# Experimental report

26/05/2025

**Proposal:** 3-17-70 **Council:** 4/2023

**Title:** Test of a compton camera (iTED) for Boron Neutron Capture Therapy

**Research area:** Methods and instrumentation

**This proposal is a new proposal**


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**Samples:**

| Instrument | Requested days | Allocated days | From | To |
|---|---|---|---|---|
| FIPPS | 5 | 5 | 26/10/2023 | 31/10/2023 |


**Abstract:**

In this proposal we aim at a comparative study between ¿conventional¿ PGAA using FIPPS versus medium-resolution Compton-imaging aided analysis using i-TED. To this aim, a detection-sensitivity characterization of both systems will be carried out using different B-10 samples and, afterwards, cells previously treated with BPA will be measured. This test is expected to provide important insight on the ability and performance of the i-TED imaging system for Boron Neutron Capture Therapy (BNCT) in a realistic situation, where a neutron beam is irradiating a biological sample previously loaded with boron. It will provide data on the boron uptake of the tumor cells that are being used for radiobiological measurements at PF1b for the Ph.D. thesis of the ILL Ph.D. student Patricia Alvarez Rodriguez.

| | |
|---|---|
| **Experiment:** 3-17-70 ILL Location: H22<br>Experiment dates: 25-31 October 2023 Report date: 26 May 2025 | |
| **Title:** Test of a Compton camera (iTED) for Boron Neutron Capture Therapy | |
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**Materials & Methods:**

In order to simultaneously measure each sample both with the FIPPS array of HPGe clover detectors and with the Compton camera, one of the HPGe was removed from the set-up, and the camera was inserted at about 45º and 10 cm distance from the sample location.

**Reference sample measurements for imaging tests**

502 ug $^{10}$B sample for Compton imaging tests and verification

A relatively large sample containing 502ug of $^{10}$B was placed in the sample holder and irradiated with the beam for about 30 minutes. The results of this test are shown below in Fig.1. The spectra shown in the figure correspond to the $^{10}$B sample (blue). The red spectrum shows the result of a background sample containing only fructose (assumed to be equivalent to the previous sample but without 10B), and the green spectrum corresponds to the background measured without neutron beam.

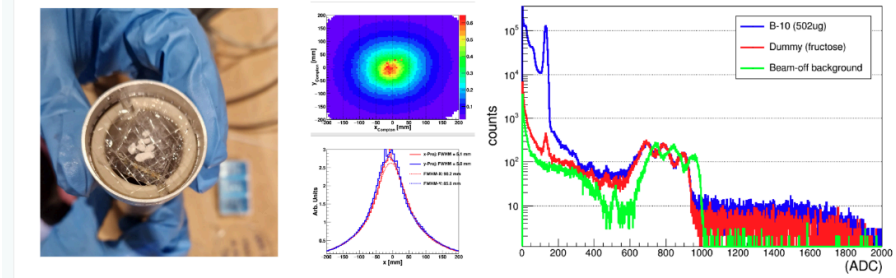


Fig.1: 500ug $^{10}$B sample distributed in small solidified droplets inside a sealed film (left). Compton image reconstructed for 478 keV gamma-rays (middle) and pulse-height spectrum for the $^{10}$B sample (blue), background of a sample without $^{10}$B (red) and without beam (green). The high-energy triple-peak is due to the intrinsic activity of the $LaCl_3$(Ce) crystals used in the gamma-ray camera.

The signature of prompt 478 keV gamma-rays arising from the de-excitation of $^{7}$Li formed in the $^{10}$B(n,a)$^{7}$Li reaction is clearly visible in the spectrum measured with the camera (blue line in Fig.3). With an energy selection on these 478 keV events the corresponding Compton image was reconstructed, as shown in the middle diagrams of Fig.1. Details on the reconstruction algorithm can be found e.g. in [Balibrea22]. A small amount of contaminant neutron-captures in $^{10}$B can still be observed in the (red) background spectrum, which nevertheless corresponds to more than two orders of magnitude difference in intensity.

**Calibration and biological sample measurements**

A sensitivity study was done with different amounts of B-10 ranging from 100 ng up to 100 µg. For this purpose, BPA-fructose was dissolved in water with a final B-10 concentration of 3 mg/mL. Then, from this stock, serial dilutions were prepared in order to work with high volumes for the smallest quantities of B-10. Finally, the respective volumes for each quantity of B-10 were placed in Teflon bags, left to dry and sealed.

On the other hand, the biological samples consisted of three different types of cancer cells:

- Cal33: tongue squamous cell carcinoma
- A375: malignant melanoma
- A172: glioblastoma

To prepare the samples, each cell type was exposed for 4 hours to the compound BPA at a final $^{10}B$ concentration of 80 ppm. After incubation, cells were collected, counted and seeded in Teflon bags. Once the cells were completely dry, the bags were sealed for measurement.

As a control, the same procedure was followed with cells that were not exposed to any compound.

| Label | Number | Run No. |
|---|---|---|
| A172 + BPA (I) | 1.40250E+07 | Run23 |
| A172 + BPA (II) | 5.92000E+06 | Run17-18 |
| A375 + BPA (I) | 1.83950E+07 | Run15-16 |
| A375 + BPA Teflon (II) | 1.11200E+07 | Run21 |
| K33+BPA (I) | 1.74E+07 | Run19-20 |
| K33+BPA (II) | 1.61E+07 | Run24 |
| K33 (no BPA) | 1.87E+07 | Run22 |

Table 1: samples of different cancer-cell lines (first column) together with the number of cells (middle column) and the run number in the experiment (last column).

Preliminary results for the sensitivity study with the HPGe FIPPS array are shown below in Fig.2. Three different background levels (dashed lines) were determined for the different cell lines or samples utilizing “dummy” samples without $^{10}B$ content. The calibration (non biological) samples (solid-blue circles) measured with FIPPS are rather linear at low concentrations, from 1 ug up to 2 ug. At higher concentrations, for about 10 ug, the linearity of the HPGe measurement decreases, a feature which is expected from possible dead-time and pile-up effects in the detectors.

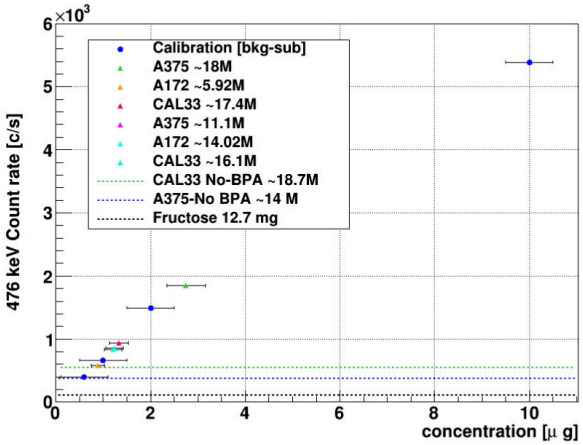


Fig. 2 Count-rate measured with FIPPS as a function of the $^{10}B$ concentration in different biological samples with different $^{10}B$ content.

The count-rates measured for the biological samples of A375, A172 and CAL33, are drawn in Fig.2 on top of the calibration curve (solid-blue circles). Thus, one can determine rather accurately the $^{10}B$ concentration (x-axis in Fig.2) for each specific sample or measurement. The thus obtained $^{10}B$ concentrations scale reasonably well with the amount of cells in each sample.

Preliminary results for the measurements taken with the Compton camera are shown below, in this case as a function of the run id. The calibration runs for 600 ng, 1 ug and 10 ug of $^{10}B$ content indicate a detection sensitivity of about 1ug for the measurements made with the Compton camera.

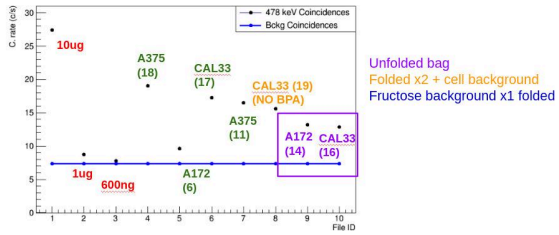


Fig. 3 Sensitivity study performed with the Compton camera for both calibration and biological samples.

For the biological samples, the count rate obtained with the Camera follows a similar behavior as the one obtained with FIPPS, essentially varying with the number of cells in each sample.

**Summary and outlook**

The experiment presented herein was carried out at ILLGrenoble using the very high thermal neutron flux of 5·107n/cm2 /s and using the FIPPS instrument as reference. One of the i-TED Compton imagers was embedded in the FIPPS HPGe array and both setups were run in parallel to detect the 478 keV γ-rays originated in 10B(n,α) 7Li in BPA samples with known 10B content and tumoral cell samples (CAL33, A172, A375) treated with BPA (80 ppm 10B). The results show that, in the low-background conditions of the FIPPS setup, i-TED is sensitive enough to measure 10B concentrations ≤1 μg and is capable to determine absolute 10B concentrations in cell samples, obtaining consistent results to the high-sensitivity FIPPS array. These results make i-TED a promising non-destructive tool for pre-clinical in-vitro studies and open the door to future online dosimetry in clinical treatment. Last, this work represents the first experimental demonstration of the Compton imaging performance of i-TED for 478 keV γ-rays. 2D Compton images of cell samples of few μg have been reconstructed, despite the presence of boron-related background.

**Publications directly related to the outcomes of this experiment:**

**Title:** “First Pilot Tests of Compton Imaging and Boron Concentration Measurements in BNCT Using i-TED”

**Authors:** J. Lerendegui-Marco, J. Balibrea-Correa, P. Álvarez-Rodríguez, V. Babiano-Suárez, B. Gameiro, I. Ladarescu, C. Méndez-Malagón, C. Michelagnoli, I. Porras, M. Porras-Quesada, C. Ruiz-Ruiz, P. Torres-Sánchez, C. Domingo-Pardo

**Journal:** Applied Radiation and Isotopes (in publication process)

**LInk:** https://doi.org/10.48550/arXiv.2409.05687