Experimental report

09/10/2016

Proposal: **3-07-363** **Council:** 4/2015

Title: Measurement of high-energy prompt gamma-rays from the fission of 235U(nth,f)

Research area: Nuclear and Particle Physics

This proposal is a resubmission of 3-07-356

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Samples: oxide of 235U

Instrument	Requested days	Allocated days	From	To
PF1B	32	32	13/10/2015	13/11/2015

Abstract:

We propose to measure the prompt fission gamma-ray spectrum (PFGS) for thermal neutron-induced fission of 235U up to energies high enough to observe the giant dipole resonance (GDR) of fission fragments for the first time in neutron-induced fission. We will use newly developed high-efficiency LaBr3(Ce) detectors (4" diameter x 5" length). The experimental program is also connected to the decommissioning of the nuclear-fuel debris in damaged Fukushima atomic power plants in Japan. The decommissioning must be done without reaching the criticality of the fuel debris. This necessitates a surveillance detector to moitor the fission rate in the debris. The prompt gamma-rays in fission with energies larger than 6 MeV, which corresponds to the highest energy for background gamma-rays from the debris, would be detected to monitor the fission rate. The surveillance detector is designed to be sensitive to the high-energy region of PFGS including the GDR.

Measurement of high-energy prompt gamma-rays from the fission of $^{235}U(n_{th},f)$

Proposal Number: 3-07-363
Beam Line: PF1B
Experiment scheduled : 13/10/2015 – 13/11/2015
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Summary

We have successfully finished the measurement of prompt fission γ-rays spectrum (PFGS) for cold-neutron induced fission of ^{235}U. We measured the spectra up to $E_\gamma \sim$ 20 MeV, by gaining the statistics of about ~10^5 compared to the literature data [1], which report the PFGS up to 7 MeV in the same reaction. The obtained PFGS does not follow the linearly decreasing trend as a function of energy (in logarithmic scale), but shows a structure beyond E_γ =12 MeV. This can be interpreted as the GDR of fission fragments, observed for the first time in neutron-induced fission. The spectrum also revealed hump structures around E_γ =4 and 6 MeV, which would be emitted from the nuclei in the vicinity of ^{132}Sn. The obtained PFGS for $^{235}U(n_{th},f)$ also gives a basis to design a surveillance detector to monitor the criticality of nuclear-fuel debris in Fukushima atomic power plans, where the decommissioning process starts from removing the debris from the primary containment vessel (PVC) without reaching the criticality.

Experimental Condition

Experimental procedure is described in the proposal documents, thus some experimental conditions are given here.

During several day in the very beginning of the run, we carefully checked the background conditions entering into the $LaBr_3$(Ce) γ-ray detector having the largest volume (diameter 4inch × length 5 inch) produced so far. The neutron beam was collimated to about 20 mm to give a neutron flux 1.0×10^8 (/s/cm^2) at the target position to optimize a counting rate of the $LaBr_3$(Ce) detectors. The high-purity ^{235}U target having thickness of 117 μg/cm^2 (diameter=30mm) was used.

Threshold for $LaBr_3$(Ce) detector was set at 0.3 MeV. In these conditions, counting rage for one detector was about 30 kHz. Both fission fragments (FFs) were detected by multi-wire proportional counters MWPCs at a counting rate of 55 kHz, where MWPCs were attached in the vacuum chamber at a 50mm distance from the target (target and central-cathode distance). To separate prompt γ–rays and neutrons, time difference between the signals from the MWPC and $LaBr_3$(Ce) was recorded. The MWPC was designed to record the incident position of FF in two dimensional area, which was used in the offline analysis to correct for the time-shift of FFs traversing the 50 mm distance. From time difference between both FFs, mass split of nuclei (mass asymmetry in fission) is determined, which will be later used for the correlation analysis between PFGS and fission mass-asymmetry.

A high-speed digital data acquisition system developed by JAEA could accept the signals with almost no dead time. The detector operation was very stable through the run, allowed us to reach high statics. During the total data acquisition time of 437 hr, number of coincided FFs reached 4.3×10^{10}.

Experimental data from preliminary analysis

Figure 1 shows the measured γ-ray spectrum from one $LaBr_3$(Ce) detector, obtained in this run. The black curve shows the total spectrum without imposing any gate conditions. Peaks from the $^{27}Al(n,\gamma)^{28}Al$ reaction is visible. The red curve is obtained by gating the prompt γ–ray peak in the TOF spectrum shown in Fig. 2. Finally, time-independent BG is estimated as shown in the blue curve, which should be subtracted from the red curve to obtain the correct PFGS.

Finally obtained PPGS is shown in Fig. 3, where spectrum was already unfolded using a response matrix, which also well reproduced the γ-rays spectrum emitted from the $^{27}Al(p,\gamma)^{28}Si$ reaction (up to 10.76 MeV) and $^{11}B(p,\gamma)^{12}C$ reaction (up to 18.36 MeV) [2]. The maximum energy up to E_γ ~20MeV is reached in this run for the first time in neutron-induced fissions. The spectrum reveals the enhanced structure in the region of E_γ >12MeV, which can be interpreted as the GDR of FFs. We also found local structures around 4 MeV and 6 MeV [3], which were also found in the PFGS of ^{252}Cf(SF) [4,5]. From the correlation of fragment mass-asymmetry and PFGS for $^{235}U(n_{th},f)$ and ^{252}Cf(SF), it is suggested that these γ–rays are emitted from fragments in the vicinity of ^{132}Sn.

References

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[3] H. Makii *et al.*, ND2016, International Conference in Nuclear Data for Science and Technology, 11-16.Sep.2016, Bruges, Belgium.
[4] P. Glässel *et al.*, Nucl. Phys. A, **502,** 315 (1989).
[5] A. Hotzel *et al.*, Z. Phys. A, **356**, 299 (1996).

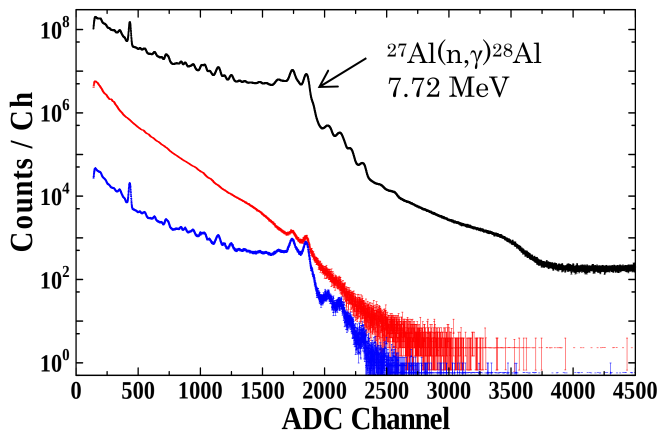

Fig. 1 Obtained γ-ray spectra from one $LaBr_3(Ce)$ detector in the reaction of $^{235}U(n_{th},f)$. The black curve shows the total spectrum without any gate conditions. Red curve is the one after gating the prompt γ-ray peak on the TOF spectrum of Fig. 2. Blue curve is the time-independent background spectrum

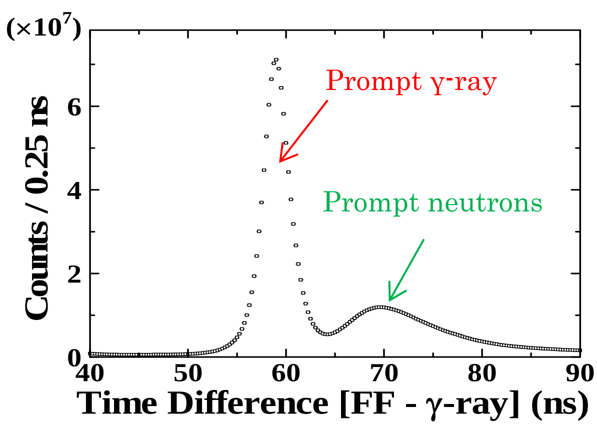

Fig. 2 TOF spectrum from the signals of MWPC and $LaBr_3(Ce)$ detectors. Prompt fission γ–rays and neutrons are observed.

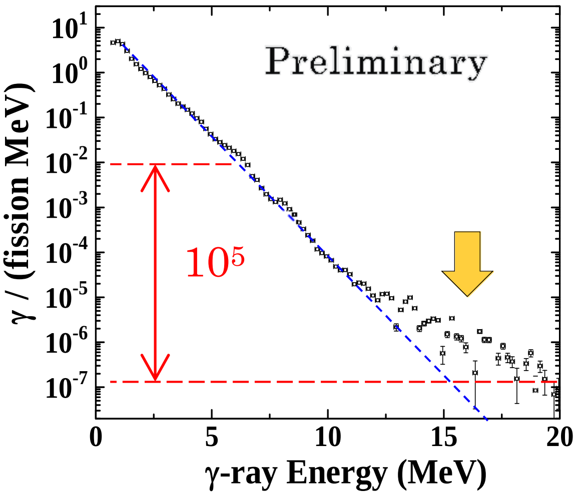

Fig. 3 Prompt fission γ–ray spectrum for $^{235}U(n_{th},f)$ obtained in this run. The blue dashed lines is the linear extrapolation of the spectra of the low energy region, E_γ < 10MeV. Factor 10^5 statistics is gained in this run compared to the literature data [1].