ENERGY DISTRIBUTIONS AND YIELDS OF ^3H , ^4He AND ^6He -PARTICLES EMITTED IN THE $^{245}\text{Cm}(\text{n}_{\text{th}},\text{f})$ REACTION

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The energy distributions and yields of light charged particles emitted during thermal neutron induced fission of ^{245}Cm have been measured at the high flux reactor of the Institute Laue-Langevin in Grenoble (France).

The detection of the ternary particles was done using a ΔE -E telescope, permitting a good separation of the ternary particles. In this way, the characteristics of the energy distribution (average energy and full width at half maximum) for ^4He , ^3H and ^6He particles as well as their emission probabilities could be determined. For the emission probabilities per fission, the following values were obtained: $\text{LRA/B} = (2.15 \pm 0.05) \times 10^{-3}$; $^3\text{H/B} = (1.85 \pm 0.10) \times 10^{-4}$ and $^6\text{He/B} = (4.95 \pm 1.25) \times 10^{-5}$.

Figure 1. Schematic view of the experimental setup used for the detection of Ternary Particles (TP). SBD= Surface Barrier Detector.

1 Introduction

Roughly 2-3 times per 1000 fission events, the two heavy fission fragments are accompanied by a light charged particle. These Ternary Particles (TP) are mainly α 's and tritons and they constitute an important source of helium and tritium production in nuclear reactors. Data concerning this production are therefore requested by nuclear industry [1]. They are also interesting for nuclear physics in order to improve our understanding of the ternary particle emission and to deduce information related to the fission process itself.

In this paper, we describe a new measurement performed on the thermal neutron induced fission of ^{245}Cm . After a description of the experimental setup, the analysis and results concerning Long Range Alpha-particles (LRA), tritons (t) and ^6He -ternary particles are reported.

2 Experimental setup

Neutron source

The $^{245}\text{Cm}(n_{th},f)$ measurement has been performed at the PF1 cold neutron guide installed at the Institute-Laue Langevin (Grenoble, France). The neutron flux at the sample position is about 5×10^9 neutrons/cm²s with an average energy of 11 meV.

Sample characteristics

The Cm sample was prepared at the Institute of Nuclear Chemistry of Mainz

University (Germany). A spot curium oxide with a diameter of 4 mm was deposited on a Ti-foil using the electrodeposition technique. Isotopic composition and layer thickness were determined via α -counting, yielding: $(15.39 \pm 1.54) \mu\text{g}$ of ^{245}Cm and $(0.56 \pm 0.06) \mu\text{g}$ of ^{244}Cm . Due to the low thermal fission cross section of ^{244}Cm (1.2 b) compared to the one of ^{245}Cm (2200 b), the neutron induced fission contribution from ^{244}Cm can be neglected. The same is true for the $^{244}\text{Cm}(\text{sf})$ contribution, which was verified during a background measurement with the neutron beam closed.

Detection system

The measurement is performed in two separate steps. In the first one, ternary particles are detected allowing the determination of both energy distributions and counting rates. In a second step, binary fission events are detected yielding the Binary fission counting rate (B). Combining both steps and making the ratio of both counting rates allows the determination of the ternary particle emission probabilities.

1. For the first step, a ΔE -E telescope (placed outside the neutron beam) was viewing the sample as shown in Fig.1. It consists of two silicon surface barrier detectors with an active area of 300 mm^2 (for ΔE) and 450 mm^2 (for E) and a depletion depth of $50 \mu\text{m}$ (for ΔE) and $1500 \mu\text{m}$ (for E). These characteristics correspond to the best compromise found in order to detect simultaneously LRA-particles and tritons. In addition, the ΔE -detector was covered with a thin Al-foil ($30 \mu\text{m}$ thick) in order to stop both fission fragments and α -particles coming from the radioactive decay of the sample. Then, a coincidence between the ΔE -signal (proportional to the energy deposited by the ternary particle traversing the silicon) and the E-signal (proportional to the remaining ternary particle energy) was imposed. These coincident signals were hence digitised and stored in a PC.
2. For the second step, the Al-foil was removed and the ΔE -detector replaced by a ring with exactly the same geometric shape. In this way, binary fission fragments could be measured (with the E-detector) under the same geometry as for ternary particles detection.

Calibration

The energy calibration of both detectors was done using the $^{10}\text{B}(\text{n}_{\text{th}},\alpha)^7\text{Li}$ and $^6\text{Li}(\text{n}_{\text{th}},\alpha)^3\text{H}$ reactions.

Figure 2. Typical example of the ΔE and E spectra obtained. The T/a spectrum is also plotted showing the good separation between ternary particles and background.

3 Analysis and results

Typical examples of the ΔE and E spectra are shown in Fig.2. The procedure used to identify ternary particles and separate them from the background was the one proposed by Goulding [4]. This method is based on the difference in energy loss of different particles in the same material (characterised by a specific constant a) leading to the simple relation $T/a = (E + \Delta E)^{1.73} - E^{1.73}$, where T is the effective thickness of the ΔE -detector. The T/a -spectrum is plotted on the bottom of Fig.2. It shows that a clear separation between ternary particles and background could be achieved. The selection of the

ternary particles was operated by putting a window on the region of interest of the T/a -spectrum. This has been done for LRA, tritons and ${}^6\text{He}$ -particles. Then, ΔE and E spectra corresponding to a given ternary particle could be obtained and the total energy distribution ($\Delta E + E + \delta E$, where δE is the calculated energy lost by the particle in the sample itself and the covering Al-foil) could be deduced.

These energy distributions are plotted in Fig.3. Note that the thresholds observed for each ternary particle are due to the thickness of our ΔE -detector as well as to the presence of the Al-foil. The average energy and the full width at half maximum of the energy distributions were obtained from a gaussian fit to the experimental data. For LRA-particles, in order to reduce the contribution of ${}^4\text{He}$ -particles coming from the disintegration of ternary ${}^5\text{He}$ -particles (see [3] for a detailed discussion of this point), the fit was performed from 13.5 MeV up to 40 MeV. For tritons, the gaussian fit started at 6 MeV, i.e, just above the threshold. For ${}^6\text{He}$ -particles the threshold is very high so the gaussian fit was done from 14 MeV, imposing an average energy of 12 MeV. The characteristics of these energy distributions are given in Tab.1, where the number of detected ternary particles and their emission probabilities are also mentioned. The uncertainties given correspond to the sum of statistical and systematic errors. From the emission probabilities, we calculated the following ratios: ${}^3\text{H}/{}^4\text{He} = (8.60 \pm 0.30) \%$ and ${}^6\text{He}/{}^4\text{He} = (2.30 \pm 0.58) \%$.

The LRA emission probability obtained in this work is in a good agreement with the measurement performed by Kozcon [5] who found $(2.00 \pm 0.45) \times 10^{-3}$. For other ternary particles, no absolute measurement is available. However, relative measurements were done at Lohengrin [6, 7]. Since the maximum electric field of Lohengrin limits the range accessible for measurements to $E/q < 6.5$ MeV, no complete energy distributions for ${}^3\text{H}$ and ${}^4\text{He}$ could be taken, and for the fit, the average energy had to be taken from systematics. So our present results could be used to determine the accurate yield of ${}^4\text{He}$, which commonly serves as a reference for the relative yields of heavier ternary particles. Anyhow, the preliminary value (assuming an average LRA energy of 15.8 MeV) of ${}^6\text{He}/{}^4\text{He} = (2.86 \pm 0.24) \%$ reported by Köster [6] agrees with our data. If we adopt the same average energy for the ${}^6\text{He}$ -particles as Köster [6], i.e. 11.3 MeV, we obtain a ${}^6\text{He}/{}^4\text{He}$ ratio of 2.67 % but the Gaussian distribution deviates too much from zero counts at $E = 0$.

The value obtained in this work for the triton-emission probability follows

Figure 3. LRA (top), triton (middle) and ^6He energy distributions. The Gaussian fits were performed from 13.5 MeV (for LRA-particles), 6 MeV (for tritons) and 14 MeV (for ^6He -particles).

very well the systematic behaviour described in [3], giving confidence in this result. Lastly, concerning the ^6He -characteristics, our result is compatible with the ones obtained for neighbouring thermal neutron induced reactions [2].

Table 1. Survey of the LRA, triton and ${}^6\text{He}$ characteristics.

	Particles detected	$\langle E \rangle$ (MeV)	FWHM (MeV)	Emission probability
LRA	363225	16.35 ± 0.10	10.10 ± 0.10	$(2.15 \pm 0.05) \times 10^{-3}$
Triton	28192	8.4 ± 0.2	7.76 ± 0.10	$(1.85 \pm 0.10) \times 10^{-4}$
${}^6\text{He}$	4073	12 (fixed)	10.08 ± 1.08	$(4.95 \pm 1.25) \times 10^{-5}$

Conclusion

In the present paper, the main characteristics (energy distribution and emission probability) of LRA, triton and ${}^6\text{He}$ particles emitted in the thermal neutron induced ternary fission of ${}^{245}\text{Cm}$ are presented. In particular, we obtain a ratio between triton and LRA emission probability of $(8.60 \pm 0.30) \%$ which confirms [8] that this ratio strongly varies depending on the fissioning nucleus.

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