Experimental report

08/03/2018

Proposal: **3-01-646** **Council:** 4/2016

Title: Application of Calorimetric Low Temperature Detectors for investigation of Z-distributions of fission fragments

Research area: Nuclear and Particle Physics

This proposal is a continuation of 3-01-637

Main proposer: **Peter EGELHOF**

Experimental team: Werner LAUTERFELD
Saskia KRAFT-BERMUTH
Manfred MUTTERER
Artur ECHLER
Pascal SCHOLZ
Peter EGELHOF
Santwana DUBEY

Local contacts: Ulli KOESTER
Aurelien BLANC

Samples:

Instrument	Requested days	Allocated days	From	To
PN1	31	26	21/11/2016	11/12/2016
			16/12/2016	22/12/2016

Abstract:

In recent experiments (2014/2015), use of the novel technology of Calorimetric Low Temperature Detectors (CLTD) proved to be very successful for the investigation of nuclear charge distributions of fission fragments at LOHENGRIN. Applying the well-known passive-absorber method with recently available homogenous silicon-nitride (Si3N4) absorber foils in combination with CLTD residual-energy detectors, shows promising Z-yield resolution. Employing several improvements to the current set-up, we intend to push the measurements from light fragments to symmetry and the light side of the heavy fragment group. Measurements near symmetry give the opportunity to study the even-odd staggering of charge yields which is a sensitive test of fission models. Also, the perspective of reaching Z-yield determination in heavy-fragment group this way, would provide an alternative and complementary method to gamma spectroscopy and radio-chemistry.

Report on the experiment 3-01-646

Our first ILL beam time in December 2014 (3-01-629) demonstrated already successfully the first ever operation of calorimetric low-temperature detectors (CLTDs) as residual energy detectors for measuring isotopic fragment yields at LOHENGRIN [1], applying the passive absorber method [2]. A further innovation was the implementation of stacks of very homogeneous silicon nitride (SiN) membranes for the passive absorber material [3], mounted on a movable manipulator outside the cryostat. For the second run in April 2015 (3-01-637) part of the SiN foils with a total thickness of 4.4 µm were placed inside the cryostat at a distance of 9 cm to the CLTD array, increasing the transmission and improving the thermal stability of the detectors [4]. (For details see “Reports on experiments 1-3-629 and 1-3-637”)

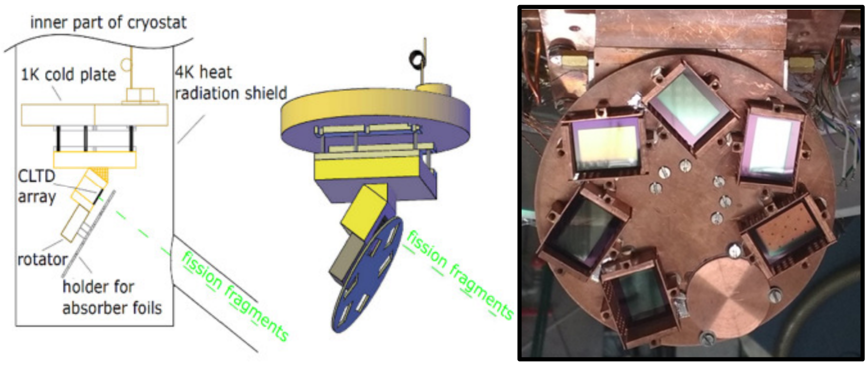

Fig. 1. Schematic view of the detector cryostat with rotatable sample changer for silicon nitride absorber stacks in front of the CLTD’s as residual-energy detector (left). Front view of the rotator disc (right). One position is occupied by a calibration α source.

For the last beam time in December 2016 (3-01-646), reported here, the experimental setup was further improved by installing a rotatable sample changer with six positions for SiN stacks of 16 x 10 mm^2 area each for SiN absorber stacks directly in front of the CLTDs. Such a modification was intended to optimize the setup with respect to transmission, resolution and flexibility for measurements in different mass and energy ranges. The design of the new system is displayed in Fig. 1. During a measuring period of about 4 weeks we investigated fragment yields in various fragment mass regions for the fissioning systems $^{235}U(n_{th},f)$, $^{239}Pu(n_{th},f)$ and $^{241}Pu(n_{th},f)$. In the following the current status of data analysis is briefly summarized :

As a first topic, we have gained first LOHENGRIN data on the isotopic yields in the light-mass group of ^{241}Pu fission, for A = 89 to 112. Fragments from $^{241}Pu(n_{th},f)$ were previously studied, for A = 91 to 110, at the ILL by time-of-flight mass spectrometry with the aid of the Cosi-Fan-Tutte spectrometer [5], but no experimental values on isotopic yields were communicated, except for data at Z = 39, 41 and 43 given as graphs. In our experiment, due to the fast target burn-up, for the overwhelming number of masses the FF fractional yields were measured at only two E values at one q state. For these measurements, we intentionally accepted inferior Z resolution using 4 µm of absorber thickness, with the aim of getting residual E spectra being widely free from contaminating masses. The element yield distributions Y(Z) deduced from the two experiments are in good agreement in view of the different experimental approaches applied.

A second topic was the study of light-fragment yields towards mass symmetry. The data on $^{241}Pu(n_{th},f)$ were extended to the range A = 110 to 112, and for ^{239}Pu (n_{th},f) known data by Schmitt et al. [6] were supplemented at A = 110 to 113. The investigation of isotopic yields for A ≥ 109 permits to elucidate how the local proton odd-even effect in the light fragments develops towards mass symmetry, which is of high interest for the nuclear model description near scission [7,8]. We observe a sharp rise in the so-called charge polarization ΔZ for Z = 44 at A > 110 attributed to stabilization by the closed shell Z = 50 in the correlated heavy fragments. The present data on $^{239}Pu(n_{th},f)$ make the situation even clearer, where Z = 44 dominates ΔZ for A up to 111.

A further issue were precise measurements for masses A = 92 and 96, performed for several ionic charges and 5 energies. The isotopic fission yields of ^{92}Rb and ^{96}Y from $^{235}U(n_{th},f)$, $^{239}Pu(n_{th}, f)$ and $^{241}Pu(n_{th}, f)$ were of particular interest, since more precise data were requested recently for achieving a better understanding of the reactor antineutrino spectrum [9,10]. The decay of these isotopes is a main contributor to the integral antineutrino spectra above 4 MeV that are important for the quantification of the so-called antineutrino anomaly and the postulation of sterile neutrinos.

A final topical issue was to elaborate our novel technology for the determination of fractional independent yields in the heavy fragment group for selected masses in $^{239}Pu(n_{th},f)$. Due to their principle of operation, CLTDs are predestined for the spectroscopy of heavy ions at low energies [12-14] and, therefore, an ideal option for measuring heavy fission fragments after degradation of a large proportion of kinetic energy. Furthermore, as preceding test measurements at the tandem accelerator at the MLL Garching with stable ^{130}Te and ^{127}I ion beams [1] revealed, SiN degraders compare favourably to formerly used Parylene C with respect to the energy-loss straggling and, thus, Z resolving power. Residual energy peaks revealed improved resolution but an increasing asymmetry in the line profile at larger degrader thicknesses, which could be well represented by a convolution of an exponential low-energy tail with a Gaussian distribution [15]. Due to these studies we have chosen a stack of 6 µm thickness for the LOHENGRIN measurements. For the heavy fragments, the obtained Z-resolution did not permit to fully resolve individual peaks in the residual energy spectra, but to reliably retrieve fractional isotopic yields by constrained fitting of the overlapping peaks. This method is well established in high-precision mass spectrometry [16]. We measured between 6×10^3 and 1.3×10^4 events per mass, for masses from 128 to 137 at 80 MeV, 128 to 133 at 88 MeV and 133 and 139 at 72 MeV, and one q state between 23 and 24. Isotopic yields for heavy masses A ≤ 132 were only sparsely measured in the past, mainly by radiochemical methods [17]. Figure 2 shows, as example, the fit results for A = 128 to 130 at 88 MeV, assuming up to three Z constituents, with reduced χ^2/N in the order of unity. The increasing dominance of the magic proton shell Z = 50 towards symmetry is obvious.

The comparison of our data for 128 ≤ A ≤ 137 with Jeff 3.1.1 proves our Z assignment to be correct, with the difference in the mass distributions for the various charges attributed to the increasing even-odd effects with kinetic energies. For the ^{239}Pu target we can also build on recent independent isotopic yields measured at LOHENGRIN with the aid of γ-ray spectrometry [18]. There is reasonable agreement for A = 133,134 and 136,137 where there are competitive results.

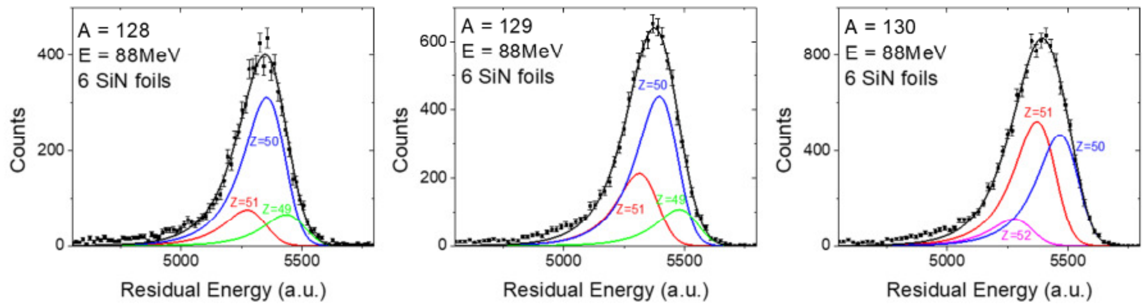

Fig. 2. Residual energy spectra of heavy-fragment masses at 88 MeV energy in $^{239}Pu(n_{th}, f)$ penetrating 6 µm of SiN degrader, from A = 128 to A = 130, with their individual Z constituents. The asymmetric peak profile was determined in a calibration measurement with stable ions (see text).

We are proud of stating that with our novel technology we were able to measure fractional independent fragment yields for the first time at LOHENGRIN by the passive absorber method also in the heavy mass group of fission fragments. We finally believe that our approach of deducing isotopic fission fragment yields with applying CLTDs and SiN degraders still provides a wide scope for further improvements both, from a methodical and technological point of view.

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