Determination of homogeneity of the top surface deadlayer in an old HPGe detector

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Abstract

A collimated source of 241Am was scanned over the endcap of a 21 year old coaxial HPGe-detector that had spent about 75% of its life at room temperature (and the remaining time at 77 K). The detector response was recorded and used as a measure of the relative thickness of the top deadlayer. This thickness was not homogeneous and was thicker near to the outer surface of the crystal compared to the centre, which could be a result of increased diffusion of Li atoms during times the detector was kept at room temperature. The results were compared with two newer HPGe-detectors that proved to have homogeneous top deadlayers.

Keywords	gamma-ray spectrometry; HPGe detector; deadlayer
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Figure 1 Scan of Hasselt detector1.ppt [Figure]

Figure 2 Scan of Ge-8.ppt [Figure]

Figure 3 Scan of SCK-detector.ppt [Figure]

Figure 4 Scan of Ta-edge.ppt [Figure]

Fig 5 dimensions UHasselt detector V3.pptx [Figure]

Figure 6 V3.ppt [Figure]

Re. Submission of an article for Applied Radiation and Isotopes

Dear Editor,

On behalf of all the co-authors, I hereby submit the an article entitled "Determination of homogeneity of the top surface deadlayer in an old HPGe detector"

Yours

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The top deadlayer of three HPGe-detectors were investigated

One detector had been kept at room temperature for about 15 years

The top deadlayer of this detector exhibited a heterogeneous structure

The strange structure is presumably due to diffusion of Li-atoms

Version 12.0

Determination of homogeneity of the top surface deadlayer in an old HPGe detector

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ABSTRACT

A collimated source of ^{241}Am was scanned over the endcap of a 21 year old coaxial HPGe-detector that had spent about 75% of its life at room temperature (and the remaining time at 77 K). The detector response was recorded and used as a measure of the relative thickness of the top deadlayer. This thickness was not homogeneous and was thicker near to the outer surface of the crystal compared to the centre, which could be a result of increased diffusion of Li atoms during times the detector was kept at room temperature. The results were compared with two newer HPGe-detectors that proved to have homogeneous top deadlayers.

Keywords: γ-ray spectrometry, HPGe detectors, deadlayer

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1. INTRODUCTION

In recent years it has become increasingly important to better understand the shape and thickness of deadlayers in HPGe-detectors, see e.g. Huy et al. (2007) and Aguayo et al. (2013). One reason is that Monte Carlo simulations using computer models of detectors are today often used for calculating efficiency transfer factors, coincidence summing correction and even absolute full energy peak efficiencies. The thicknesses of deadlayers in germanium detectors are necessary to know quite well to be able to create good computer models. It is therefore a topic that has given rise to much discussion. At e.g. conferences organized by the ICRM (International Committee for Radionuclide Metrology) it has been discussed that a better name for deadlayer could be zombielayer as it is not excluded that for certain energies, an interaction of a gamma-ray inside a deadlayer can result in a pulse. Manufacturers have generally a good understanding of the thickness of the contact structures they produce, but this is not necessarily exactly the same as the thickness of the deadlayer. Furthermore, one cannot assume (like is done in most computer models) that deadlayers are perfectly straight and parallel with crystal surfaces. To make things more complicated one has to take into account that the Li-atoms that are introduced for creating an n^+ contact structure can migrate by interstitial diffusion. This process will be enhanced drastically if the Ge-crystal is not constantly kept cold at liquid nitrogen temperature (77 K).

This paper describes the analyses of surface scans of the top deadlayer of a 21 year old HPGe-detector (Detector-1), that was kept cold only 25% of its life-time. The same instrumentation as was used by Andreotti et al. (2014) for another HPGe-detector was employed for the scanning. The paper also describes a measurement of a 13 year old detector (DET28) that has been kept cold for 98.7% of its life-time as well as a detector (Ge-8) with thin deadlayer that was also kept cold more or less all the time.

2. MATERIALS AND METHODS

2.1 The HPGe-detectors

Three detectors were used in this study. The first detector, which was the main detector under investigation, is operated by University of Hasselt and will be referred to as Detector-1. The second detector was also used by Andreotti at al. (2014) and is used here as reference to check the scanning system but also in order to provide information on the evolution of deadlayer characteristics with time for this detector, which has the name Ge-8 and is operated by JRC-Geel. The third detector is named DET28 and is operated by SCK•CEN in Mol, Belgium. It is a standard coaxial HPGe-detector with a deadlayer thickness somewhat below 1 mm. The characteristics of the three detectors are given in Table 1.

Table 1. Characteristics of the two detectors used in this study.

	Detector-1	**Ge-8**	**DET28**
Crystal type	coaxial	Planar	coaxial
Manufacturer and model	Oxford, Tennelex/Nucleus, CPVDS30-20190	Canberra BE2825 (BEGe)	Canberra GC4018
Nominal top deadlayer thickness	0.6 mm	0.0003 mm	0.45 mm
Nominal side	0.6 mm	0.6 mm	0.45 mm

deadlayer thickness			
Relative efficiency	22.6%	19%	40.4%
FWHM at 1332 keV	1.74 keV at delivery	1.72 keV	1.78 keV
Crystal height	49.6 mm	26 mm	61.5 mm
Crystal diameter	51.7 mm	60 mm	61 mm
Endcap	1.0 mm aluminium	1.5 mm aluminium	1.5 mm aluminium
Endcap diameter	76.2 mm	82.5 mm	76.2 mm
Age at the time of the scanning	21 years	10 years	13 years
Time kept at room temperature	~15 years	~1 month	2 months
Operated by	Hasselt University	JRC-Geel	SCK•CEN
n+ contact (top deadlayer)	Li-diffused	Not known but probably not Li-diffused	Li-diffused

2.2 The scanning system

The scanning system, named Brady, was developed for the GERDA project (The GERDA Collaboration, 2017) and was used for scanning the specially designed Ge-crystals used in the GERDA Phase II experiment. It is described in detail by Andreotti et al. (2013 and 2014) and is now available for scanning other Ge-detectors. It is especially important to study the deadlayer variation of older detectors. A point source of ^{241}Am (5 MBq) was inserted in a 30 mm thick copper-collimator, which has a 1 mm diameter hole. It was carefully positioned 2 mm above the endcap of each HPGe-detector in the study. The source was moved in steps of 0.1 mm (0.2 mm for DET28) in an almost straight line across the endcap surface. Due to small imperfections in the mechanics, the line was somewhat bent and resulted in an 8% offset (i.e. bending-radius of 42 cm) compared to a perfectly straight line. Three line-scans covering 76.1 mm each (the endcap diameter), and oriented in three different directions, each rotated by 60°, were performed on Detector-1. Two line-scans covering 77 mm each (slightly less than the endcap diameter of 82.5 mm), oriented in two directions differing by 20°, were performed on Ge-8. Two line-scans covering 76.1 mm each (the endcap diameter), separated by 60° were performed on DET28. At each step, data was collected for 3 minutes resulting in a 38 hour acquisition time for each line-scan (19 hours for DET28). A fourth measurement was performed by scanning DET28 with a 0.4 mm (28 mm diameter) tantalum-disc placed at the centre of the detector window. The aim was to determine the lateral resolution of the scanning system. The measurement set-up is located in the underground laboratory HADES (Andreotti et al., 2011). The main reason for this was to minimise the exposure to cosmic rays for the GERDA crystals but it is also advantageous when detectors from HADES and other underground laboratories need to be scanned.

2.3 Monte Carlo simulations

The Monte Carlo simulations of Detector-1 and Ge-8 were performed using the EGSnrc code with the add-on code "hpge3" (Lutter et al., 2017) for simulating HPGe-detectors and gamma-ray emitting radionuclides. The EGS package (and formerly EGS4) has been used at JRC-Geel since 1998 to simulate the response of HPGe-detectors (Gasparro et al., 2008). The Monte Carlo simulations of DET28 were performed using the EFFTRAN software (Vidmar, 2005). A crucial parameter when setting up computer models of detectors is the deadlayer thickness. In the present work the thickness of the top deadlayer as a function of radial position was tested (for Detector-1) for a number of different configurations to see which configuration best replicated the scanning-results. For DET28 the simulation was solely used to determine the relative thickness variations of the deadlayer.

3. MEASUREMENTS AND RESULTS

3.1 The line scans of the three detectors

Figure 1 shows the results of the three line-scans performed on Detector-1. The y-axis shows the raw-data, which is reported in counts per 3 minutes (the acquisition time per data point). Figure 2 shows the same as Figure 1 but for Ge-8. Figure 3 shows the same as Figure 1 but for DET28. The rising and tailing slopes of the scans provide some information. The lateral distance of the 12%-88% count-rate at the rising and tailing slopes, was 3.05 ± 0.16 mm for the three line-scans of Detector-1. The uncertainty is the standard-deviation of the six slopes in the three plots in Figure 1. This value is a convolution of (i) the resolving power of the system, (ii) the side deadlayer thickness including imperfections and variations (iii) charge collection inefficiencies in the corner and (iv) the possible small tilting of the crystal. The same value for Ge-8 was 1.01±0.03 mm and for DET28 1.23±0.03 mm.

The flat profile of the scan of Ge-8 indicates that very change of the deadlayer has taken place and as the scan-result agrees with the previous scan made 2 years earlier (Andreotti et al., 2014), we conclude that the scanning system is giving the same response as during this previous study. Since the n+ contact of Ge-8, presumably, does not contain Li-atoms one can assume that t should remain stable and is therefore useful as reference.

3.2 Lateral resolution of the scanning system

Figure 4 shows a scan (using DET28) over an edge of a 0.4 mm thick piece of tantalum. The slopes (12%-88%) at the edges of the Ta are 0.78±0.01 mm. The same result exactly was obtained by fitting a cumulative distribution function. This value is a direct measure of the resolving power (FWHM) of the system[1]. Subtracting in quadrature the FWHM of the system-resolution (0.78 mm) results in side edges of 2.95 mm, 0.64 mm and 0.95 mm, respectively for Detector-1, Ge-8 and DET28. This value is a convolution of the effects of the thickness of the side deadlayer, the alignment of the crystal and charge collection inefficiencies in the corner.

A radiograph of Ge-8 reveals that there is no discernible tilting of the crystal so she sharp slopes of Ge-8 are indicative of a side deadlayer (at least the top 10 mm of the crystal) very close to the nominal value of 0.6 mm.

---

[1] After finalising the scanning of the detectors described in this paper, the lateral resolution of the scanning system was improved to 0.706±0.015 mm by using a slightly smaller aperture.

3.3 Computer models based on the scans

The obtained line scans can be used to build good computer models of the detectors. The top deadlayer is one of the most important parameters in a computer model of a HPGe-detector. As the line-scans of detector Ge-8 and DET28 were perfectly straight it was trivial to introduce straight top deadlayers in the computer models. Also in the corners, a straight top deadlayer combined with a straight side deadlayer gave a good result. For Detector-1 the situation was completely different. An iterative procedure (mainly trial and error) was used to find a model of the deadlayer that well replicated the experimental results. The resulting model of the top deadlayer of Detector-1 is shown in Figure 5. The simulation results that this model generates (for ^{241}Am) are shown in Figure 6 together with the absolute and relative difference between the model and the measurements results. It was not possible to generate a good response unless making the model quite detailed towards the corner with steps of uneven lengths.

4. DISCUSSION AND CONCLUSIONS

The "reference-detector" (Ge-8) has a micro-metre-sized top deadlayer which is probably not created using Li-diffusion. Therefore is the scan of DET28 important as it proves that a detector with a thick, i.e. mm-sized, deadlayer can have a flat profile when kept cold.

The general feature of the top deadlayer profile of Detector-1 is that the top deadlayer is about a factor 1.5 thicker at the rim compared to near the centre. Furthermore, there is a clear "dip" in the response at the centre, which indicates a slightly thicker deadlayer at the centre of the crystal compared to 5 mm away from the centre. A tentative explanation of the shape is that Li-diffusion follows the crystal orientation and that diffusion from the side deadlayers contribute to the top deadlayer thickness near the rim. The model in Fig. 5 can generate results that replicate the scanning results very well. It is, however, possible to continue to adjust the model so that the difference between the model and the measurement is further minimised but this makes little sense as it is still a model and not exactly reality. The impact of introducing the inhomogeneous deadlayer of Detector-1 compared to using a model with a straight deadlayer profile can be exemplified by a few cases of common types of samples and radionuclides given in Table 2.

One must bear in mind that although a Monte Carlo simulation using an advanced computer model can replicate the obtained measurement results rather well, it is still only a model. Reality can be different and one will have to study many different geometrical configurations of sources and at a wide range of energies before making strong claims about the true configuration. Still, for calculating correction factors for efficiency transfer and true summing a computer model (even a crude one) is very useful. Future studies should focus on the effect of different energies on deadlayer structure. As the interaction probabilities of photoelectric effect, Compton scattering and pair-production changes with gamma-ray energy, it is likely that they also affect the response of the detector.

HPGe-detectors that are well taken care of can operate nicely for several decades also if kept uncooled from time to time. Therefore it is important to understand and study the extent by which deadlayers in Li-diffused contacts change and how it affects the quantitative results obtained by a specific detector.

The resolving power of the scanning system can be slightly increased by reducing the diameter of the hole in the collimator (possibly to 0.8 mm) and by making the collimator thicker. Using a smaller collimator aperture would reduce the count rate, but that can be compensated by using a source of higher activity to obtain good line-scan data within a reasonable time. A lateral resolution of a few hundred µm seems realistic to achieve.

Table 2. The relative difference in FEP peak efficiency, Δε, of Detector-1 using a flat top deadlayer of 0.6 mm compared to a deadlayer with the structure given in Fig. 5. The data is given for common types of samples placed directly on the endcap. The data is obtained from simulations using EGSnrc.

Sample type	**Δε**				
	46.5 keV	**59 keV**	**92.5**	**186 keV**	**662 keV**
Filter (∅ 50 mm, t=2 mm)	73%	43%	20%	8.9	2.7
Soil (50 g, ∅ 50 mm, t=40 mm)	67%	40%	19%	8.1	1.7
Steel (304 g, ∅ 50 mm, t=20 mm)	72%	41%	19%	7.7	1.6
Maize-powder (50 g, ∅ 50 mm, t=40 mm)	67%	40%	20%	8.0	1.8

Acknowledgements

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Figure captions

FIG. 1. Top scan results for Detector-1 at three orientations (0°, 60°, 120°): the total counts in the 59.5 keV peak are plotted as a function of the collimated source position along the detector diameter.

FIG. 2. Top scan results for Detector Ge-8 at two orientations (0°, 20°): the total counts in the 59.5 keV peak are plotted as a function of the collimated source position along the detector diameter.

FIG. 3. Top scan results for Detector DET28 at two orientations (0°, 45°): the total counts in the 59.5 keV peak are plotted as a function of the collimated source position along the detector diameter.

FIG. 4. A scan using DET28 over a piece of tantalum that is 0.4 mm thick and 30 mm in diameter. The red line is a fit using the cumulative normal distribution function with a different width for the different edges.

FIG. 5. The computer model of the Ge-crystal of Detector-1 that best reproduced the experimental results. The orange (hatched) is the modelled deadlayer. The grey is the bore-hole. All numbers are given in mm but note that the sketch is not to scale. The deadlayer structures have been enlarged to facilitate visibility.

FIG. 6. The normalized count-rate for the scan of Detecor-1 at 0° for both the experimental results and the Monte Carlo simulation with the most successful detector model. The difference and relative difference between the model and the experimental results are shown below.

FIGURE 1

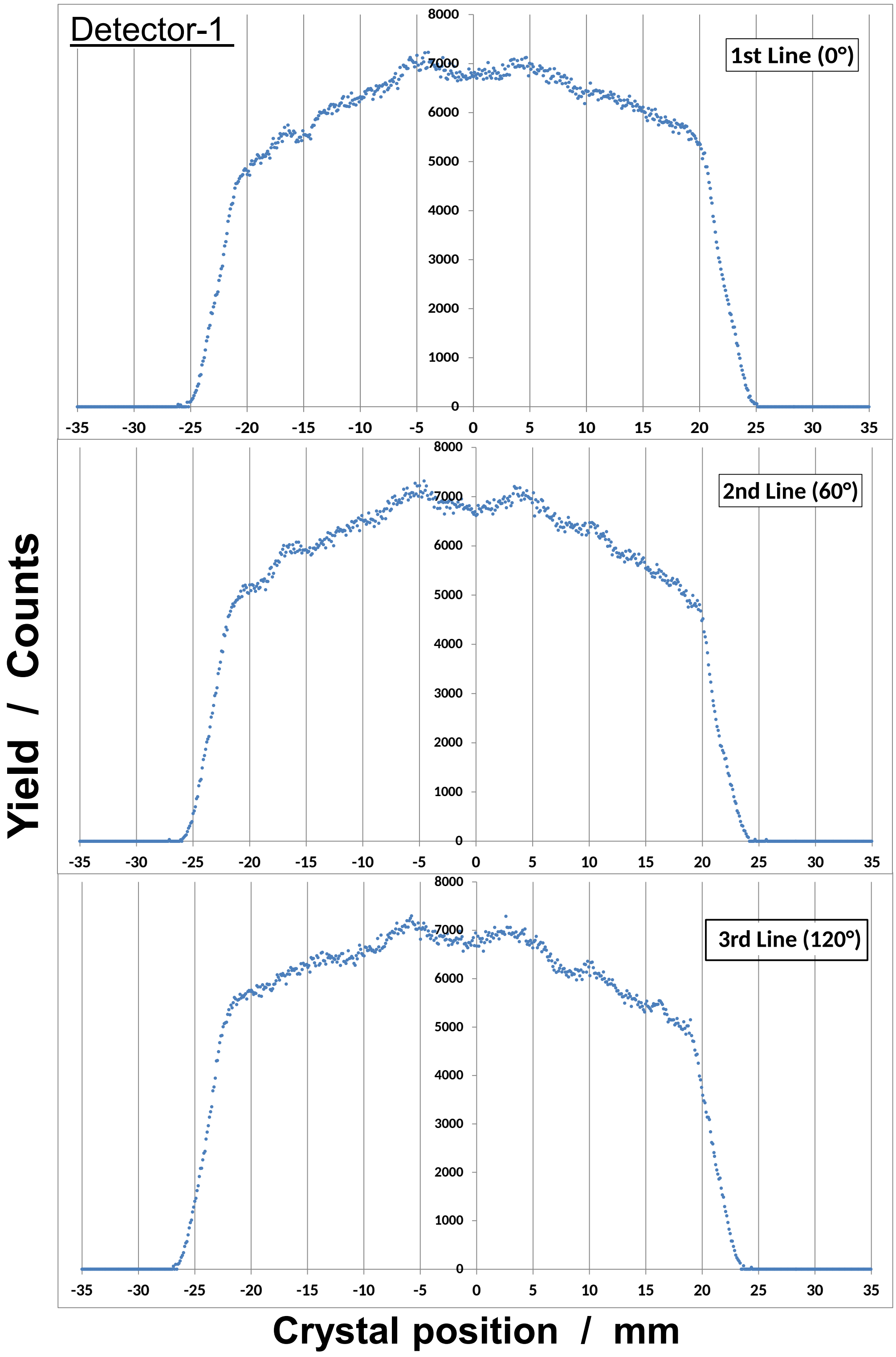

Detector-1
1st Line (0°)
2nd Line (60°)
3rd Line (120°)
Yield / Counts
Crystal position / mm
0
1000
2000
3000
4000
5000
6000
7000
8000
-35
-30
-25
-20
-15
-10
-5
0
5
10
15
20
25
30
35

FIGURE 2

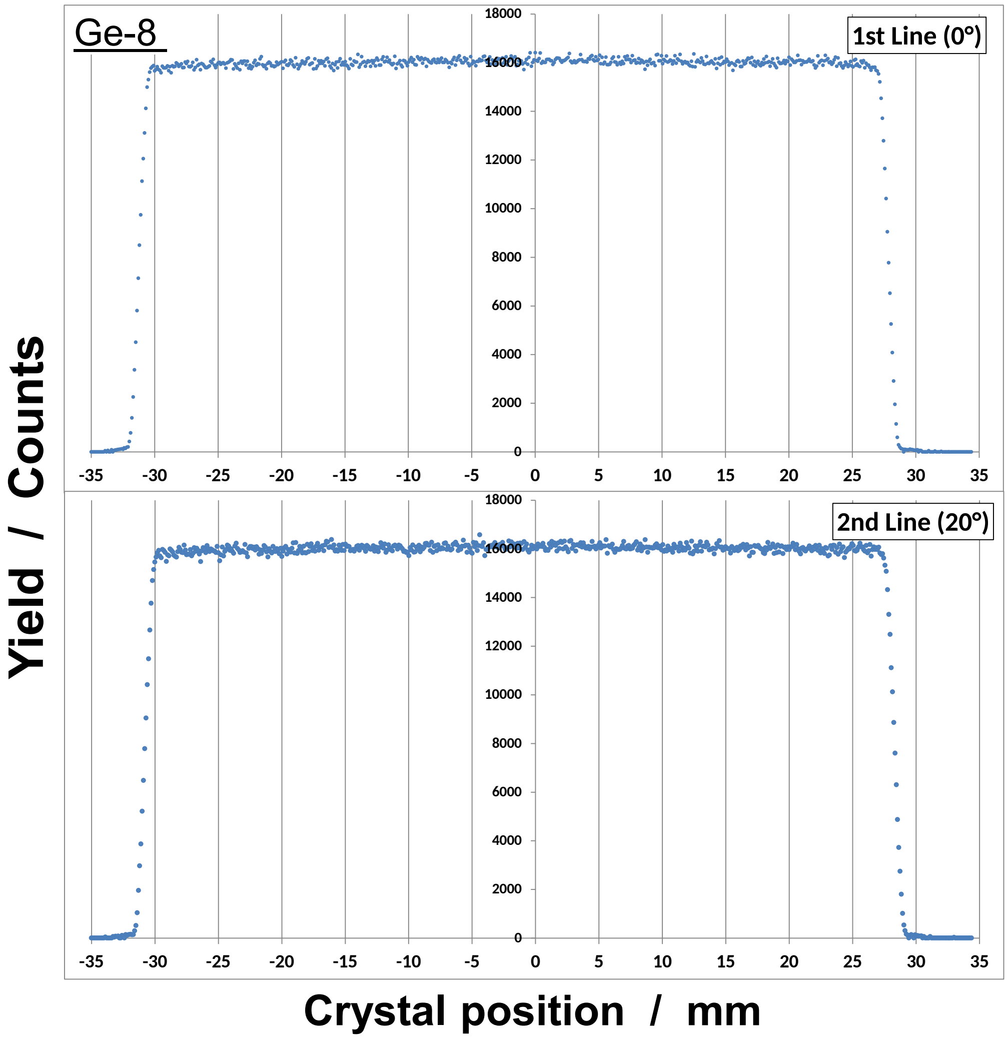

Ge-8
1st Line (0°)
2nd Line (20°)
Yield / Counts
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
-35
-30
-25
-20
-15
-10
-5
0
5
10
15
20
25
30
35
Crystal position / mm

FIGURE 3

300

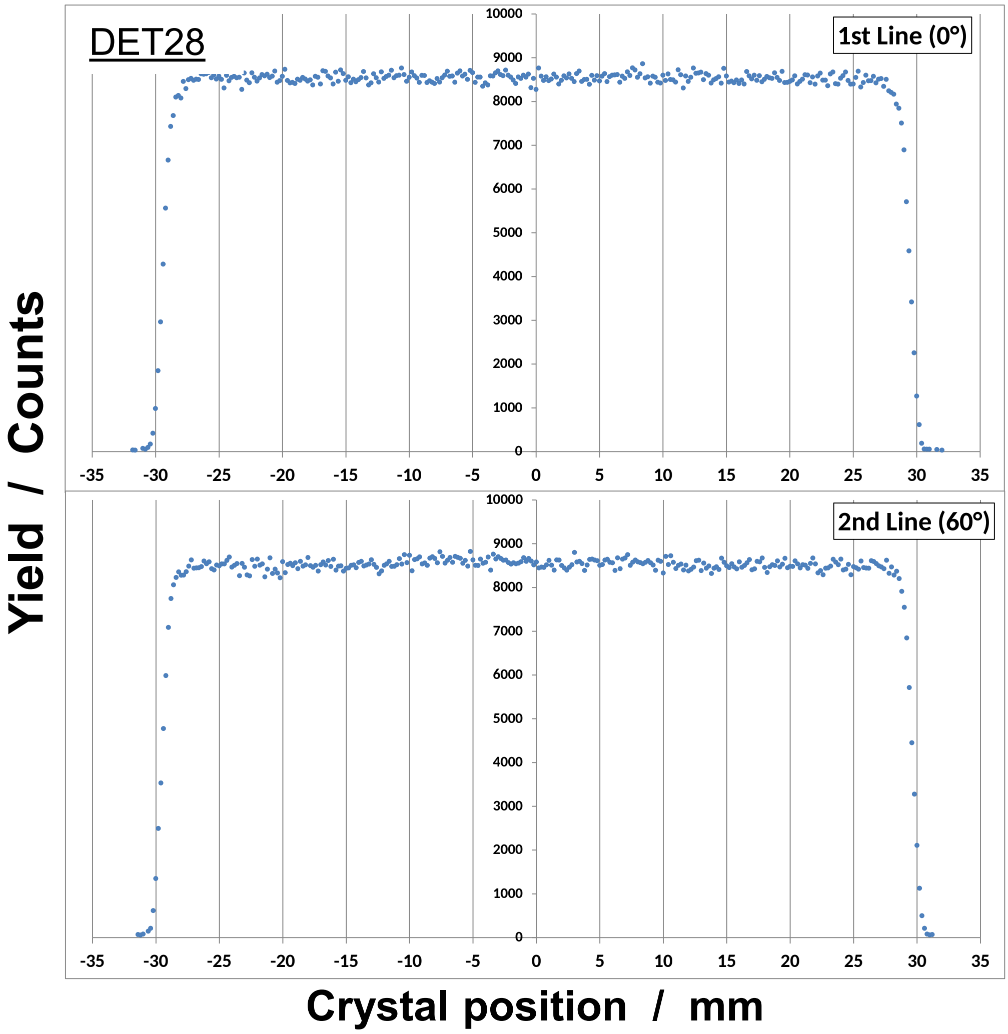

DET28
1st Line (0°)
2nd Line (60°)
Yield / Counts
Crystal position / mm
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
-35
-30
-25
-20
-15
-10
-5
0
5
10
15
20
25
30
35

FIGURE 4

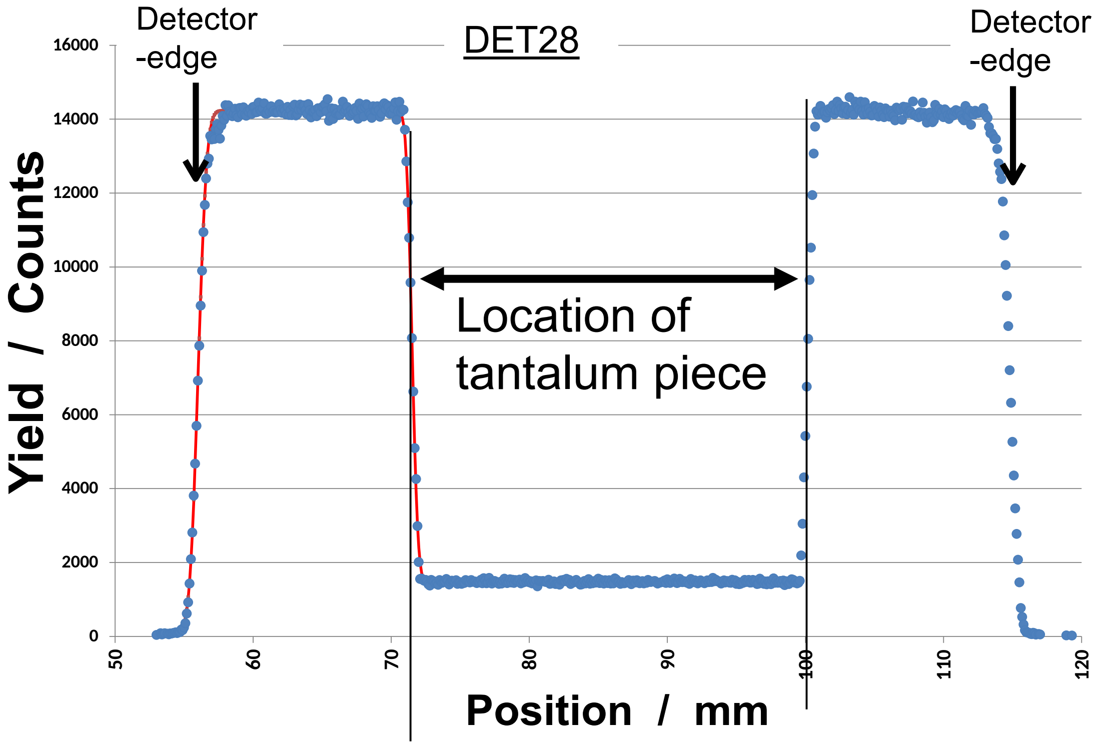
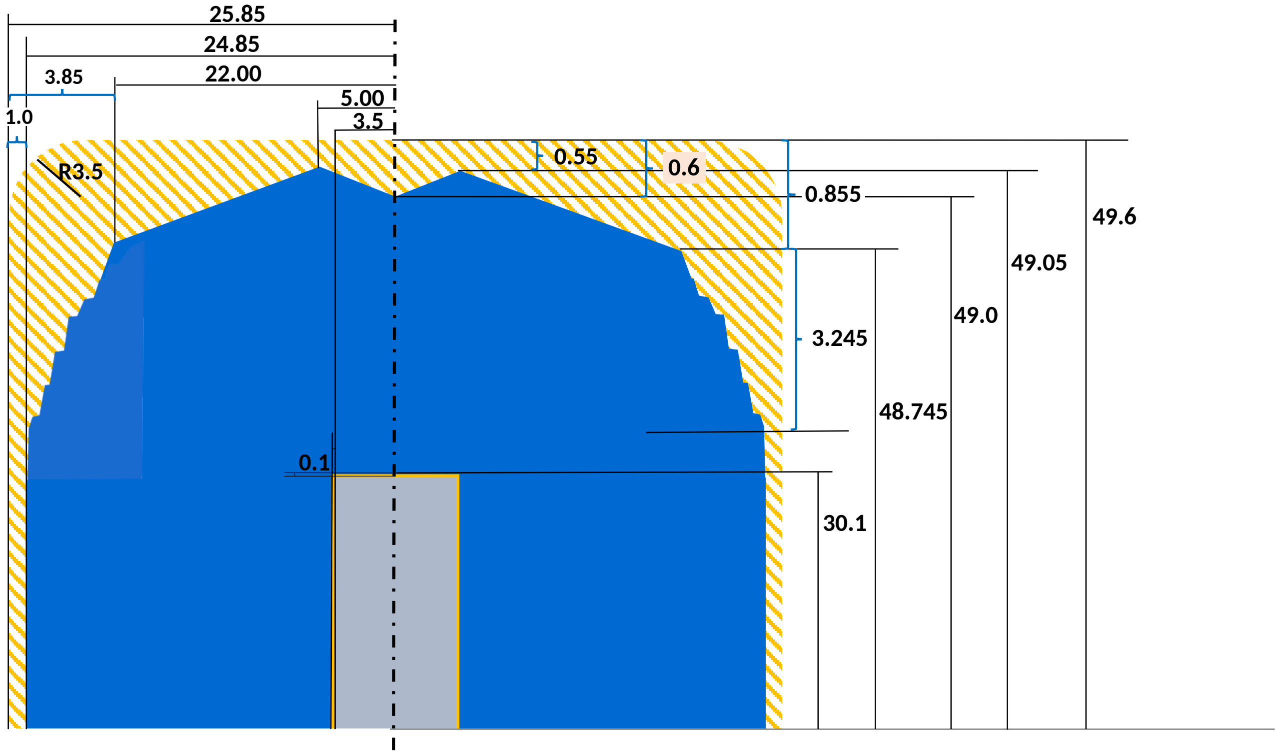

Detector
-edge
DET28
Detector
-edge
Location of
tantalum piece
Yield / Counts
Position / mm
16000
14000
12000
10000
8000
6000
4000
2000
0
50
60
70
80
90
100
110
120

FIGURE 5


25.85
24.85
3.85
22.00
5.00
3.5
1.0
R3.5
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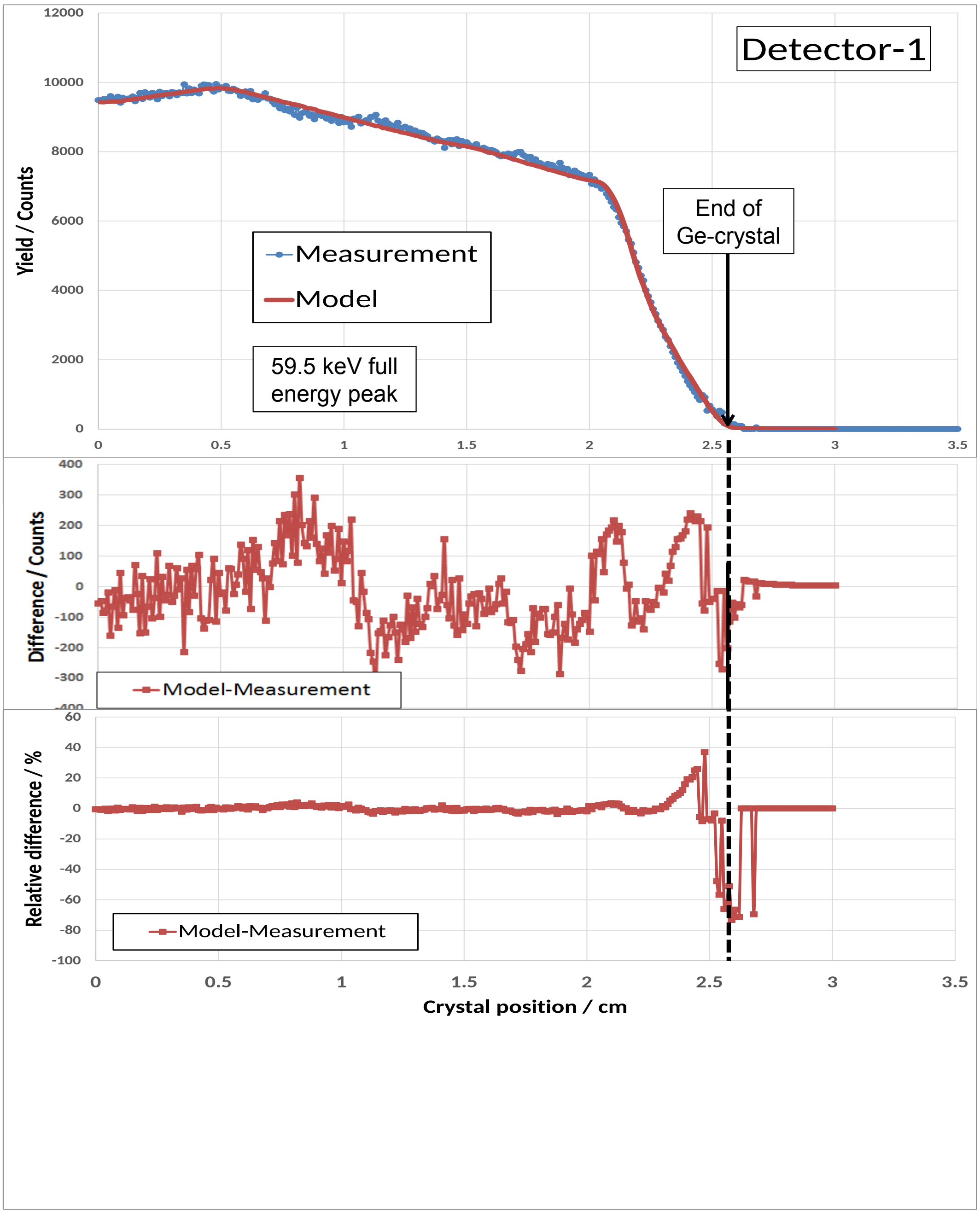
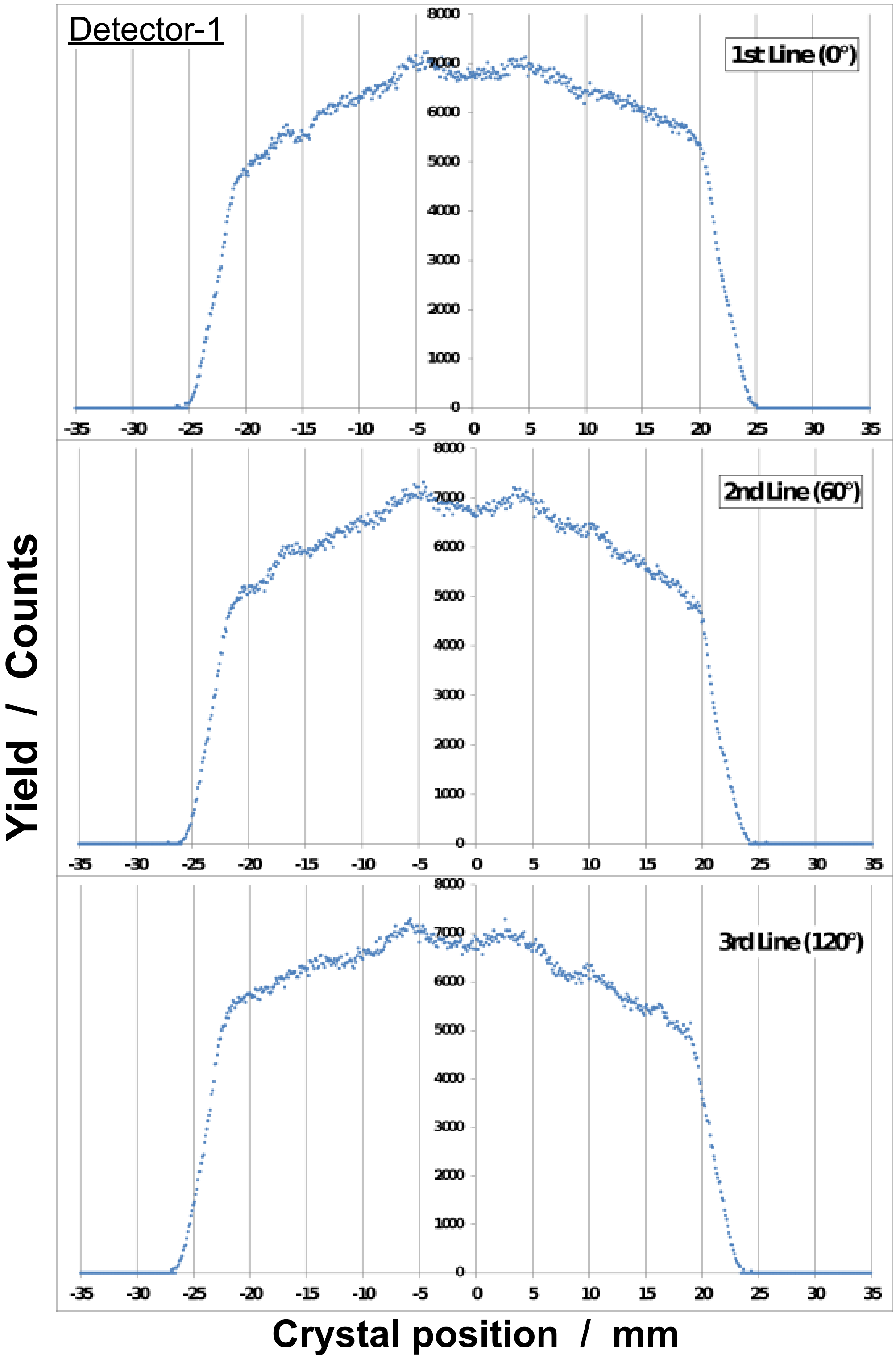
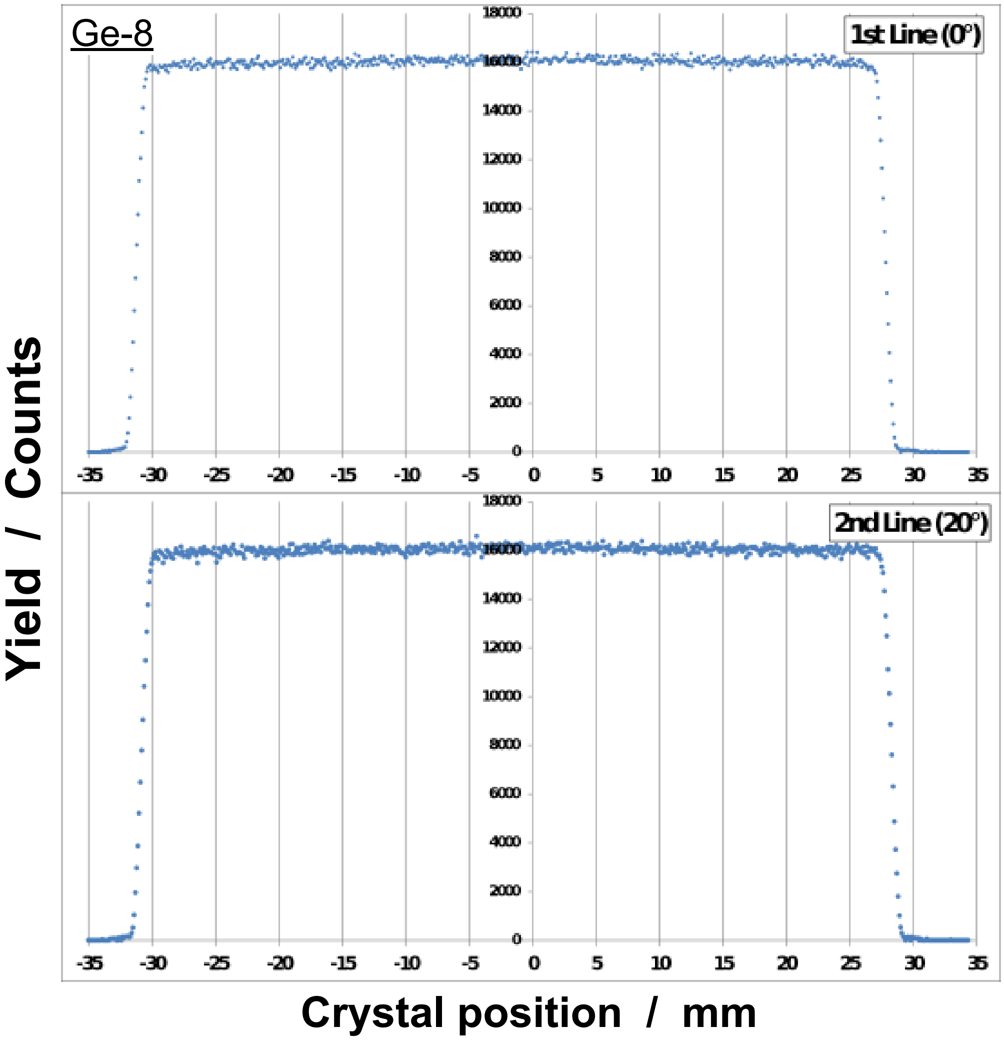
0.6
0.855
49.6
49.05
49.0
3.245
48.745
0.1
30.1

310

FIGURE 6


Detector-1
Yield / Counts
12000
10000
8000
6000
4000
2000
0
0
0.5
1
1.5
2
2.5
3
3.5
Measurement
Model
59.5 keV full energy peak
End of Ge-crystal
Difference / Counts
400
300
200
100
0
-100
-200
-300
-400
Model-Measurement
Relative difference / %
60
40
20
0
-20
-40
-60
-80
-100
Model-Measurement
Crystal position / cm


Detector-1
1st Line (0°)
2nd Line (60°)
3rd Line (120°)
Yield / Counts
Crystal position / mm
0
1000
2000
3000
4000
5000
6000
7000
8000
-35
-30
-25
-20
-15
-10
-5
0
5
10
15
20
25
30
35


Ge-8
1st Line (0°)
2nd Line (20°)
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
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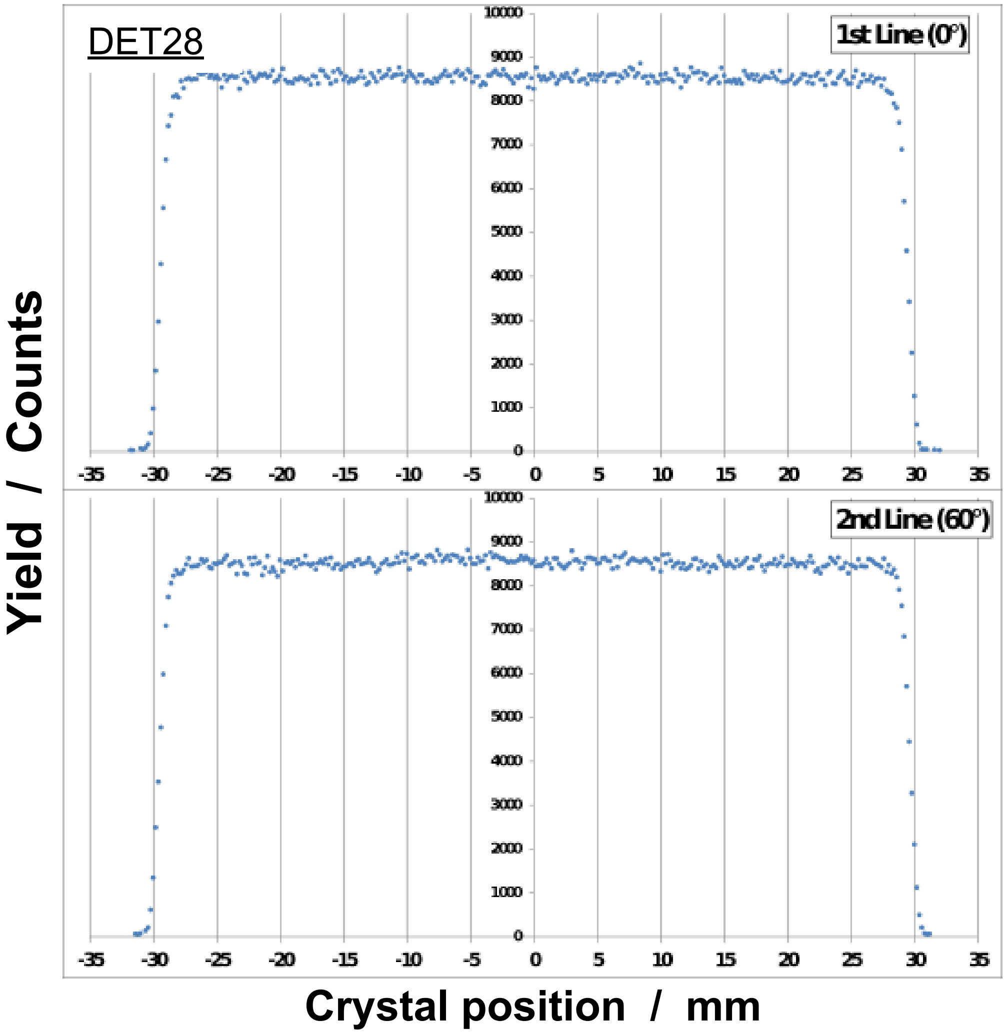
30
35
Yield / Counts
Crystal position / mm


DET28
1st Line (0°)
2nd Line (60°)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
-35
-30
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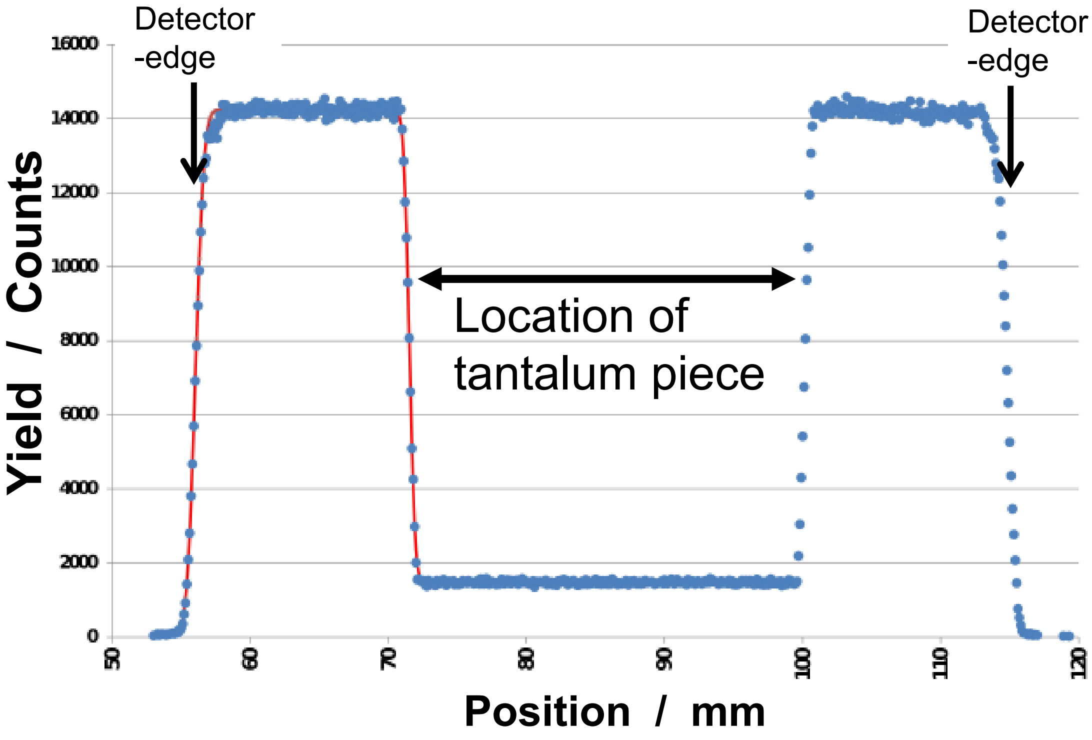
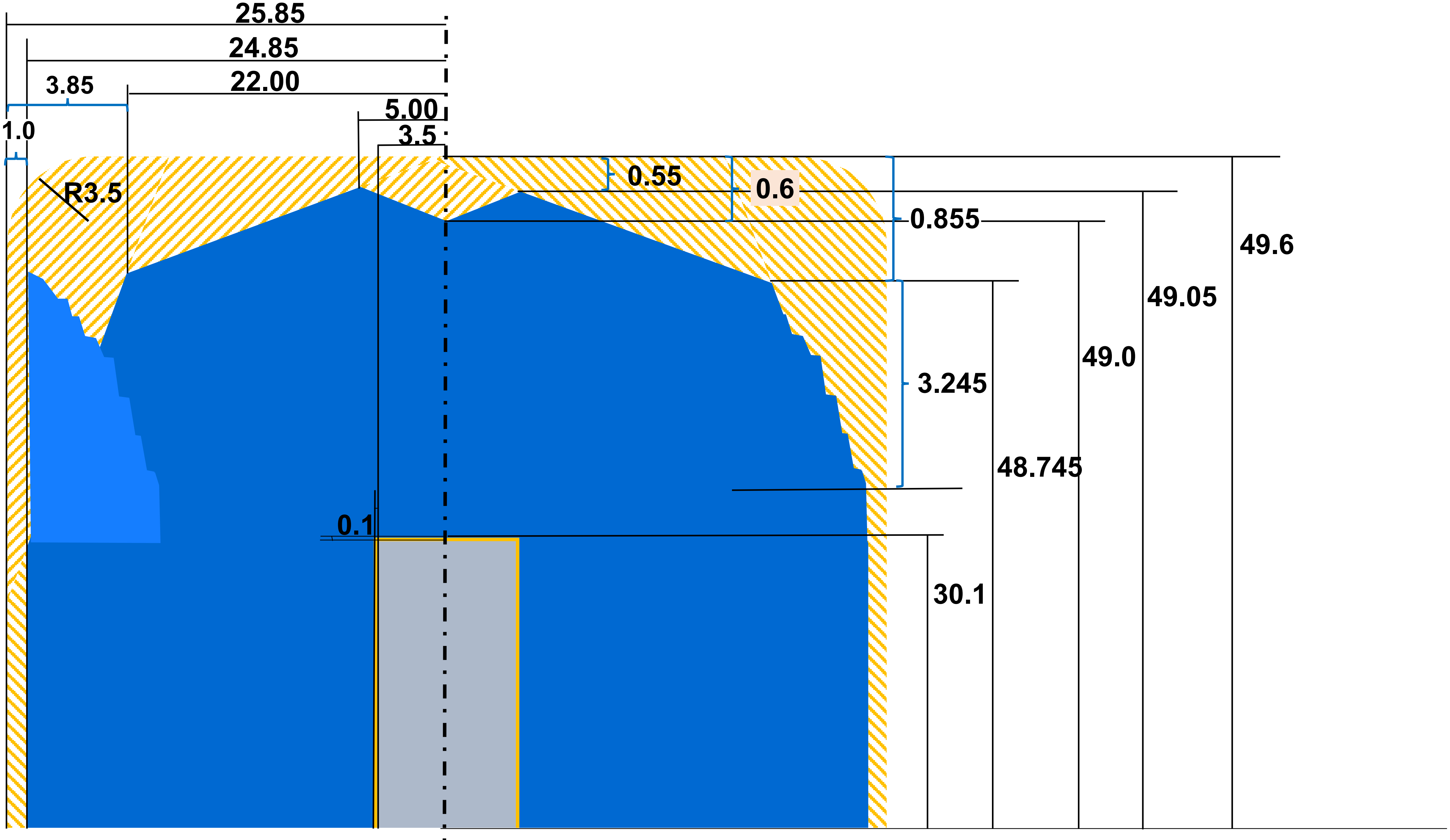
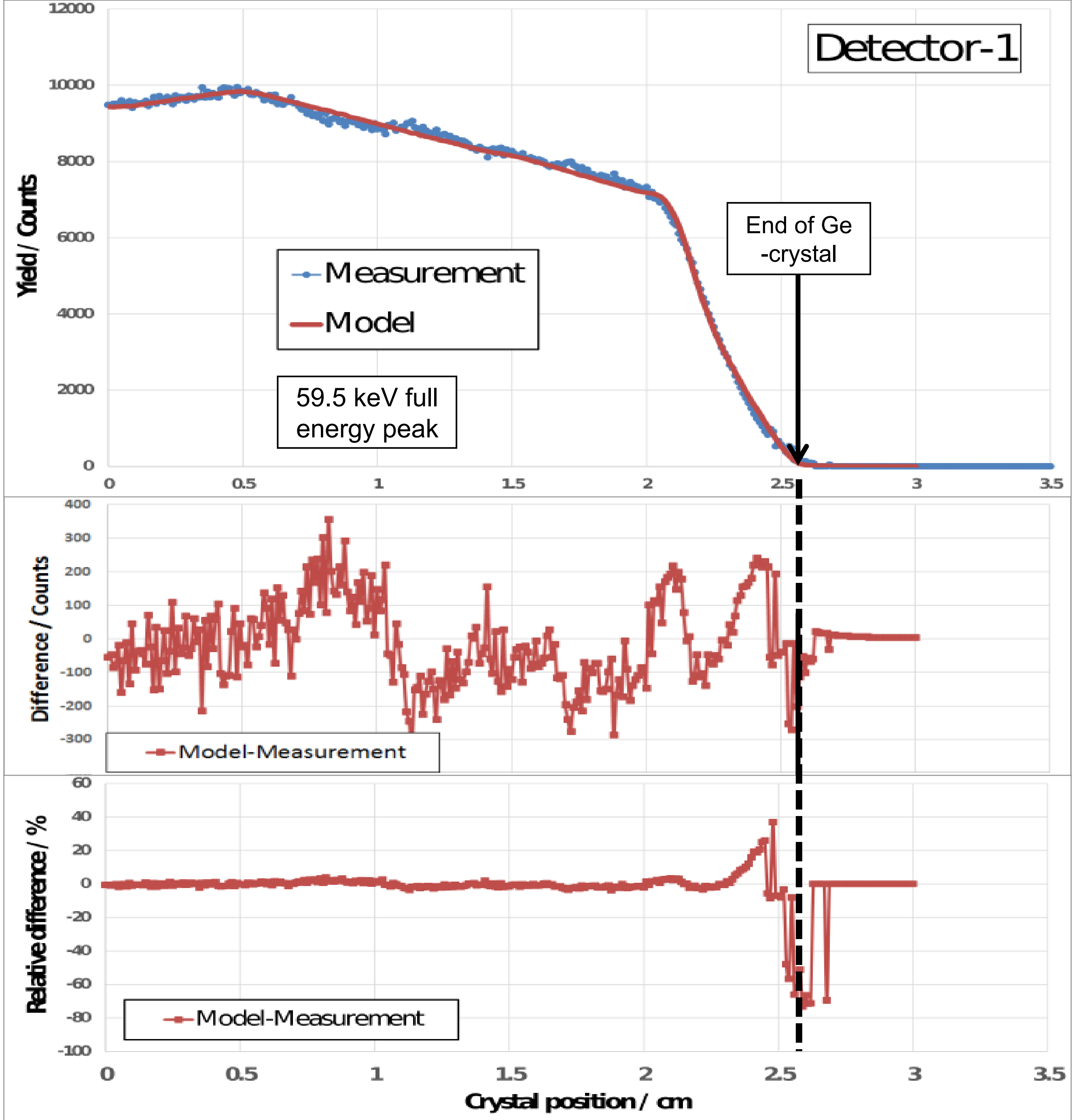
-15
-10
-5
0
5
10
15
20
25
30
35
Yield / Counts
Crystal position / mm


Detector
-edge
Detector
-edge
Location of
tantalum piece
Yield / Counts
0
2000
4000
6000
8000
10000
12000
14000
16000
Position / mm
50
60
70
80
90
100
110
120


25.85
24.85
3.85
22.00
5.00
3.5
1.0
R3.5
0.55
0.6
0.855
49.6
49.05
49.0
3.245
48.745
0.1
30.1


Detector-1
Yield / Counts
12000
10000
8000
6000
4000
2000
0
Measurement
Model
59.5 keV full energy peak
End of Ge -crystal
0
0.5
1
1.5
2
2.5
3
3.5
Difference / Counts
400
300
200
100
0
-100
-200
-300
Model-Measurement
Relative difference / %
60
40
20
0
-20
-40
-60
-80
-100
Model-Measurement
0
0.5
1
1.5
2
2.5
3
3.5
Crystal position / cm