission neutron theories, the big progress obtained in this field during the last years was demonstrated at the CM. Especially the theories developed at LASL, TUD and RIL in the frame of statistical approaches of the description of neutron emission from fully accelerated fragments, which now definitely can be stated as by far the dominating component of all prompt fission neutrons, have strongly increased the predictive capability of the theory. Besides this, during the recent years also a few other theoretical approaches to different possible mechanisms of fission neutron emission have been reported in the literature. However, the missing, so far, capability of quantitative predictions of approaches at the one side and the stated above dominance of the neutron emission from fully accelerated fragments of the other side do not allow, at present, a definitive conclusion about the real observation of one of this mechanisms in neutron experiments (this is in contrast to the situation for the emission of light charged particles). Nevertheless, further theoretical studies in this direction are needed. In particular, on the long time scale a full-range time-depending Hartree-Fock theory for the fission process, including neutron emission, should be developed. In any case, the theoretical description of the main component of neutron emission in the frame of the statistical model has to be further improved as much as possible.

The presently existing approaches in the frame of the statistical model could be divided into three categories, as following :

(i) Approaches within an approximative statistical model, partially using input paramaters averaged over fission fragment distributions. The development of this type of models was started by Madland Nix at LASL. Later Märten and Seeliger from TUD proposed a more sophisticated approach of this type, including detailed distributions over fission fragment mass number A, as well as a rough consideration of n-γ-competition and c.m. anisotropy of neutron emission (so-called GMNM). At the present CM, Madland reported about the introduction of further improvements into this approach, f.e. the fragment charge distribution.

After all this developments, these models now are capable for the description of angle integrated spectra as well as differential spectra N(E, θ) for the Cf-252 spontaneous fission neutron emission . But, the most promising capability of this approaches seems to be the prediction of neutron induced fission neutron spectra, including multiple chance fission, over a broad range of incidence energies. For the determination of input parameters in this case a two-spheroid model (TSM) was developed at TUD.

(ii) Approaches within the Weisskopf-Ewing statistical theory, being valid for continuous state densities in the final nuclei, including all steps of cascade particle emission.

The cascade evaporation model(CEM) developed at TUD is an approach of this type of approximation, taking into account the diversity of distributions in the fission fragments, including individual level density parameters. The further application of this theory to the description of the new experimental differential data N(E, θ) for Cf-252 s.f. seems to be useful for the physical understanding of this process. First comparisons have been presented at the CM by Märten.

(iii) The most general approach within the statistical model, including angular momentum coupling, can be provided by the Hauser-Feshbach theory using the whole diversity of input distributions over all fission fragments. At present, attempts in this direction are undertaken at the RI Leningrad, but still within a limited scale (concerning the diversity of fission fragment distribution and angular distributions). Examples for this approach were presented at the CM by Blinov. At the long term a fully established HF-code for the calculation of fission neutron spectra seems desirable. However, the broad-range application of this theory needs an improved situation concerning our knowledge of necessary input distributions (over E,I,A,Z,TKE a.s.o.). level density parameters a and the isospin-dependence of the optical model parameters.

It should be pointed out also, that a fully-established description of neutron emission from fissioning nuclei need also a proper theoretical description of pre-fission neutrons and accompanying neutron induced reactions including collective direct and partical-hole excitations. Besides well-established codes like STAPRE, newly developed multistep statistical theories could be used as a proper base for this.

General Recommendation

Having in mind the fast development in this field during the recent years, but also the common interest of laboratories oriented both towards basic as well as nuclear data research, it was recommended by the WG to establish by the INDC of the IAEA a new Co-ordinated Research Programme on "Physics of fission neutron emission and its nuclear data applications". This CRP could be also a way for transfer of the newly developed techniques and technologies in the field of fission research to appropriate laboratories in developing countries and therefore, it could contribute to the transfer of nuclear technology to developing countries, being one of the main issues of the IAEA.