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A STUDY OF DELAYED NEUTRONS AND NUCLEAR FISSION AT THE DUBNA IBR-2 PULSED REACTOR

(Proposal for New Experiments)

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Introduction

We propose an international collaboration between the Frank Laboratory of Neutron Physics and other Laboratories that may be interested in studying delayed neutrons (DN) and nuclear fission. In accordance with recommendations of OECD/NEA experts [1], further measurements of the total yields of DN with enhanced precision are important both for modern nuclear reactor technology and for nuclear safeguarding purposes.

We intend to perform the DN measurements using our facility installed in the neutron beam № 11 of the Dubna IBR-2 pulsed reactor (PR). The facility consists of two principal parts: the slow neutron chopper (SNC), which is synchronized with the reactor bursts, and the high efficiency 4π-geometry multicounter neutron detector (ND). The "IBR-2 + SNC + ND" facility is briefly described in our report [2].

Studying delayed neutrons

We propose a method, involving periodical irradiation of a target composed of fissionable isotopes, which differs from, but also complements other methods and techniques applied for determination of ν_{DN} values discussed by Keepin [3] and by Tuttle [4]. This method is described in greater detail in the attached paper. However, we shall briefly mention some of the advantages of the said method and of our facility as compared with others:

- the IBR-2 PR provides the extremely high thermal neutron density of $\approx 3.10^{16}$ $n/sec.cm^2$ corresponding to the maximum neutron burst at the reactor moderator;

- owing to the SNC, which is synchronized with the IBR-2 PR, one can detect the DN in between the exposures;

- several minutes after the measurement starts an equilibrium DN emission is attained in between the reactor bursts;

- in the attached paper it is shown that all 6 groups of DN contribute to this emission without suffering significant losses in their counting rates, which means that their contributions correspond to their yields.

On the basis of the listed advantages one might expect the measured data on DN yields to exhibit good statistical accuracy, which would make possible a consistency check of our data relative to the six-group approach [3, 4].

Since the detection of DN starts several ms after the reactor beam is cut off and the duration between the reactor bursts may vary from 200 ms up to 1 s, this method provides a unique possibility of checking whether an unknown group of DN exists with a half-lifetime shorter than ≈ 0.2 s.

On the other hand, high intensity neutron bursts generated by the IBR-2 PR allow the yields of DN at subthreshold fission of ^{237}Np and ^{241}Am to be remeasured with higher accuracy, at least for the 5-th and 6-th groups of DN.

Therefore, we suggest performing the following DN measurements:

(a). Measurements of total DN yields for thermal neutron induced fission of ^{233}U, ^{235}U and ^{239}Pu. The main purpose of these measurements is to determine the ν_{DN} values and, if possible, to make a consistency check of our data within Keepin's 6-group approach. To make these measurements more reliable a set of metal samples of highly enriched ^{233}U, ^{235}U and ^{239}Pu has to be used. Their weights should be between 0.1 g and 10 g, and the cladding must be as thin as possible. Samples of round shapes are preferred, with diameters of 30 - 70 mm.

To avoid any pile up and/or drift of the electronics during long-time measurements it is necessary to make use of more stable high resolution electronics.

(b). Searching for a group of DN with a lifetime shorter than 200 ms. Already in the fifties significant interest arose in short-lived delayed neutrons [5], however, the obtained results turned out to be contradictory. It would now be reasonable to go back to such measurements taking advantage of modern technology. Since measurement of the DN decay curve between two consecutive reactor bursts can start a few ms after the neutron beam is cut off, the search for a group of short-lived DN with half-lifetimes shorter than 200 ms is possible. Correct decomposition of this decay curve into 6 or more components requires as strong suppression as possible of the DN fast neutron background and a good determination of its level. We expect that by introducing a cooled SiO_2 crystal into the neutron beam as a filter for the thermal neutrons [6] and by improving the neutron collimators between the reactor core and the SNC it will be possible to lower the neutron background down to the necessary level. This work is now in progress.

(c). Measurements of DN yields in subthreshold fission of ^{237}Np and ^{241}Am seem to be important in connection with the problem of accelerator driven transmutation of nuclear waste [7]. Estimations reveal that with a neptunium sample of ≈ 10 g and an americium sample of ≈ 0.1 g it is possible to measure the total yields of DN for both nuclei. However, the content of ^{235}U and ^{239}Pu in these samples should not exceed $\approx 10^{-6}$. For enhancement of the neutron detection efficiency we intend to equip the ND with 36 ^{3}He proportional counters. Then the measurement time is estimated to be of about 100 - 200 hours.

Study of Nuclear Fission

In principle, the "IBR-2 + SNC + ND" facility can also be used in studies of other delayed nuclear processes characterized by delays of $\approx 10^1 - 10^3$ ms. Below we shall briefly consider some applications of this facility for studying isomeric fission and (n, γ)-reaction induced isomeric states with half-lifes of $10^1 - 10^3$ ms.

(a). Measurements of the average number of ν_{if} of prompt fission neutrons per isomeric fission of $^{242if}Am$ [8]. According to the double-humped fission barrier hypothesis of Strutinsky [9] the compound nucleus can emit several pre-fission gamma-quanta and then reach the shape-isomeric ground state close to the bottom of the 2-nd well. Comparing the ν_{if} and ν_{th} values, which correspond to the isomeric (delayed) and "normal" thermal neutron fission, respectively, and extrapolating the well-known experimental relationship $\Delta\nu/\Delta E^* \approx 0.1$ to the subbarrier region one can find the estimated value for the shape isomer ground state [8]. Here ΔE^* is the change of excitation energy due to the emission of pre-fission gamma-rays. On the other hand, Weber et al. [10] found $(TKE)_{if}$ to exceed $(TKE)_{th}$ in thermal neutron induced fission by ≈ 2 MeV. Since TKE and ν anticorrelate [11], the difference $\Delta\nu = \nu_{th} - \nu_{if}$ is expected to be a result of both effects: the change of E^* and of TKE. Assuming ΔE^* to be ≈ 2.5 MeV and $\Delta(TKE) \approx 2$ MeV, one should expect that $\nu_{th} > \nu_{if}$ within 10 - 15 %.Observation of such a change in ν_{th} as compared with ν_{th} would serve as an important argument in favour of the existence of pre-fission gamma-ray cascades associated with the double-humped fission barrier.

Various modifications of the proposed experiment are considered in ref. [8]. The most realistic set-up seems to involve a thin-thick-target approach in combination with the spark chamber technique for fission fragment detection and a ND adapted for neutron multiplicity measurements. Since the half-life of the $^{242if}Am$ fission isomer is about ≈ 14 msec [12], the "IBR-2 + SNC + ND" facility is the most convenient one for performing the proposed measurement. The estimated amount of ^{241}Am necessary for this experiment is ≈ 100 mg and the total measurement time is expected to amount of ≈ 200 hours. However, operation of the chamber with such an amount of Am is an extremely difficult task, owing to the counting rate of α-particles.

(b). Searching for a γ-branch in the decay of the fission shape isomer ground state. Two competing decay branches from the fission isomer ground state are possible: **(1)** a decay back through the inner barrier or **(2)** a fission through the outer barrier. However, the ^{238}Np and ^{239}U fission shape isomers have not yet been found. Therefore, the most probable one would be a decay of the shape isomer ground state through the inner barrier. The estimated half-time of ^{238}Np varies between 10 ms [13] and 10 s [14]. Børggreen et al. [15] made an attempt to find a delayed γ-branch emitted by the hypothetical ^{238}Np shape isomer. However, this attempt turned out to be unsuccessful owing to the insufficient experimental sensitivity of their measurements.

At present, a modern gamma-ray detection technique, similar to the one described in ref. [16], can be utilized. Combining it with our "IBR-2 + SNC" facility one may, perhaps, realize the best experimental approach for searching for the γ-branch in a time interval from 10 ms up to 1 s.

Below we present some estimates for the expected number of delayed gamma-rays and delayed neutrons, which can be treated as an unpleasant neutron background for the gamma-ray detector. If a sample with 7 g of ^{237}Np is used and if an isomeric ratio of $\approx 10^{-5}$ assumed, then the number of delayed gamma-rays and neutrons per hour will be $\approx 4.10^3$ and $\approx 5.10^4$, respectively. Some serious experimental problems arise, such as the need to protect the gamma-ray detector against the fast neutrons, or the problem of distinguishing the gamma-rays associated with the shape isomer ground state decay from unknown isomeric states of the fission fragments in the millisecond range etc.

The proposed measurements appear to be extremely difficult. However, their importance justifies any efforts that will be made in performing them.

(c). Searching for thermal neutron capture induced isomeric states in the millisecond range. Another possible application of our facility would be searching for thermal neutron capture induced isomeric states in the millisecond range.

There exists a certain lack of information concerning the excited states with half-lifetimes of $10^1 - 10^3$ ms. One of the main difficulties in studying them in the "ms" range consists in there being two contradictory requirements: the need for a high intensity neutron flux, to provide for the experiments to exhibit sufficient sensitivity, and the low repetition rate of neutron bursts of 1 - 10 Hz, that is necessary for "ms" measurements. The "IBR-2 + SNC" facility meets these requirements and seems to be the best one for searching for isomeric states in the "ms" range.

Conclusion

The Proposal should be considered as an attempt to draw the reader's attention to the unique facilities provided by the Dubna IBR-2 PR and the SNC for performing certain important experiments involving DN and nuclear fission.

We would be very glad, if with this Proposal we could launch an international collaboration for performing both experiments, that will provide nuclear data important for nuclear reactor technology and data, that give us a better understanding of nuclear fission.

References

1. A. Filip, A. D'Angelo, "Nuclear Data for Science and Technology", Proceedings, FRG, Juelich, 13-17 May 1991, p.946, Springer-Verlag, Berlin.

2. E. Dermendjiev, V. Nazarov, S. Pavlov, Iv. Ruskov, Yu.S. Zamyatnin, JINR Report E13-93-6, 1993, Dubna.

3. G.R. Keepin, "Physics of Nuclear Kinetics", Addison Wesley, Reading Mass. (1965).

4. R.J. Tuttle, Nucl.Sci. Eng., **56**, 37 (1975).

5. G.R. Keepin, T.F.Wimett, Proc. of the Int.Conf. on the Peaceful Uses of Atomic Energy, Geneva, 1955, v.4, paper p/831.

6. A.K. Freund, Nucl.Instr. Meth., **213**, 495 (1983).

7. P.W. Lisowski, C.D. Bowman, E.D. Arthur, P.G. Young. See ref.1, p.92.

8. E. Dermendjiev, Proc. of the Vth Int. Symp. on the Interactions of Fast Neutrons with Nuclei. November 17-21, 1975, Gaussig, DDR. Report ZfK-324, p.169, Dresden, 1976.

9. V.M. Strutinsky, Nucl.Phys. **A95**, 420 (1967).

10. J. Weber, B.R. Erdal, A. Gavron, J.B. Wilhelmy. Phys.Rev. **C13**, 189 (1976).

11. F.-J. Hambsch, H.-H. Knitter, C. Budtz-Jørgensen, J.P. Theobald, Nucl.Phys. **A491**, 56 (1989).

12. S.M. Polikanov et al. Sov. J.JETP, **42**, 1964 (1962).

13. J.E. Lynn, Rep. AERE-M2505.

14. B.B. Back, J.P. Bondorf, G.A. Otroschenko, J. Pedersen, B. Rasmussen. Nucl.Phys. **A165**, 449 (1971).

15. J. Børggreen, J. Hattula, E. Kashy, V. Maarbjerg. Nucl.Phys. **A218**, 621 (1974).

16. S. Oberstedt, H. Weigmann, H. Wartena, C.D. Burkholz, J.P. Theobald. Proc. of the Seminar on Fission, Pont D'Oye II, Oct.23-25, 1991, page 158 (Ed. C. Wagemans).

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