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RADIATIVE NEUTRON CAPTURE IN FISSIONABLE NUCLEI

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Abstract

RADIATIVE NEUTRON CAPTURE IN FISSIONABLE NUCLEI. Because of the great success of the (n,γ) method in nuclear structure studies, it is desirable to extend such measurements to fissionable target nuclei. A suitable spectrometer for investigating the high-energy radiative capture spectrum without significant interference from the fission process has been installed at the Karlsruhe research reactor FR-2. The instrument is briefly discussed. First preliminary results are presented.

Studies of the radiative neutron capture process have revealed detailed information on nuclear structure. As yet, however, the application of this method has been restricted to compound nuclei which are stable against nuclear fission. With fissile target material the capture spectrum is masked by the prompt gamma-ray spectrum from fission and – to a lesser extent – by the delayed gamma rays arising from the beta decay of the fission products. The target nucleus ^{235}U, for instance, has a thermal neutron fission cross-section of 578 b while the capture cross-section is only 101 b. Thus the thermal neutron capture reaction accounts for 14.9% of the neutron absorption in ^{235}U, with the fission process accounting for the remaining 85.1%. For the total energy released in prompt photon emission from fission values of 7.2 and 8 MeV are given [1]. This energy is distributed between 9 ± 2 photons per fission. The multiplicity for the radiative capture process is probably less than 5 photons per capture. Thus it is evident that the prompt gamma rays emitted in the fission process provide the dominant structure in the ^{235}U spectrum. As further confirmation of this conclusion, a comparison of the spectra from uranium and plutonium shows that these spectra are essentially identical; only very minor, and probably not significant, differences occur [2].

Because of the great success of the (n,γ) method in nuclear structure studies, it is desirable to extend these measurements on fissionable nuclei. Moreover, such an extension will reveal new possibilities for the non-destructive assay of nuclear fuel. Preliminary attempts should be directed to the high-energy spectrum, since at high energies the most favourable intensity distribution between capture gamma rays, prompt radiation from fission and delayed photons from fission products is expected. As has been proposed by one of us [3], the interfering component from fission may be suppressed by detecting the fast fission neutrons in anticoincidence and in 4π geometry. Since the average number of neutrons emitted per fission is 2.5 or even 3.0, a detection efficiency of about 70% for the single neutron is sufficient to obtain 95% total efficiency. The proposed principle can be sketched as follows: The sample is surrounded by a plastic or a liquid scintillator of appropriate thickness. Neutrons scattered in the target are

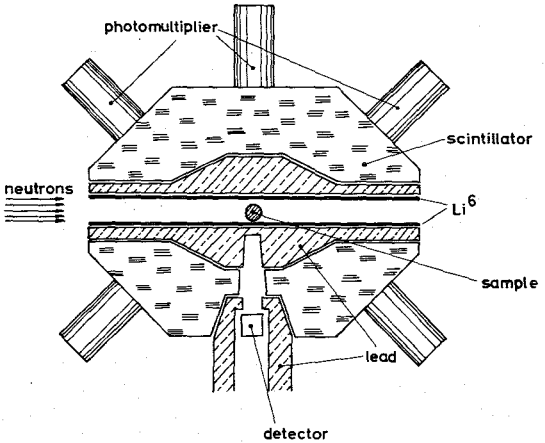


FIG. 1. Schematic outline of the neutron-anticoincidence spectrometer.

kept off the detectors by a shield of ^6Li. The gamma rays are filtered by a few millimetres of lead to reduce the count rate from soft fission gamma rays. The photons are detected in a Ge(Li) counter which is used as a double-escape spectrometer. A lead shield of about 5 cm thickness between sample material and neutron detector prevents suppression of the capture gamma rays by coincident low-energy photons. A detailed analysis of the system may be found in Ref. [3].

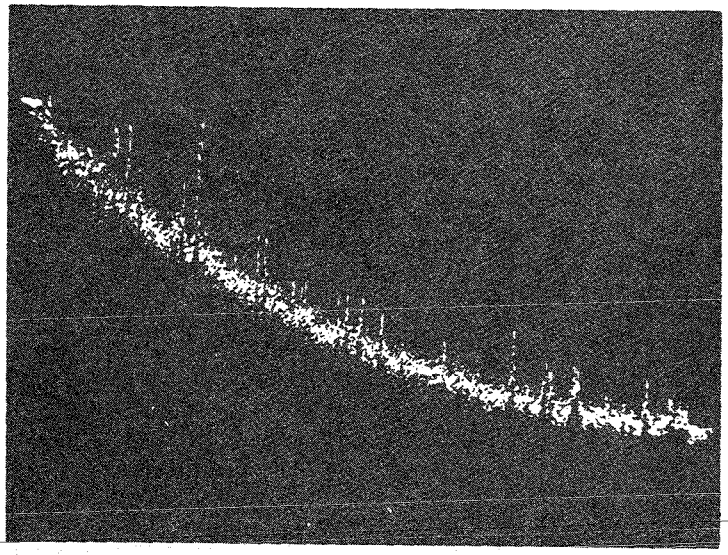
Gamma rays arising from beta decay of the fission products are no severe obstacle in the case of short measuring intervals. If all half-lives between 350 msec and 1 h are included, the intensity ratio for the prompt and delayed spectrum is about 2 : 1 at 4 MeV and about 10 : 1 at 6 MeV. This was calculated in Ref. [3] from the experimental data reported in Refs [4-7].

To demonstrate the feasibility of the neutron-anticoincidence spectrometer, an experimental set-up has been installed at the reactor FR-2 consisting of a Ge(Li) counter and a 44 cm diam. × 60 cm plastic scintillator. The scintillator is provided with appropriate wells for the neutron beam and the gamma detector. A schematic drawing of this instrument is shown in Fig. 1. To obtain a maximum signal-to-background ratio the scintillator was bevelled on both ends.

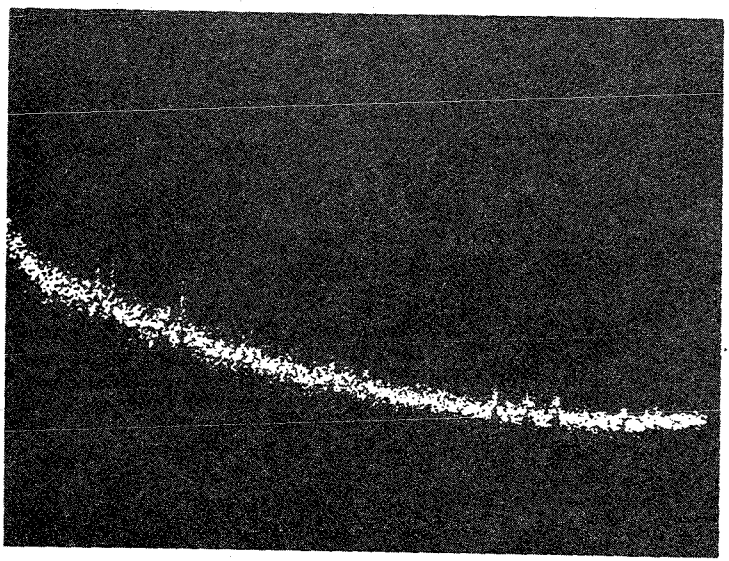
Delayed gamma rays occurring in the measured spectra will be identified by means of a combined fast/slow chopper system which has been installed at the reactor to study the delayed radiation from fission [8].

A preliminary test spectrum obtained with the neutron-anticoincidence spectrometer and a spectrum taken in single mode are presented in Fig. 2. The energy interval ranges from about 3.4 to 6.4 MeV. The sample was uranium oxide enriched to 20% in ^{235}U. The spectra were measured using a provisional electronic system. Only a coarse adjustment of the various components had been performed. The spectra are therefore considered as preliminary. Nevertheless, a clear structure already appears in the anticoincidence result. The suppression of the fission gamma rays can certainly be improved further and probably the spectrum still contains

some contamination from delayed fission gamma rays and from neutron capture in germanium caused by fission neutrons. By placing the detector in a proper geometry relative to the plastic scintillator interference from capture in germanium can be eliminated. In this case the scintillator serves at the same time as an anticoincidence shield for capture events occurring in the detector.



a)



b)

FIG. 2. Preliminary results from a sample of uranium enriched to 20% in ^{235}U: (a) spectrum taken in anticoincidence; (b) spectrum observed in single mode.

It should be pointed out that ^{235}U is one of the most unfavourable target materials [3]. For other samples the capture-to-fission ratio is much higher. It is, for instance, 0.358 for ^{239}Pu and about 0.39 for ^{241}Pu.

In summary, we can conclude that it will be possible to extend (n,γ) investigations also to fissionable nuclei.

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