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Prompt γ-rays from the fast neutron induced fission on ^{235,238}U and ^{232}Th

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Abstract

Preliminary results from the first experiment using the LICORNE neutron source at the IPN Orsay are presented. Prompt fission gamma rays from fast-neutron induced fission of ^{238}U , ^{232}Th and ^{235}U were detected. Thick samples of around 50g of ^{238}U and ^{232}Th are used for the first part of the experiment. An ionisation chamber containing ∼ 10 mg samples of ^{238}U and ^{235}U to provide a fission trigger is used for the second part of the experiment. Gamma rays have been detected using 17 high efficiency BaF_2 detectors and 6 $LaBr_3$ scintillator detectors.

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1. Introduction

In a reactor core the major nuclear reaction is fission. It is a the origin of the majority of the power released. During the fission process, γ-raysand neutrons are released. Due to the reactor design, γ-rays have an average mean free path greater than neutrons (tenth of centimeters) and then can carry, far from the initial reaction site, roughly 10% of the energy released in the process. During reactor operation, gamma heating process dominate in all non-fissile materials in the reactor core – e.g. structural materials, core shielding, reactor instrumentation, etc. Then, calculation of reactor core temperatures becomes a difficult problem. When the reactor is shut down, gamma heating is the dominant energy deposition process for all core materials and thus the problem of gamma heating is directly related to reactor safety. Currently, benchmark models of gamma heating in reactor cores underestimate heating effects by up to 30% when compared to experimental results (Rimpault, 2005). This is mainly due to insufficiently accurate nuclear data and possibly also deficiencies in the modeling. The gamma rays originating from neutron capture, inelastic scattering and beta decay of the fission fragments are fairly well understood. However, about 40% of this energy

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is prompt gamma emission (< 1 ns) and here, the available data for thermal neutron induced fission date from the early 1970's (Verbinski et al., 1973; Pelle et al., 1971). However, these data have the potential for improvement and such measurements are at the top of the high priority nuclear data list of the NEA/OECD (NEA, 2006). Since future generation IV reactor concepts will mostly use fast neutron spectra, prompt γ emission data in fast neutron induced fission are very important. However, currently very little data of this kind exists. For fast neutron induced fission the spectral shape, mean multiplicities and energies are expected to be different because excitation energy and angular momentum of the fissioning compound nucleus will change, along with the resulting fission yields, average neutron energies and multiplicities. There are particular technical challenges associated with prompt γ-ray emission measurements for fast neutron induced fission. Firstly, fission cross sections are typically three orders of magnitude lower than those for thermal neutron induced fission. To produce high fluxes the target and γ detectors need to be very close to the neutron source. However, since conventional quasi mono-energetic neutron sources emit neutrons isotropically γ detectors will require heavy shielding to avoid being blinded by neutrons form the source, which is often highly impractical – a problem that LICORNE has now solved.

2. Experimental Measurement

A first experiment using LICORNE was conducted in July 2013 over a period of two weeks to measure prompt fission γ ray spectra of ^{232}Th , ^{238}U , ^{235}U and ^{252}Cf. The experiment was financed by ERINDA and was split into two parts with around 100 h of beam time allocated to each part.

2.1. Fission tag with an ionisation chamber

The first part used a cylindrical twin Frisch grid ionization chamber of 28 cm diameter and 20 cm length. The chamber was filled with P10 counting gas (90% argon, 10% methane) to detect fission fragments with an efficiency of almost 100%. Two targets of ^{235}U and ^{238}U were placed back to back at the central cathode position and signals from the cathode and anode were digitized and recorded to disk. The targets consisted of approximately 10 mg of uranium, forming circular deposits of 6.5 cm diameter on aluminium backings of 30 μm thickness. Fission fragments emitted from the surface of the targets were identified by measuring the anode and cathode signals in coincidence and placing a constraint on the minimum pulse heights recorded to reject intrinsic alpha activity. For γ detection 14 hexagonal BaF_2 scintillator crystals were configured into two independent clusters of seven detectors. Each crystal measured 10 cm diameter and 14 cm in length for a total mass of scintillator of 62 kg. The two clusters were placed at 29 cm from the target position at angles of ± 62 degrees to the beam axis. In such a configuration, the total geometric efficiency of the two clusters was estimated to be 7%. MCNP simulations of the clusters and targets show that each cluster has a high photo-peak efficiency of 2.1% and a peak-to-total ratio of 75% for γ-rays of energy 1 MeV. Figure 1 shows a schematic diagram of the setup for the first part of the experiment.

Neutrons of average energy 1.5 MeV from the LICORNE inverse kinematics neutron source were used to bombard the targets with estimated fluxes at the target position of up to 2×10^5 n/s/cm^2 . This gave maximum fission rates of around 0.3 fissions per second and 1.2 fissions per second for ^{238}U and ^{235}U targets respectively. In total 4.2×10^4 fission events of ^{238}U and 1.5×10^5 fission events for ^{235}U were recorded to disk over a period of around 3 days. The data acquisition system is based on a triggerless COMET–6X (COdage et Marquage En Temps) module that allows us to encode in amplitude the signals delivered by up to 6 detectors per module with a capacity to chain five modules together, and to associate with each amplitude encoding an absolute and high resolution (400 ps) time information.

2.2. Fission tag with BaF_2 clusters

The second part of the experiment involved the same two clusters of 14 BaF_2 in a close packed geometry around thick samples (replacing the ionization chamber) of ^{238}U (38 g) and ^{232}Th (50 g), forming a calorimeter with a geometric efficiency of approximately 70%. The ^{238}U sample was a disc of 6.5 cm diameter and the thorium sample a square of dimensions 5 cm × 5 cm. The cone of neutrons was produced from a ^{7}Li beam of 15 MeV bombarding energy was emitted at a maximum opening angle of 20 degrees and passed through the centre of the calorimeter to