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# Collection of medium-resolution gamma spectra of certified Pu reference materials

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Artur Mühleisen
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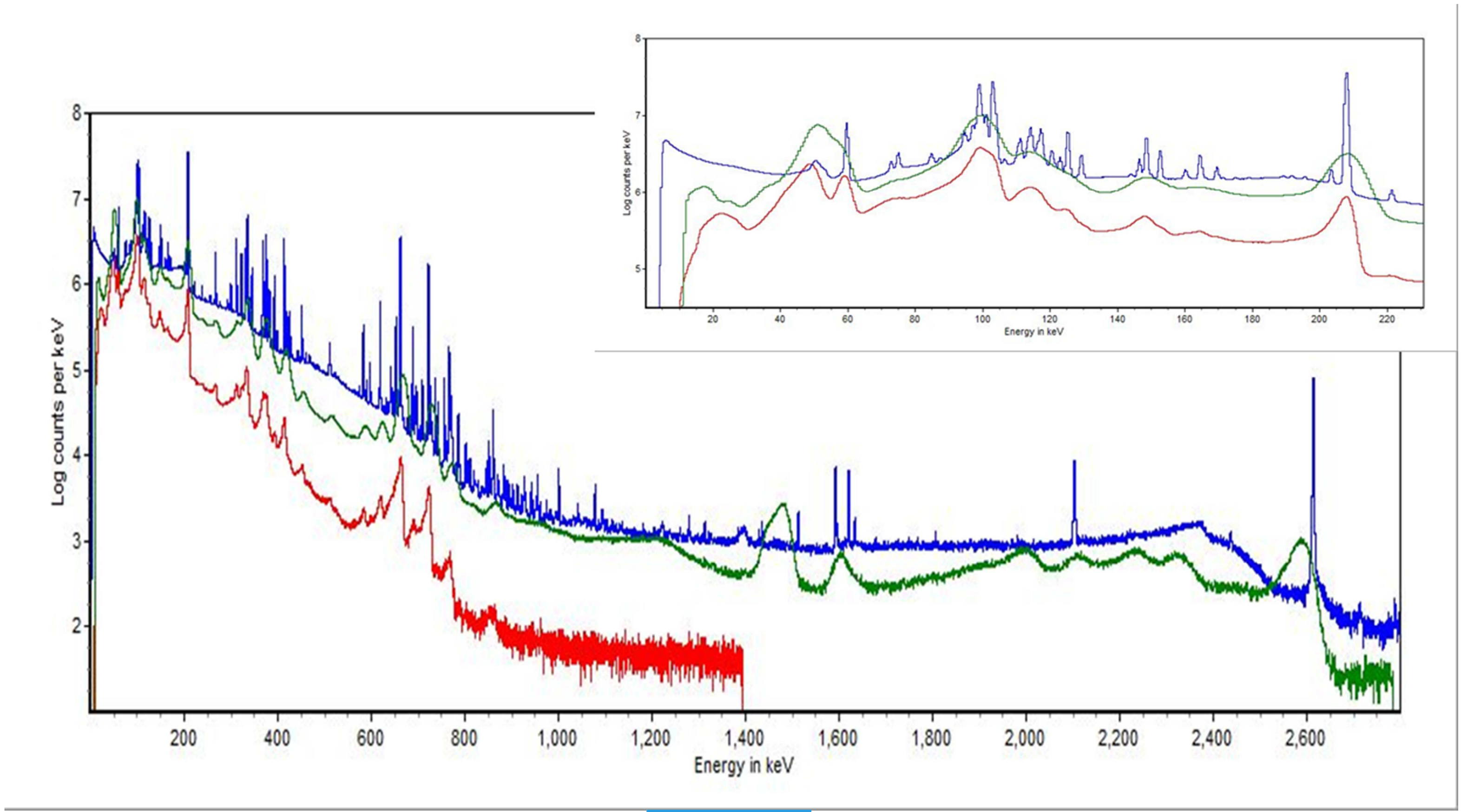


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Joint Research Centre

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Spectra of CBNM Pu61 reference sample measured by HPGe, CZT and $LaBr_3$ detectors.

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# Abstract

A collection of medium resolution gamma-ray spectra from well-characterized Pu certified reference materials has been recorded using $LaBr_3$(Ce) (2.0″ x 0.5″) and CZT (500 $mm^3$) detectors. Aiming to acquire the highest quality reference data, the spectra were measured for long acquisition times, ensuring very good counting statistics across potentially useful spectral intervals - up to 1.4 MeV for the CZT and up to 2.8 MeV for the $LaBr_3$(Ce) detector. The experimental setup assures that the measurement geometry is stable and reproducible, and that the spectra have minimum influence from background radiation and pile-up effects. The spectra are available at the data library of The international working group on gamma spectroscopy techniques for U and Pu isotopics. They feed phase I of the Pu isotopic inter-comparison exercise jointly organized by the ESARDA NDA Working Group and IAEA.

## 1. Introduction

Medium resolution gamma detectors are becoming widely used for (in-field) nuclear safeguards related measurements. Such detectors do not have to be cooled, so they have obvious benefits for in-field applications, like portability and easy maintenance. There still seems to be room for (further) development of medium resolution spectra analysis software and of applications for such detectors. High quality spectra are needed for testing and development.

This report describes collecting a set of high-quality reference medium-resolution gamma-spectra of Pu certified reference materials with CZT and $LaBr_3$ detectors in well-controlled conditions. The collection of analogous spectra of U reference materials is described in JRC technical report 98340 (Ref. 1). This work has been performed as part of IAEA support project JNT A 01684 EC on Sustainability and Maintenance of Software for Pu-isotopics and U-enrichment. The spectra will be used within the international exercise on medium-resolution gamma spectrometry as reference spectra for gamma-ray analysis code developers for testing their codes.

## 2. Experimental setup for Pu measurements

The spectra have been measured at the Institute for Transuranium Elemets (ITU) using equipment (detectors, electronics) provided by the IAEA. This equipment consisted of Ritec CZT 500S large volume hemispherical detector (500 $mm^3$, no. 427), Saint Gobain Crystals $LaBr_3$:Ce detector (2"x0.5", mod. 51sea13, S/N 2301 with PM R6231-100-01), absorbers (3mm steel and 1mm Cd), Canberra InSpector 2000 electronics and netbooks with installed corresponding GENIE2000 software. The recorded spectra had 4096 channels with energy range up to 2.8 MeV for $LaBr_3$ and 1.4 MeV for CZT detector. The electronics has been set up accordingly.

A shielded experimental setup with well-defined geometry has been set for the gamma-spectrometric measurements in a hot lab in ITU. The shield consists of 5 cm Pb and 2 mm of Cu. Mechanical setups for holding the Plutonium samples at a fixed distance above the $LaBr_3$ and CZT detectors have been manufactured in the ITU workshop. The setups allow for introduction of absorbers of different thicknesses between the source and the detector without affecting the source-to-detector distance. The distances between elements of the experimental setup and the thicknesses of materials are presented in Table 1. PMMA there stands for poly(methyl methacrylate) ("plexiglass") with chemical composition $(C_5O_2H_8)_n$. The sample-to-detector distances are distances between the top of the detector and the lowest point of the sample's encapsulation. The sample holder plates had a round engraving at their middle to facilitate centered sample positioning on the detector axis.

**Table 1: Setup distances and the thicknesses of materials (*PMMA="plexiglass").**

| Detector | Distances (mm) from the detector | | | Total thickness of material (mm) | | | |
|---|---|---|---|---|---|---|---|
| | Steel filter | Cd filter | Sample | Cd | Steel | PMMA* | Air |
| **CZT** | - | 6 | 60 | 1 | 0 | 22 | 37 |
| | 6 | 9 | 100 | 1 | 3 | 22 | 74 |
| **$LaBr_3$** | - | 5 | 200 | 1 | 0 | 21 | 178 |
| | 5 | 8 | 300 | 1 | 3 | 21 | 275 |

Figures 1 and 2 show the dimensions relevant to the gamma spectrometric measurement. Fig. 3 presents the photo of the experimental setup for CZT detector and Pu samples. Fig. 4 presents the Pu LaBr3 setup. Here the detector that is outside the experimental box is inside a cylinder with 1 cm Pb and 3 mm Cu shield.

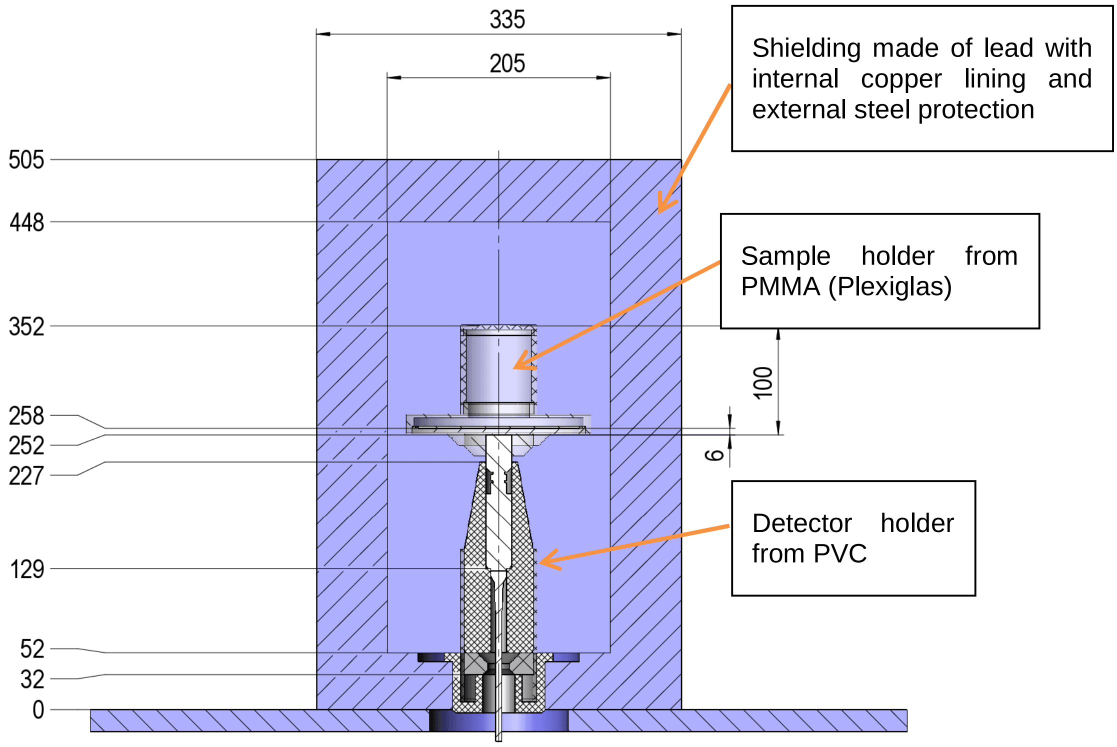



**Figure 1: Experimental setup for the CZT detector inside lead shielding. The configuration for measurements at 100 mm sample-to-detector distance is shown.**

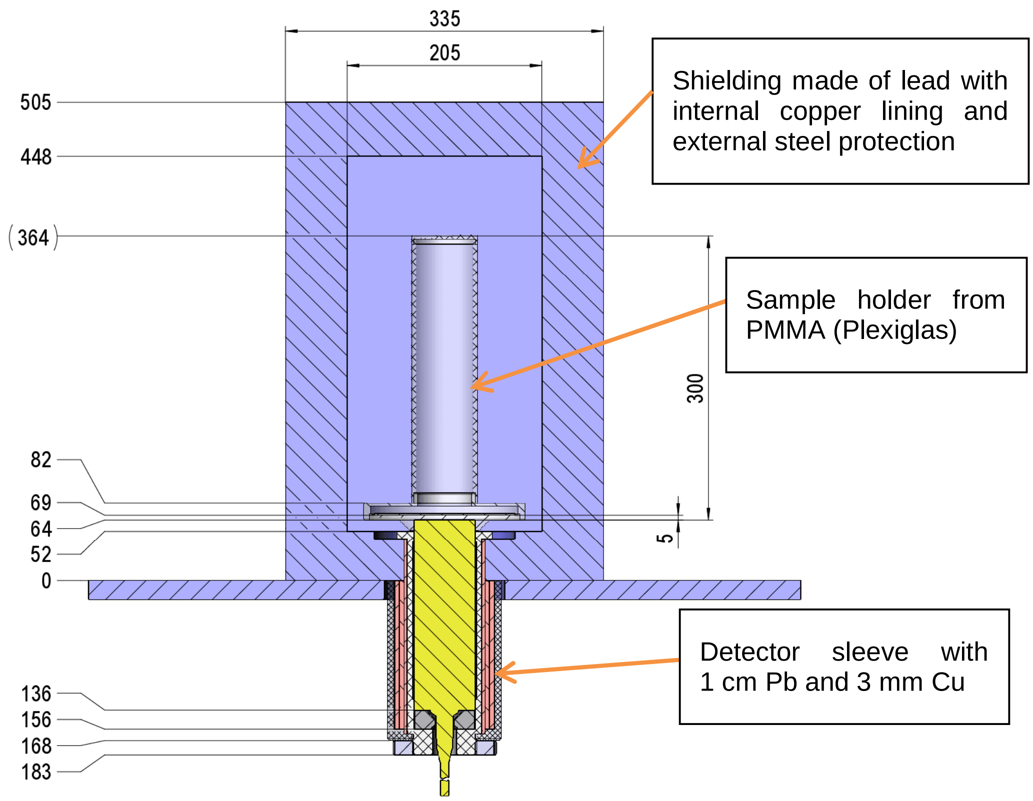
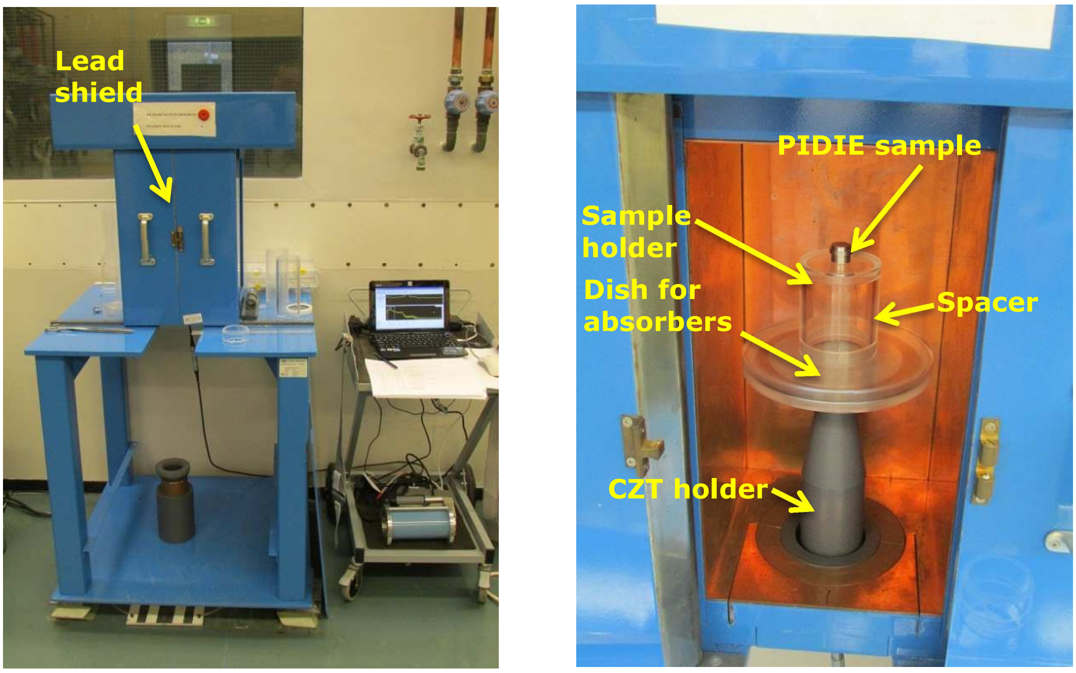
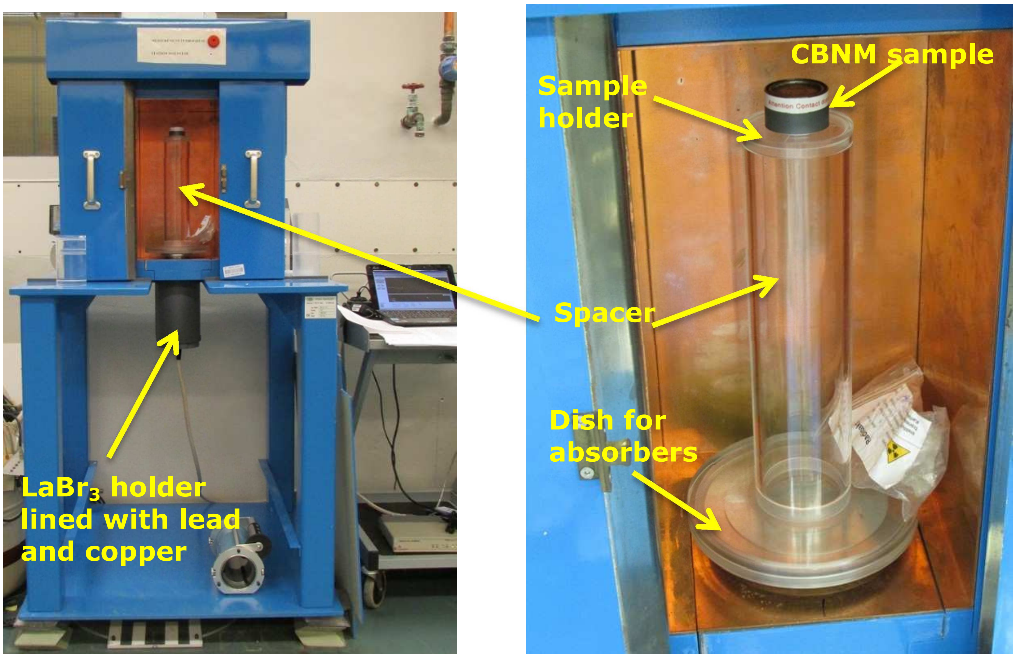



**Figure 2: Experimental setup for the LaBr3 detector inside lead shielding. The configuration for measurements at 300 mm sample-to-detector distance is shown.**




a) b)

**Figure 3: a) Closed shield with CZT detector inside. b) Interior of the shield with the CZT detector and a PIDIE sample above it.**




a) b)

**Figure 4: a) Open shield with LaBr3 detector. b) Interior of the shield with CBNM sample above the LaBr3 detector.**

# 3. Pu reference materials

The reference materials measured have been PIDIE-1, 3, 5 and 7 (described in Refs. 2-4) and items Pu-61, 70, 84 and 93 from the CBNM Nuclear Reference Material set "271" (described in Refs. 5-6).

The PIDIE samples consist of ca. 0.425g Pu each in the form of a $PuO_2$ pressed pellet encapsulated in a welded steel container. The measured samples are from set number 4. The samples have been manufactured specifically for inter-comparison of the measurement capabilities of gamma spectrometry (Ref 3). The results of accompanying destructive analyses performed during the exercise are presented in Ref. 3. Unfortunately the exact mass of the pellets has not been recorded (Ref. 4). Isotopic composition of PIDIE samples based on data from Appendix A in Ref. 3, recalculated to weight % and renormalized to total Pu is presented in Table 2. The samples' drawing is presented in Figure 5.

**Table 2: Isotopic composition of PIDIE samples in weight % (normalized to sum of Pu isotopes) with 2s absolute uncertainty for reference date 1.1.1988.**

| Reference sample | | Isotope | | | | | |
|---|---|---|---|---|---|---|---|
| | | $^{238}Pu$ | $^{239}Pu$ | $^{240}Pu$ | $^{241}Pu$ | $^{242}Pu$ | $^{241}Am$ |
| PIDIE 1 | weight % | 0.01101 | 93.7650 | 5.99025 | 0.19920 | 0.0346 | 0.2304 |
| | 2s | 0.00033 | 0.0065 | 0.0052 | 0.00255 | 0.0015 | 0.0060 |
| PIDIE 3 | weight % | 0.04716 | 84.5795 | 14.1442 | 0.9953 | 0.2338 | 0.6282 |
| | 2s | 0.00038 | 0.0094 | 0.0052 | 0.0036 | 0.0075 | 0.0151 |
| PIDIE 5 | weight % | 0.1314 | 75.8862 | 21.2169 | 2.0638 | 0.7017 | 1.7488 |
| | 2s | 0.0011 | 0.0147 | 0.0115 | 0.0042 | 0.0015 | 0.0387 |
| PIDIE 7 | weight % | 1.253 | 61.9848 | 25.5941 | 6.4919 | 4.6763 | 3.5287 |
| | 2s | 0.016 | 0.0420 | 0.0195 | 0.0132 | 0.0081 | 0.1111 |

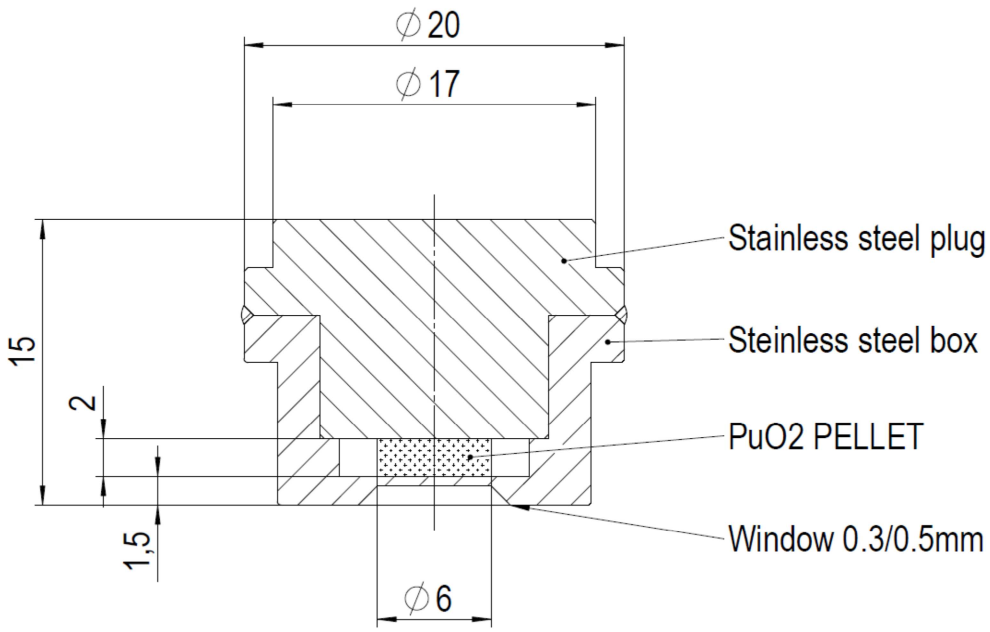



**Figure 5: Drawing of a PIDIE sample (reproduced based on Ref. 3).**

The CBNM Nuclear Reference Material "271" (Refs. 5 and 6) has been produced by Central Bureau for Nuclear Measurements of EC JRC. It consists of four plutonium oxide sintered pellets encased in stainless steel and protected by a plastic cap. Each pellet contains 6.65±0.06 g of $PuO_2$. The protective cap has been left on during the measurements. Plastic cap has a thickness of 2 mm, in addition there is a ca. 1mm air gap between the plastic and the metallic bottom of the sample (overall height of the sample is 24.1±0.1 mm). The samples' drawing and description are also presented in Refs. 5-6. The reference sample Pu93 is from set no. 0/10 and the reference samples Pu61, Pu70 and Pu84 are from set no. 0/12. The isotopic composition of the reference samples as in Ref. 5 is for convenience presented in Table 3 and the samples' drawing in Figure 6.

**Table 3: Isotopic composition of CBNM standard's reference samples in weight % with 2s absolute uncertainty and reference date 20.6.1986.**

| Reference sample | | Isotope | | | | | |
|---|---|---|---|---|---|---|---|
| | | $^{238}Pu$ | $^{239}Pu$ | $^{240}Pu$ | $^{241}Pu$ | $^{242}Pu$ | $^{241}Am$ |
| CBNM Pu93 | weight % | 0.0117 | 93.4123 | 6.3131 | 0.2235 | 0.0395 | 0.1047 |
| | 2s | 0.00003 | 0.004 | 0.0039 | 0.0004 | 0.0003 | 0.0021 |
| CBNM Pu84 | weight % | 0.0703 | 84.3377 | 14.2069 | 1.0275 | 0.3576 | 0.2173 |
| | 2s | 0.0006 | 0.0084 | 0.0085 | 0.0018 | 0.001 | 0.0022 |
| CBNM Pu70 | weight % | 0.8458 | 73.3191 | 18.2945 | 5.4634 | 2.0772 | 1.1705 |
| | 2s | 0.0018 | 0.0098 | 0.0087 | 0.0034 | 0.0023 | 0.0117 |
| CBNM Pu61 | weight % | 1.1969 | 62.5255 | 25.4058 | 6.6793 | 4.1925 | 1.4452 |
| | 2s | 0.0025 | 0.0283 | 0.0241 | 0.0087 | 0.0064 | 0.0144 |

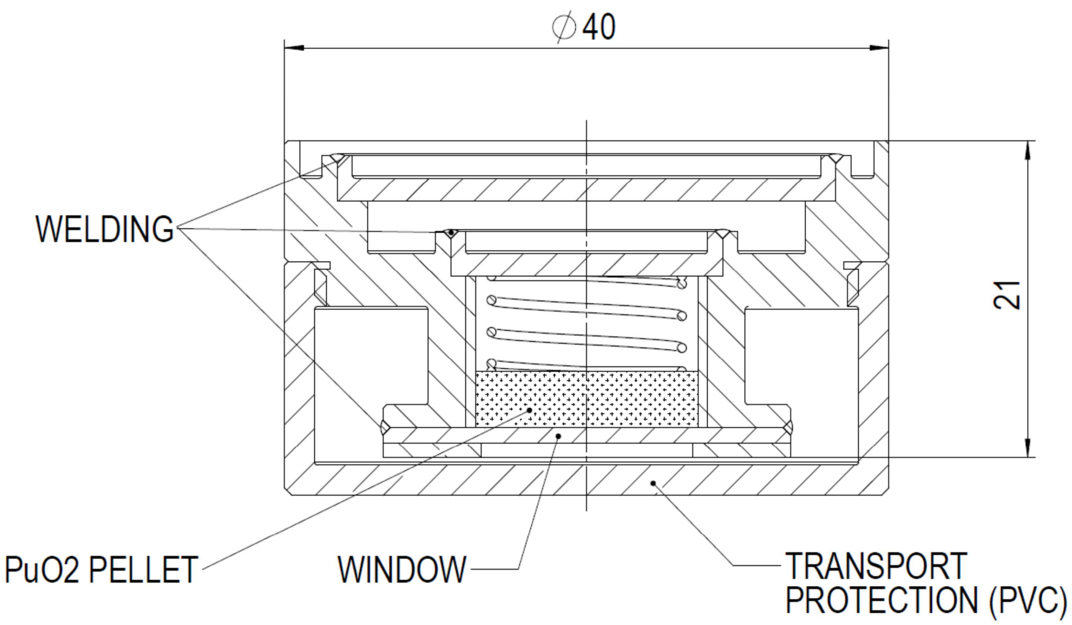



**Figure 6: Drawing of a CBNM reference sample (reproduced based on Ref. 6).**

# 4. Measurements and experimental conditions

Five spectra of each reference sample with 100.000s live time per spectrum have been recorded with each detector. An overview of the measurements is presented in Table 4.

The lab in which the measurements were performed had a slightly elevated temperature (around 28 degrees) that was not very stable. This might have affected stability of the measurements (energy scale) and resolution of the spectra (especially spectra measured with $LaBr_3$ detector). Fine gain of $LaBr_3$ detector had to be corrected sometimes to maintain the same energy scale (when the drift caused 208 keV peak to move for more than 1-2 channels the fine gain has been adjusted). Automatic energy scale stabilization was not used.

**Table 4: Overview of the measurements (X indicates that a series of measurements has been performed for a given detector, distance (d) and absorbers (s)).**

| | | **CZT detector** | | **$LaBr_3$ detector** | |
|---|---|---|---|---|---|
| **Reference material** | Approx. $^{239}$Pu | d=100mm | d=60mm | d=300mm | d=200mm |
| | [%] | s: 1mm Cd + 3mm Fe | s: 1mm Cd | s: 1mm Cd + 3mm Fe | s: 1mm Cd |
| CBNM Pu61 | 61 | **X** | - | **X** | - |
| CBNM Pu70 | 70 | **X** | - | **X** | - |
| CBNM Pu84 | 84 | - | **X** | - | **X** |
| CBNM Pu93 | 93 | - | **X** | - | **X** |
| PIDIE-1 | 94 | - | **X** | - | **X** |
| PIDIE-3 | 85 | - | **X** | - | **X** |
| PIDIE-5 | 76 | - | **X** | - | **X** |
| PIDIE-7 | 62 | **X** | - | **X** | - |

One of the two power supplies for the Inspector2000 provided by IAEA has developed a fault during the measurements (if used it gets really hot and is unable to provide stable power conditions for the $LaBr_3$ detector and its electronics). As the two power supplies provided by the IAEA are the same, the functioning one has been used for the measurements.

The above problems have not substantially affected the execution of the task. The list of spectra, attached to this report, provides names of the recorded spectra, dates of the measurements as well as data on absorbers and detector-to-sample distances used. The spectra, converted to Ortec CHN format, were introduced to the data library of The international working group on gamma spectroscopy techniques for U and Pu isotopics (Ref. 7).

## 5. Conclusion

High quality medium-resolution gamma spectra of Pu reference samples have been measured by CZT and $LaBr_3$ detectors. They will used as reference in phase I of the international exercise on medium resolution gamma spectrometry. All spectra are available at no charge via the data library of The international working group on gamma spectroscopy techniques for U and Pu isotopics (Ref. 7).

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## List of spectra

| Spectra of Pu standards recorded by CZT detector | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Meas. date | |
| Meas # | Sample | Replicate # | Distance, mm | Shield | LT, sec | DT, % | YYYY-MM-DD | Spectrum name |
| | | | | | | | | |
| 1 | Bkg-A | 1 | - | 1 mm Cd + 3 mm steel | 100000 | 0.00 | 2013-07-16 | CZT500_background_1mmCd_3mmSteel_01.cnf |
| | | | | | | | | |
| 2 | Pu-61 | 1 | 100 | 1 mm Cd + 3 mm steel | 100000 | 2.14 | 2013-07-17 | CZT500_Pu61_@100mm_1mmCd_3mmSteel_01.cnf |
| 3 | Pu-61 | 2 | 100 | 1 mm Cd + 3 mm steel | 100000 | 2.14 | 2013-07-18 | CZT500_Pu61_@100mm_1mmCd_3mmSteel_02.cnf |
| 4 | Pu-61 | 3 | 100 | 1 mm Cd + 3 mm steel | 100000 | 2.13 | 2013-07-22 | CZT500_Pu61_@100mm_1mmCd_3mmSteel_03.cnf |
| 5 | Pu-61 | 4 | 100 | 1 mm Cd + 3 mm steel | 100000 | 2.13 | 2013-07-23 | CZT500_Pu61_@100mm_1mmCd_3mmSteel_04.cnf |
| 6 | Pu-61 | 5 | 100 | 1 mm Cd + 3 mm steel | 100000 | 2.14 | 2013-07-25 | CZT500_Pu61_@100mm_1mmCd_3mmSteel_05.cnf |
| | | | | | | | | |
| 7 | Bkg-A | 2 | - | 1 mm Cd + 3 mm steel | 20000 | 0.00 | 2013-07-31 | CZT500_background_1mmCd_3mmSteel_02.cnf |
| | | | | | | | | |
| 8 | Pu-70 | 1 | 100 | 1 mm Cd + 3 mm steel | 100000 | 1.77 | 2013-08-01 | CZT500_Pu70_@100mm_1mmCd_3mmSteel_01.cnf |
| 9 | Pu-70 | 2 | 100 | 1 mm Cd + 3 mm steel | 100000 | 1.76 | 2013-08-02 | CZT500_Pu70_@100mm_1mmCd_3mmSteel_02.cnf |
| 10 | Pu-70 | 3 | 100 | 1 mm Cd + 3 mm steel | 100000 | 1.76 | 2013-08-05 | CZT500_Pu70_@100mm_1mmCd_3mmSteel_03.cnf |
| 11 | Pu-70 | 4 | 100 | 1 mm Cd + 3 mm steel | 100000 | 1.77 | 2013-08-07 | CZT500_Pu70_@100mm_1mmCd_3mmSteel_04.cnf |
| 12 | Pu-70 | 5 | 100 | 1 mm Cd + 3 mm steel | 100000 | 1.77 | 2013-08-08 | CZT500_Pu70_@100mm_1mmCd_3mmSteel_05.cnf |
| | | | | | | | | |
| 13 | Bkg-A | 3 | - | 1 mm Cd + 3 mm steel | 20000 | 0.00 | 2013-08-12 | CZT500_background_1mmCd_3mmSteel_03.cnf |
| | | | | | | | | |
| 14 | Bkg-B | 1 | - | 1 mm Cd | 100000 | 0.00 | 2013-08-12 | CZT500_background_@60mm_1mmCd_01.cnf |
| | | | | | | | | |
| 15 | Pu-84 | 1 | 60 | 1 mm Cd | 100000 | 2.22 | 2013-08-14 | CZT500_Pu84_@60mm_1mmCd_01.cnf |
| 16 | Pu-84 | 2 | 60 | 1 mm Cd | 80000 | 2.22 | 2013-08-15 | CZT500_Pu84_@60mm_1mmCd_02.cnf |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| 17 | Bkg-B | 2 | - | 1 mm Cd | 70000 | 0.00 | 2013-09-17 | CZT500_background_@60mm_1mmCd_02.cnf |
| | | | | | | | | |
| 18 | Pu-84 | 3 | 60 | 1 mm Cd | 100000 | 2.22 | 2013-09-18 | CZT500_Pu84_@60mm_1mmCd_03.cnf |
| 19 | Pu-84 | 4 | 60 | 1 mm Cd | 100000 | 2.22 | 2013-09-19 | CZT500_Pu84_@60mm_1mmCd_04.cnf |
| 20 | Pu-84 | 5 | 60 | 1 mm Cd | 100000 | 2.22 | 2013-09-23 | CZT500_Pu84_@60mm_1mmCd_05.cnf |
| | | | | | | | | |
| 21 | Bkg-B | 3 | - | 1 mm Cd | 20000 | 0.00 | 2013-09-25 | CZT500_background_@60mm_1mmCd_03.cnf |
| | | | | | | | | |
| 22 | Pu-93 | 1 | 60 | 1 mm Cd | 100000 | 1.24 | 2013-09-25 | CZT500_Pu93_@60mm_1mmCd_01.cnf |
| 23 | Pu-93 | 2 | 60 | 1 mm Cd | 100000 | 1.25 | 2013-09-27 | CZT500_Pu93_@60mm_1mmCd_02.cnf |
| 24 | Pu-93 | 3 | 60 | 1 mm Cd | 100000 | 1.25 | 2013-09-30 | CZT500_Pu93_@60mm_1mmCd_03.cnf |
| 25 | Pu-93 | 4 | 60 | 1 mm Cd | 100000 | 1.24 | 2013-10-02 | CZT500_Pu93_@60mm_1mmCd_04.cnf |
| 26 | Pu-93 | 5 | 60 | 1 mm Cd | 100000 | 1.24 | 2013-10-04 | CZT500_Pu93_@60mm_1mmCd_05.cnf |
| | | | | | | | | |
| 27 | Bkg-B | 4 | - | 1 mm Cd | 100000 | 0.00 | 2013-10-07 | CZT500_background_@60mm_1mmCd_04.cnf |
| | | | | | | | | |
| 28 | PIDIE-3 | 1 | 60 | 1 mm Cd | 100000 | 0.51 | 2013-10-09 | CZT500_PIDIE3_@60mm_1mmCd_01.cnf |
| 29 | PIDIE-3 | 2 | 60 | 1 mm Cd | 100000 | 0.51 | 2013-10-11 | CZT500_PIDIE3_@60mm_1mmCd_02.cnf |
| 30 | PIDIE-3 | 3 | 60 | 1 mm Cd | 100000 | 0.51 | 2013-10-14 | CZT500_PIDIE3_@60mm_1mmCd_03.cnf |
| 31 | PIDIE-3 | 4 | 60 | 1 mm Cd | 100000 | 0.51 | 2013-10-15 | CZT500_PIDIE3_@60mm_1mmCd_04.cnf |
| 32 | PIDIE-3 | 5 | 60 | 1 mm Cd | 100000 | 0.51 | 2013-10-17 | CZT500_PIDIE3_@60mm_1mmCd_05.cnf |
| 33 | PIDIE-3 | 6 | 60 | 1 mm Cd | 100000 | 0.51 | 2013-10-18 | CZT500_PIDIE3_@60mm_1mmCd_06.cnf |
| | | | | | | | | |
| 34 | Bkg-B | 5 | - | 1 mm Cd | 20000 | | 2013-10-21 | CZT500_background_@60mm_1mmCd_05.cnf |
| | | | | | | | | |
| 35 | PIDIE-5 | 1 | 60 | 1 mm Cd | 100000 | 1.15 | 2013-10-21 | CZT500_PIDIE5_@60mm_1mmCd_01.cnf |
| 36 | PIDIE-5 | 2 | 60 | 1 mm Cd | 100000 | 1.15 | 2013-10-23 | CZT500_PIDIE5_@60mm_1mmCd_02.cnf |
| 37 | PIDIE-5 | 3 | 60 | 1 mm Cd | 100000 | 1.16 | 2013-10-24 | CZT500_PIDIE5_@60mm_1mmCd_03.cnf |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 38 | PIDIE-5 | 4 | 60 | 1 mm Cd | 100000 | 1.16 | 2013-10-28 | CZT500_PIDIE5_@60mm_1mmCd_04.cnf |
| 39 | PIDIE-5 | 5 | 60 | 1 mm Cd | 100000 | 1.16 | 2013-10-29 | CZT500_PIDIE5_@60mm_1mmCd_05.cnf |
| | | | | | | | | |
| 40 | Bkg-B | 6 | - | 1 mm Cd | 100000 | | 2013-10-31 | CZT500_background_@60mm_1mmCd_06.cnf |
| | | | | | | | | |
| 41 | Bkg-A | 4 | - | 1 mm Cd + 3 mm steel | 20000 | 0.00 | 2013-11-14 | CZT500_background_1mmCd_3mmSteel_04.cnf |
| | | | | | | | | |
| 42 | PIDIE-7 | 1 | 100 | 1 mm Cd + 3 mm steel | 100000 | 0.45 | 2013-11-15 | CZT500_PIDIE7_@100mm_1mmCd_3mmSteel_01.cnf |
| 43 | PIDIE-7 | 2 | 100 | 1 mm Cd + 3 mm steel | 100000 | 0.45 | 2013-11-19 | CZT500_PIDIE7_@100mm_1mmCd_3mmSteel_02.cnf |
| 44 | PIDIE-7 | 3 | 100 | 1 mm Cd + 3 mm steel | 100000 | 0.45 | 2013-11-20 | CZT500_PIDIE7_@100mm_1mmCd_3mmSteel_03.cnf |
| 45 | PIDIE-7 | 4 | 100 | 1 mm Cd + 3 mm steel | 100000 | 0.45 | 2013-11-22 | CZT500_PIDIE7_@100mm_1mmCd_3mmSteel_04.cnf |
| 46 | PIDIE-7 | 5 | 100 | 1 mm Cd + 3 mm steel | 100000 | 0.45 | 2013-11-25 | CZT500_PIDIE7_@100mm_1mmCd_3mmSteel_05.cnf |
| | | | | | | | | |
| 47 | Bkg-A | 5 | - | 1 mm Cd + 3 mm steel | 100000 | 0.00 | 2013-11-26 | CZT500_background_1mmCd_3mmSteel_05.cnf |
| | | | | | | | | |
| 48 | PIDIE-1 | 1 | 60 | 1 mm Cd | 100000 | 0.21 | 2013-12-03 | CZT500_PIDIE1_@60mm_1mmCd_01.cnf |
| 49 | PIDIE-1 | 2 | 60 | 1 mm Cd | 100000 | 0.21 | 2013-12-04 | CZT500_PIDIE1_@60mm_1mmCd_02.cnf |
| 50 | PIDIE-1 | 3 | 60 | 1 mm Cd | 100000 | 0.22 | 2013-12-06 | CZT500_PIDIE1_@60mm_1mmCd_03.cnf |
| 51 | PIDIE-1 | 4 | 60 | 1 mm Cd | 100000 | 0.22 | 2013-12-09 | CZT500_PIDIE1_@60mm_1mmCd_04.cnf |
| 52 | PIDIE-1 | 5 | 60 | 1 mm Cd | 100000 | 0.22 | 2013-12-10 | CZT500_PIDIE1_@60mm_1mmCd_05.cnf |
| | | | | | | | | |
| 53 | Bkg-B | 7 | - | 1 mm Cd | 100000 | 0.00 | 2013-12-12 | CZT500_background_@60mm_1mmCd_07.cnf |

Notes:

Requirements: DT <= 3% RT = 5.6 us FT = 0.8 us
Used initial gain: coarse: 20x, fine: 1.2404
Fine gain has been changed between measurements to keep ca. 0.34 keV/ch
Date of measurement is date of start of the measurement (the same as stated within the spectrum)
Bkg-A means background with setup for measurements at 100mm source-detector distance
Bkg-B means background with setup for measurements at 60mm source-detector distance

| Spectra of Pu standards recorded by LaBr3 detector | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Meas. date | |
| Meas # | Sample | Replicate # | Distance, mm | Shield | LT, sec | DT, % | YYYY-MM-DD | Spectrum name |
| | | | | | | | | |
| 1 | Bkg-A | 1 | - | 1 mm Cd + 3 mm steel | 100000 | 0.01 | 13/12/2013 | LaBr3_background_1mmCd_3mmSteel_01.cnf |
| | | | | | | | | |
| 2 | Pu-61 | 1 | 300 | 1 mm Cd + 3 mm steel | 100000 | 1.18 | 16/12/2013 | LaBr3_Pu61_@300mm_1mmCd_3mmSteel_01.cnf |
| 3 | Pu-61 | 2 | 300 | 1 mm Cd + 3 mm steel | 100000 | 1.18 | 17/12/2013 | LaBr3_Pu61_@300mm_1mmCd_3mmSteel_02.cnf |
| 4 | Pu-61 | 3 | 300 | 1 mm Cd + 3 mm steel | 100000 | 1.11 | 09/01/2014 | LaBr3_Pu61_@300mm_1mmCd_3mmSteel_03.cnf |
| 5 | Pu-61 | 4 | 300 | 1 mm Cd + 3 mm steel | 100000 | 1.11 | 11/01/2014 | LaBr3_Pu61_@300mm_1mmCd_3mmSteel_04.cnf |
| 6 | Pu-61 | 5 | 300 | 1 mm Cd + 3 mm steel | 100000 | 1.11 | 13/01/2014 | LaBr3_Pu61_@300mm_1mmCd_3mmSteel_05.cnf |
| | | | | | | | | |
| 7 | Bkg-A | 2 | - | 1 mm Cd + 3 mm steel | 100000 | 0.01 | 14/01/2014 | LaBr3_background_1mmCd_3mmSteel_02.cnf |
| | | | | | | | | |
| 8 | Pu-70 | 1 | 300 | 1 mm Cd + 3 mm steel | 100000 | 0.93 | 16/01/2014 | LaBr3_Pu70_@300mm_1mmCd_3mmSteel_01.cnf |
| 9 | Pu-70 | 2 | 300 | 1 mm Cd + 3 mm steel | 100000 | 0.92 | 17/01/2014 | LaBr3_Pu70_@300mm_1mmCd_3mmSteel_02.cnf |
| 10 | Pu-70 | 3 | 300 | 1 mm Cd + 3 mm steel | 100000 | 0.92 | 20/01/2014 | LaBr3_Pu70_@300mm_1mmCd_3mmSteel_03.cnf |
| 11 | Pu-70 | 4 | 300 | 1 mm Cd + 3 mm steel | 100000 | 0.92 | 21/01/2014 | LaBr3_Pu70_@300mm_1mmCd_3mmSteel_04.cnf |
| 12 | Pu-70 | 5 | 300 | 1 mm Cd + 3 mm steel | 100000 | 0.91 | 23/01/2014 | LaBr3_Pu70_@300mm_1mmCd_3mmSteel_05.cnf |
| | | | | | | | | |
| 13 | Bkg-A | 3 | - | 1 mm Cd + 3 mm steel | 100000 | 0.01 | 24/01/2014 | LaBr3_background_1mmCd_3mmSteel_03.cnf |
| | | | | | | | | |
| 14 | PIDIE-7 | 1 | 300 | 1 mm Cd + 3 mm steel | 100000 | 0.22 | 27/01/2014 | LaBr3_PIDIE7_@300mm_1mmCd_3mmSteel_01.cnf |
| 15 | PIDIE-7 | 2 | 300 | 1 mm Cd + 3 mm steel | 100000 | 0.22 | 28/01/2014 | LaBr3_PIDIE7_@300mm_1mmCd_3mmSteel_02.cnf |
| 16 | PIDIE-7 | 3 | 300 | 1 mm Cd + 3 mm steel | 100000 | 0.21 | 30/01/2014 | LaBr3_PIDIE7_@300mm_1mmCd_3mmSteel_03.cnf |
| 17 | PIDIE-7 | 4 | 300 | 1 mm Cd + 3 mm steel | 100000 | 0.21 | 31/01/2014 | LaBr3_PIDIE7_@300mm_1mmCd_3mmSteel_04.cnf |
| 18 | PIDIE-7 | 5 | 300 | 1 mm Cd + 3 mm steel | 100000 | 0.21 | 03/02/2014 | LaBr3_PIDIE7_@300mm_1mmCd_3mmSteel_05.cnf |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| 19 | Bkg-A | 4 | - | 1 mm Cd + 3 mm steel | 20000 | 0.01 | 04/02/2014 | LaBr3_background_1mmCd_3mmSteel_04.cnf |
| | | | | | | | | |
| 20 | Bkg-B | 1 | - | 1 mm Cd | 100000 | 0.01 | 05/02/2014 | LaBr3_background_1mmCd_01.cnf |
| | | | | | | | | |
| 21 | Pu-84 | 1 | 200 | 1 mm Cd | 100000 | 1.12 | 07/02/2014 | LaBr3_Pu84_@200mm_1mmCd_01.cnf |
| 22 | Pu-84 | 2 | 200 | 1 mm Cd | 100000 | 1.12 | 10/02/2014 | LaBr3_Pu84_@200mm_1mmCd_02.cnf |
| 23 | Pu-84 | 3 | 200 | 1 mm Cd | 100000 | 1.13 | 11/02/2014 | LaBr3_Pu84_@200mm_1mmCd_03.cnf |
| 24 | Pu-84 | 4 | 200 | 1 mm Cd | 100000 | 1.13 | 13/02/2014 | LaBr3_Pu84_@200mm_1mmCd_04.cnf |
| 25 | Pu-84 | 5 | 200 | 1 mm Cd | 100000 | 1.12 | 14/02/2014 | LaBr3_Pu84_@200mm_1mmCd_05.cnf |
| | | | | | | | | |
| 26 | Bkg-B | 2 | - | 1 mm Cd | 20000 | 0.01 | 17/02/2014 | LaBr3_background_1mmCd_02.cnf |
| | | | | | | | | |
| 27 | Pu-93 | 1 | 200 | 1 mm Cd | 100000 | 0.67 | 17/02/2014 | LaBr3_Pu93_@200mm_1mmCd_01.cnf |
| 28 | Pu-93 | 2 | 200 | 1 mm Cd | 100000 | 0.68 | 20/02/2014 | LaBr3_Pu93_@200mm_1mmCd_02.cnf |
| 29 | Pu-93 | 3 | 200 | 1 mm Cd | 100000 | 0.67 | 21/02/2014 | LaBr3_Pu93_@200mm_1mmCd_03.cnf |
| 30 | Pu-93 | 4 | 200 | 1 mm Cd | 100000 | 0.67 | 24/02/2014 | LaBr3_Pu93_@200mm_1mmCd_04.cnf |
| 31 | Pu-93 | 5 | 200 | 1 mm Cd | 100000 | 0.67 | 25/02/2014 | LaBr3_Pu93_@200mm_1mmCd_05.cnf |
| | | | | | | | | |
| 32 | Bkg-B | 3 | - | 1 mm Cd | 20000 | 0.01 | 27/02/2014 | LaBr3_background_1mmCd_03.cnf |
| | | | | | | | | |
| 33 | PIDIE-1 | 1 | 200 | 1 mm Cd | 100000 | 0.11 | 28/02/2014 | LaBr3_PIDIE1_@200mm_1mmCd_01.cnf |
| 34 | PIDIE-1 | 2 | 200 | 1 mm Cd | 100000 | 0.11 | 05/03/2014 | LaBr3_PIDIE1_@200mm_1mmCd_02.cnf |
| 35 | PIDIE-1 | 3 | 200 | 1 mm Cd | 100000 | 0.11 | 10/03/2014 | LaBr3_PIDIE1_@200mm_1mmCd_03.cnf |
| 36 | PIDIE-1 | 4 | 200 | 1 mm Cd | 100000 | 0.11 | 11/03/2014 | LaBr3_PIDIE1_@200mm_1mmCd_04.cnf |
| 37 | PIDIE-1 | 5 | 200 | 1 mm Cd | 100000 | 0.11 | 13/03/2014 | LaBr3_PIDIE1_@200mm_1mmCd_05.cnf |
| | | | | | | | | |
| 38 | Bkg-B | 4 | - | 1 mm Cd | 20000 | 0.01 | 17/03/2014 | LaBr3_background_1mmCd_04.cnf |
| | | | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 39 | PIDIE-3 | 1 | 200 | 1 mm Cd | 100000 | 0.23 | 18/03/2014 | LaBr3_PIDIE3_@200mm_1mmCd_01.cnf |
| 40 | PIDIE-3 | 2 | 200 | 1 mm Cd | 100000 | 0.23 | 20/03/2014 | LaBr3_PIDIE3_@200mm_1mmCd_02.cnf |
| 41 | PIDIE-3 | 3 | 200 | 1 mm Cd | 100000 | 0.23 | 21/03/2014 | LaBr3_PIDIE3_@200mm_1mmCd_03.cnf |
| 42 | PIDIE-3 | 4 | 200 | 1 mm Cd | 100000 | 0.23 | 24/03/2014 | LaBr3_PIDIE3_@200mm_1mmCd_04.cnf |
| 43 | PIDIE-3 | 5 | 200 | 1 mm Cd | 100000 | 0.23 | 25/03/2014 | LaBr3_PIDIE3_@200mm_1mmCd_05.cnf |
| | | | | | | | | |
| 44 | Bkg-B | 5 | - | 1 mm Cd | 20000 | 0.01 | 27/03/2014 | LaBr3_background_1mmCd_05.cnf |
| | | | | | | | | |
| 45 | PIDIE-5 | 1 | 200 | 1 mm Cd | 100000 | 0.50 | 28/03/2014 | LaBr3_PIDIE5_@200mm_1mmCd_01.cnf |
| 46 | PIDIE-5 | 2 | 200 | 1 mm Cd | 100000 | 0.49 | 31/03/2014 | LaBr3_PIDIE5_@200mm_1mmCd_02.cnf |
| 47 | PIDIE-5 | 3 | 200 | 1 mm Cd | 100000 | 0.48 | 01/04/2014 | LaBr3_PIDIE5_@200mm_1mmCd_03.cnf |
| 48 | PIDIE-5 | 4 | 200 | 1 mm Cd | 100000 | 0.48 | 03/04/2014 | LaBr3_PIDIE5_@200mm_1mmCd_04.cnf |
| 49 | PIDIE-5 | 5 | 200 | 1 mm Cd | 100000 | 0.47 | 04/04/2014 | LaBr3_PIDIE5_@200mm_1mmCd_05.cnf |
| | | | | | | | | |
| 50 | Bkg-B | 6 | - | 1 mm Cd | 20000 | 0.01 | 07/04/2014 | LaBr3_background_1mmCd_06.cnf |

Notes:

Requirements: RT = 5.6 us FT = 0.8 us

Gain adjusted to have approx. 0.68 keV/ch (208 keV peak in approx. 306 ch)

Date of measurement is date of start of the measurement (the same as stated within the spectrum)

Power supply failed over new year 2013/14, new one initially caused strange results, after cable reconnection & restart OK

Temperature in the lab has been often relatively high (24-28 degree C and even above) and varied substantially

Bkg-A means background with setup for measurements at 300mm source-detector distance

Bkg-B means background with setup for measurements at 200mm source-detector distance

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