BrightnESS

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List of Abbreviations

ESS European Spallation Source

CERN European Organization for Nuclear Research

MPGD Micro Pattern Gaseous Detectors

GEM Gas Electron Multiplier

MPD Maximum Penetration Depth

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Executive Summary

This deliverable, D4.3: Natural and enriched Gadolinium converters design, is about determining a viable approved design for Gadolinium convertors for detectors. It establishes a design and engineering technique baseline for the detectors. There are three main aspects to this deliverable:

1. The requirements for the converters layers by understanding the desired properties.
2. Established a mechanical technique, by which relatively large areas (up to 60x60 cm^2) of thin Gadolinium foils can be produced.
3. Present isoptope-enriched Gadolinium as a possible future upgrade for the detectors, by determining that there is a limited, but realistic strategic availability of the material.

The development of Gadolinium (Gd) based GEM detectors for the NMX instrument at the European Spallation Source ERIC (ESS) in Lund, Sweden is funded by the European Union through the BrightnESS project. Simulations and first measurements, taken during experiments at CERN and at the R2D2 beamline at IFE, Norway, demonstrate that the Gd-GEM detector will be able to successfully tackle the position resolution challenge. A position resolution of around 200μm is achievable, which is below state-of-the-art of ca. 1mm position resolution.

Large progress has been made in the understanding of the properties of Gd converters, leading to the determination of the appropriate converter and drift thickness. The detected gamma background will be higher than for a ^{10}B or ^{3}He based detector, but with around 0.1$\%$, depending on the incoming gamma energy, this is reasonable. This meets the detector requirements for the NMX instrument at ESS in Lund, Sweden.

The strategic availability of enriched Gadolinium has been ascertained. Two potential suppliers, who have access to limited stocks of this enriched material, have been identified, and an industrial collaboration with Goodfellow Ltd (UK) and Neonest AB (SE) is ongoing to study the subsequent manufacturing of enriched Gd converters. This collaboration has determined that it is possible to produce thin foils of Gadolinium with almost no production losses, which is important for the economic viability of the process. Any such upgrade of the detectors using enriched Gadolinium would take place after the operation phase at ESS has started, however it is important to determine whether this represents a viable future upgrade path for the detectors, or whether an upgrade by expanding the available area is a better direction.

As producing a single Gd foil of 60x60cm^2 is not possible, there is a performance risk if several foils cannot be joined without a seam, and into a mechanically stable structure that can be mounted into the detector. Ultrasonic welding using a machine by Branson Ultrasonics (CH and ES) has been identified as suitable technology to produce a 60 x 60 cm^2 natural Gd cathode. Welding Gd is novel, and was investigated jointly with the industrial producer. A mechanically reliable and affordable cathode can be produced in this manner.

The complete work on Gd converters is presently being summarised for a future journal publication on this topic.

The work and contents of this deliverable establish a baseline for the Gadolinium converter cathodes needed for the NMX instrument at the ESS, in Lund, Sweden.

Report on Natural and enriched Gadolinium converters design

Efficient neutron converters are a key component of a neutron detector. A good neutron converter has to have a high neutron capture cross section and has to produce with a high probability charged secondary particles. Further, the charged secondary particles should be able to escape from the converter and to reach the active volume of the detector, where they deposit a large amount of energy. Ideally, the charged secondaries are fully contained in the detector, i.e. they loose all their energy in the active volume.

Gadolinium, a chemical element with symbol Gd and atomic number 64, is a light rare earth metal. Named after the Finnish chemist Johan Gadolin, it is a silvery-white, malleable and ductile metal that occurs in nature only in salt form. The primary source of Gadolinium are the Bastnäsite ore deposits in China, Russia and the US. Gadolinium is one of the rare-earth elements, and has a few specialized industrial uses. It is used for example as contrast agent for MRI examinations, or due to its magneto-caloric properties as refrigerant in magnetic refrigeration. A small percentage of Gadolinium added to a metallic alloy improves its workability and resistance to high temperature oxidation. Since Gadolinium has an exceptionally high neutron capture cross section, it is used for shielding in neutron radiography and in nuclear reactors. Gadolinium has also fluorescent properties and is therefore used as scintillator material.

Natural Gadolinium contains 14.80$\%$ of ^{155}Gd and 15.65$\%$ of ^{157}Gd, the remainder are Gd isotopes without significant cross section for thermal neutrons. ^{155}Gd has a capture cross section for thermal neutrons of 60740.1 barns, whereas the capture cross section of ^{157}Gd even amounts to 252928 barns [1]. Despite the very large neutron capture cross section, Gd is not a popular converter due to the nature and the energy of the secondary particles produced after the neutron capture. In fact, Gadolinium releases prompt γs with an energy of up to 9 MeV and conversion electrons with energies ranging from 29 keV to 250 keV.

Neutron detectors consisting of Gas electron multipliers (GEMs) [2] and natural Gd converters are the baseline detector technology for the Macromolecular Diffractometer (NMX) [3] instrument at ESS. Whereas macromolecular crystallography instruments at reactor sources typically use neutron image plates [4] with around 200 μm spatial resolution, spallation source instruments require time resolution that the image plates lack altogether. Scintillation based detectors [5, 6] are currently limited to around 1 mm spatial resolution. For these instruments solid converters in combination with Micro Pattern Gaseous Detectors (MPGDs) [7] are a promising option, as they fill the gap of detectors with a position resolution below 1 mm and good time resolution. A position resolution of better than 250 μm has been obtained with $^{10}B_4C$ [8] and natural Gd converters [9].

GEM detectors with Gd cathode are usually used in *backwards configuration*, i.e. the neutron beam, impinging orthogonally to the detector, crosses the readout board and the GEMs before reaching the cathode (figure 4.1). In this way the conversion electrons do not need to traverse the entire gadolinium thickness in order to reach the active volume (the so-called drift space), which leads to a higher neutron detection efficiency. In *forwards configuration* the neutron impinges directly on the cathode, and the majority of the conversion electrons have to transverse the converter. Since most of the neutrons interact in the first few hundred nanometres of the converter, a smaller percentage of the conversion electrons manages to reach the drift space of the detector. The detection efficiency in *forwards configuration* is thus always lower than in *backwards configuration*. If a very thin Gd converter is used, a second

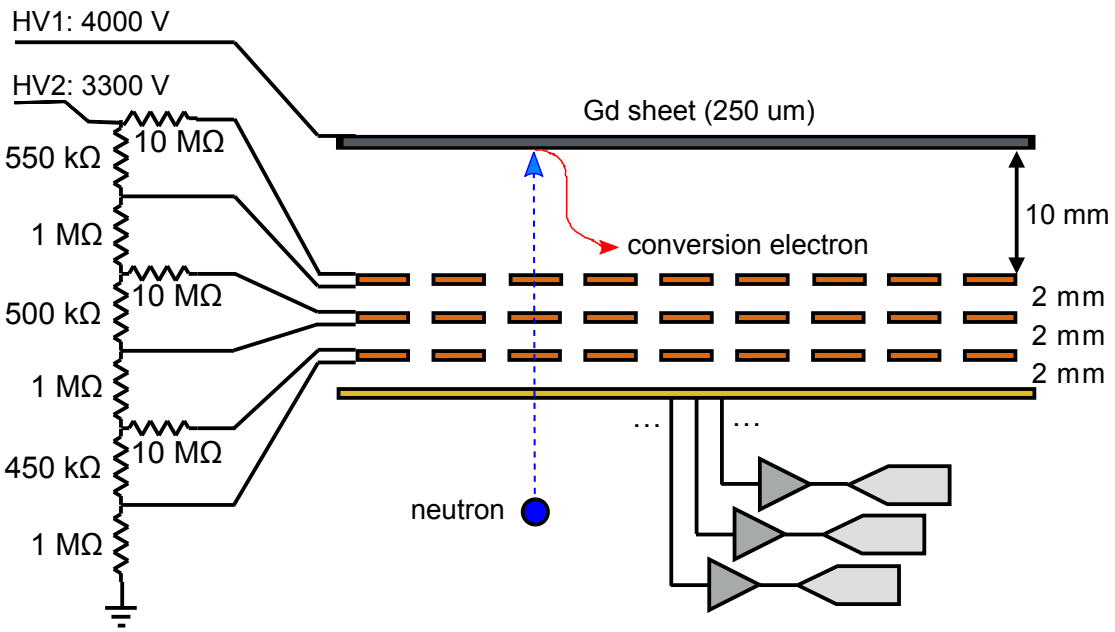


Figure 4.1. *Schematic representation of the detector used in backwards configuration.*

mirrored detector that uses the same Gd cathode as the first detector can be added. In this way the maximum number of conversion electrons reaches the active volume, but the resulting detector is more complex and costly. All studies in the next chapter therefore assume only one neutron detector with a cathode used in *backwards configuration*.

Technical Content

5.1 Properties of Gd converters

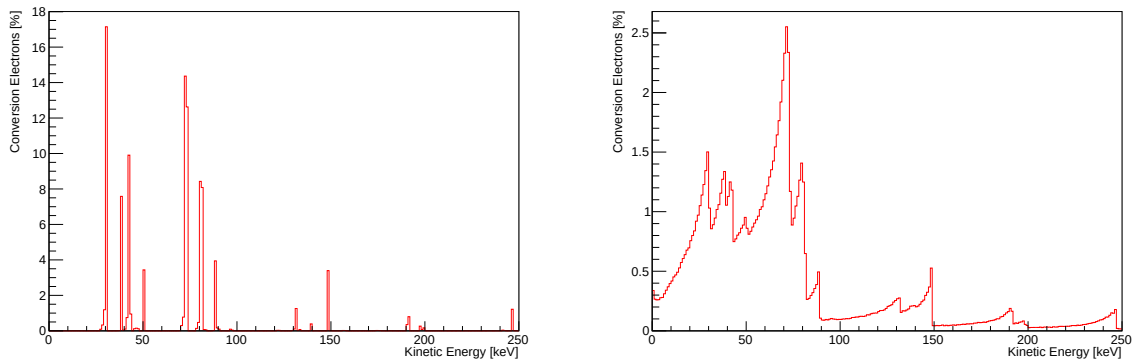
The converter simulations were carried out with Geant4 [11] version 10.1 using the high-precision neutron data G4NDL4.5.PUB, the gamma level data PhotonEvaporation3.1, the flag G4NEUTRONHP_USE_ONLY_PHOTONEVAPORATION and NTP conditions [1]. The wavelength of the neutrons in the simulation was set to 1.8 Å. In all cases, sufficient statistics were obtained in the simulation to ensure that the statistical uncertainty on the presented results is small.

Figure 5.1 shows the simulated kinetic energy distribution of the conversion electrons after the neutron capture in a 250 μm thick natural Gd converter, and at the moment when they are leaving the converter. Since the conversion electrons loose energy in the Gd, the discrete energy distribution present in the converter smears out and turns into a more continuous spectrum when the conversion electrons leave the converter. The mean kinetic energy of the conversion electrons escaping from the converter is 70 keV.

The conversion electron spectrum of natural Gd contains conversion electrons from the

[1] Normal Temperature and Pressure is defined as a temperature of 293.15 K and a pressure of 1 atm.

neutron capture of ^{157}Gd and ^{155}Gd. The most intense conversion electrons emitted during the de-excitation of ^{158}Gd* and ^{156}Gd* come from internal conversion in the K,L and M shells during the two lowest E2 transitions to the ground state. The energy of a conversion electron is equal to the transition energy minus the binding energy of the shell. Therefore for ^{157}Gd, the main conversion electron energies are 29 keV, 71 keV, 78 keV, 131 keV, 173 keV, 180 keV and 228 keV, whereas for ^{155} they are 39 keV,81 keV,88 keV,149 keV,191 keV,198 keV and 246 keV [10].



(a) In Gd before interaction with converter

(b) Leaving converter (backwards configuration)

Figure 5.1. *Kinetic energy of conversion electrons (bin size 1 keV) as simulated with Geant4.*

Table 5.1 shows the Continuous Slowing Down Approximation (CSDA) range and the maximum penetration depth of electrons between 10 keV and 250 keV in Ar/CO_2 70/30 at Normal Temperature and Pressure (NTP). Whereas the CSDA range is defined as the mean path length of a charged particle in an absorber, the maximum penetration depth is defined as the depth in the absorbing medium beyond which no particles are observed to penetrate [12]. In the gaseous detector under study, the absorbing material is the 10 mm long drift volume filled with Ar/CO_2 70/30 (figure 4.1). The conversion electron track is fully contained in the drift space if its maximum penetration depth is smaller than the drift length. Conversion electrons between 10 keV and 250 keV have a maximum penetration depth between 1 mm and 26 cm. Therefore, depending on the initial position and angle and the size of the drift volume, only a fraction of the conversion electrons tracks will be fully contained in the detector.

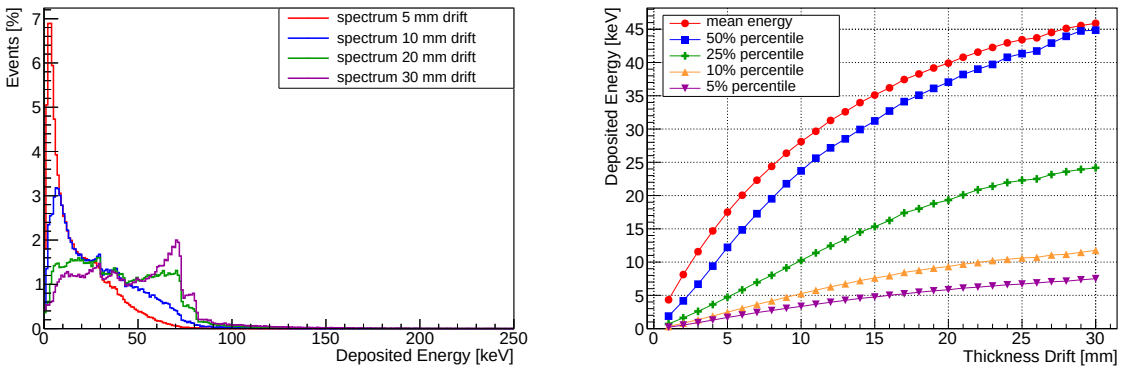
Figure 5.2 confirms that the energy deposit of the conversion electrons highly depends on the size of the drift. To detect the 70 keV peak that dominates the spectrum in figure 5.1(b) in the spectrum of the deposited energies, the drift space would have to be around 30 mm long. For a 10 mm drift, only tracks of conversion electrons with an energy of up to 30 keV will be fully contained. Figure 5.2(b) depicts the mean deposited energy and the 5$\%$, 10$\%$, 25$\%$ and 50$\%$ percentiles depending on the drift size. For a 10 mm drift, Gd conversion electrons on average deposit only 28 keV in the drift space by ionizing the Ar/CO_2. The most probable energy deposition is 24 keV, and an energy threshold of 5 keV will cut away 10$\%$ of the conversion electron signal.

The deposited energy of the conversion electrons is thus small when compared to the secondaries from ^{3}He, ^{6}Li, and ^{10}B converters. Additionally, the Gd conversion electrons have also on average a far larger range, and do not leave a straight ionization track. The long curved tracks of the conversion electrons make it more difficult to determine the start of the track and thus the interaction point of the neutron with the converter. The μTPC data analysis technique,

Kinetic Energy [keV]	CSDA Range [cm][a]	Maximum Penetration Depth [cm][b]	Standard Deviation [cm][c]
10	0.20	0.09	0.03
20	0.66	0.33	0.09
30	1.34	0.69	0.19
40	2.21	1.16	0.32
50	3.26	1.73	0.47
60	4.46	2.39	0.64
70	5.81	3.13	0.83
80	7.29	3.95	1.04
90	8.90	4.85	1.28
100	10.62	5.80	1.53
125	15.40	8.51	2.21
150	20.76	11.49	2.94
175	26.61	14.74	3.79
200	32.90	18.33	4.62
250	46.55	26.18	6.57

Table 5.1. *Path length and maximum penetration depth of electrons in Ar/CO_2 70/30 at NTP.*

[a] Continuous slowing down approximation (CSDA) range from ESTAR database [13].
[b,c] Maximum Penetration Depth simulated with Geant4 Photoabsorption Ionization Model.



(a) Simulated spectrum of conversion electrons

(b) Deposited energy in drift

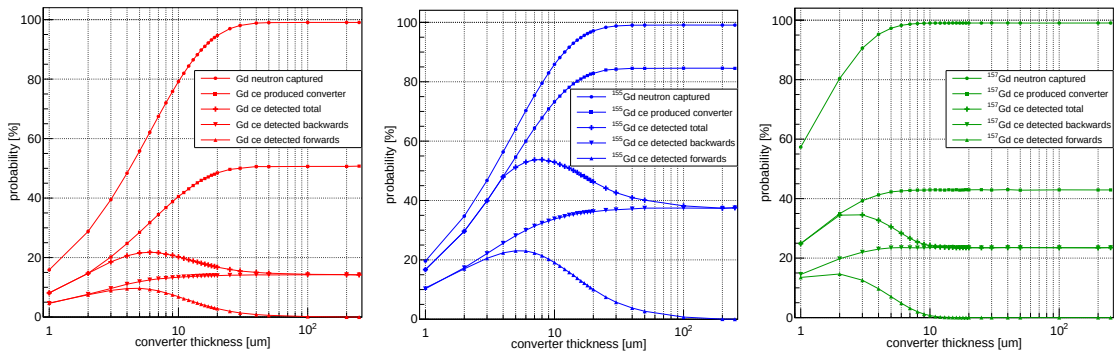
Figure 5.2. *Simulated spectrum of conversion electrons in drift (bin size 1 keV) and deposited energy in drift depending on the drift space .*

which is based on the principle of the Time Projection Chamber (TPC), has been developed to overcome this problem [9], and a position resolution of better than 250μm has been obtained.

The neutron capture probability for thermal neutrons depends on the thickness of the converter. Figure 5.3 shows the result of Geant4 simulations that compare the neutron capture probability in natural Gd, ^{155}Gd and ^{157}Gd. Due to the huge neutron capture cross section, 8 μm of ^{157}Gd already capture more than 99 $\%$ of all thermal neutrons, whereas 30 μm of ^{155}Gd or 40 μm of natural Gd are needed to capture the same percentage.

According to the simulations, 127 conversion electrons per 100 captured neutron are produced in a ^{155}Gd converter, and 52 conversion electrons per 100 captured neutron in a ^{157}Gd converter. Harms and McCormack [14] determined that 61.7 conversion electrons are produced per 100 captured neutrons in ^{155}Gd, and 59.56 in ^{157}Gd. Hargrove et al. [15] on the other hand based on the gamma level schemes in the work of Bäcklin et al. [16] and Greenwood et al. [17], state a value of 79 for ^{155}Gd, and 61 for ^{157}Gd. Apparently the numbers obtained with Geant4 are much too large for ^{155}Gd and too small for ^{157}Gd. The simulated neutron detection efficiency that depends on the number of conversion electrons per captured neutron, is thus not correct for ^{155}Gd and ^{157}Gd. For natural Gadolinium though, 65.6 conversion electrons are created per 100 captured neutrons, which seems reasonable compared to the values found in the literature. A number of 59.91 conversion electrons per 100 captured neutrons can be found in the work of Harms and McCormack, whereas Hargrove et al. arrive at 66.

To calculate the neutron detection efficiency of the detector, it is not the number of conversion electrons per captured neutron that is relevant, but the probability that at least one conversion electron is produced and reaches the drift. The simulated probability for the production of at least one conversion electron in a natural Gd converter amounts to 51.1$\%$. This number is lower than the number of conversion electrons per 100 neutrons, because in some cases more than one conversion electron is produced during the neutron capture. Data on the conversion electron coincidence is difficult to obtain from literature.



(a) natural Gd (b) ^{155}Gd (c) ^{157}Gd

Figure 5.3. *Properties of natural Gd, ^{155}Gd and ^{157}Gd converters*

Bruckner et al. calculated the detection efficiency for a 100$\%$ efficient Si detector with a Gd converter of 25 μm thickness in backwards configuration [18]. For neutrons with 1.8 Å wavelength, the calculated efficiency was around 11.6$\%$ for natural Gd, 18$\%$ for ^{155}Gd and 23$\%$ for ^{157}Gd. According to Abdushukurov, the calculated detection efficiency amounts to 15.2$\%$ for natural Gd and 31$\%$ for ^{157}Gd [19]. Geant4 arrives at a detection efficiency of 13.9$\%$ for natural Gd, the values for ^{155}Gd and ^{157}Gd cannot be used as explained above. The simulated effi-

ciencies for natural Gd are thus slightly lower than the efficiency calculated by Abdushukurov and slightly higher than the efficiency calculated by Bruckner et al., but agree reasonably well with the literature.

The measured efficiency by Bruckner et al. for various wavelengths was considerably higher than their calculation, e.g. for 1.7 Å neutrons 19% were measured with a 25 μm thick converter of natural Gd, and 34% with ^{157}Gd. The authors explain the discrepancy with the partial detection of the X-rays and gamma rays that are produced during the neutron capture. For a GEM detector with a natural Gd cathode of 250 μm thickness, a detection efficiency of 11.8% has been measured for neutrons with a wavelength of 2 Å in backwards configuration. If one corrects this efficiency for neutrons that were scattered when hitting the readout board, one arrives at an efficiency of 14.5%. The efficiency measurement was carried out using a threshold of 2 keV.

After simulating and measuring the efficiency and comparing the results to the literature, it seems that the maximum obtainable detection efficiency in backward mode amounts to about 15% for a natural Gd converter, and 31% for ^{157}Gd. A thickness of 10μm - 30μm seems to be a good choice for a natural Gd converter in backwards configuration, whereas for ^{157}Gd only a thickness of around 10μm is needed. Measurement of the detection efficiency of a detector with ^{155}Gd converter are nor available in the literature.

To summarize, the implementation and treatment of Gd in Geant4 needs improvement, in particular for the individual isotopes. The numbers obtained for natural Gd seem to be acceptable compared to published literature. In the latest Geant4 version 10.2.p02 the amount of conversion electrons per captured neutron has changed for ^{157}Gd and ^{155}Gd, and agrees now roughly with the literature. But unfortunately in the new version the kinetic energies of the conversion electrons are not correct, since conversion electrons are only produced from the lowest E2 transition. Additionally, the gamma energies are also wrong. This improvement of the description is an ongoing process within the Geant4 collaboration.

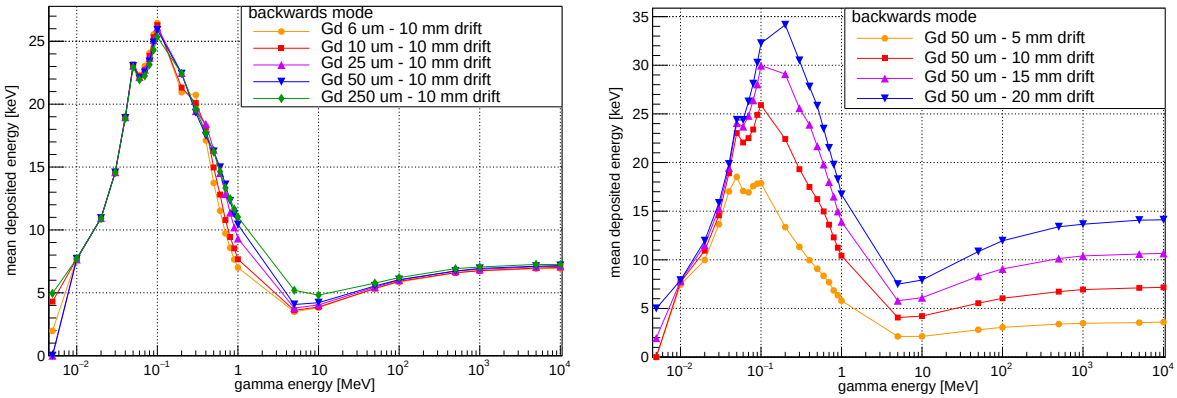
5.2 Gamma sensitivity of Gd based neutron detectors

There are two reasons why Gadolinium-based neutron detectors are more sensitive to gamma background than ^{3}He, ^{6}Li, or ^{10}B based detectors. As explained in section 5.1, the Gd conversion electrons deposit only a small amount of energy, which makes it difficult to use the signal amplitude to discriminate between conversion electrons and gammas. Note that the gammas are detected by processes which produce an electron, and therefore are very similar in nature to the signal events of interest from neutrons. In addition to the small amount of deposited energy, Gadolinium is also a high Z material. In a high Z material gammas have a high probability to interact via Compton scattering or pair production. The resulting electrons then lead in the drift space of the detector to a similar signal as the conversion electrons. The direct detection of a gamma particle in the gas is very unlikely, since the interaction cross section for the used Ar/CO_2 70/30 at NTP is very low.

The gammas that are produced during the gamma cascade after the neutron capture are not considered background, and hence not treated in this section. These gammas also interact via Compton Scattering and Pair production with the converter, and one or more of the resulting electrons can reach the drift space and is detected. For a detector with a natural Gd converter of 25μm thickness and a 10 mm drift, for 1.5% of the neutrons an electron produced by one of the gammas of the gamma cascade reaches the drift space. The positions at which these electrons exit the converter are comparable to the position at which the conversion electrons exit the converter. The gammas that are produced during the cascade are therefore not

compromising the position resolution of the detector.

Figure 5.4 shows the mean deposited energy of gamma particles of different energies that impinge in the backwards direction on the converter. Figure 5.4(a) proves that the mean deposited energy per gamma depends only weakly on the thickness of the converter. In general, the thinner the converter the smaller the mean deposited energy, but this effect is only apparent for gammas between 200 keV and 10 MeV. With a mean energy deposit of 23 keV to 27 keV, the mean energy deposition of the gammas between 50 keV and 300 keV is very similar to the mean energy deposited by the conversion electrons for the same drift thickness (5.2(b)). Figure 5.4(b) illustrates that the larger the drift space of the detector, the larger the mean deposited energy of gammas with an energy of 40 keV or larger.



(a) Varying converter thickness,10 mm drift length

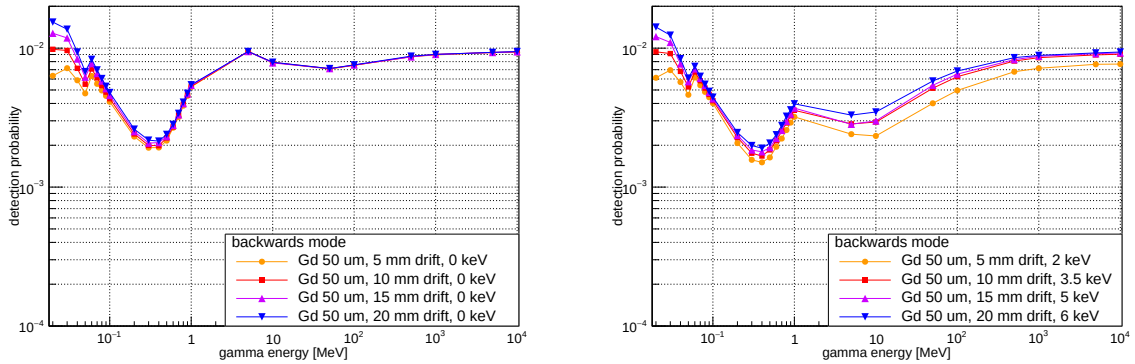
(b) Varying drift length, 50 μm converter thickness

Figure 5.4. *Mean deposited energy of gammas in backwards configuration depending on varying converter thickness and drift length.*

In figures 5.5 and 5.6 the influence of different energy thresholds on the gamma detection probability is studied. Without an energy threshold, the gamma sensitivity lies between 10^{-3} and 10^{-2}. The sensitivity of the detector is the highest for X-rays between 20 keV and 60 keV and for fast gammas with energies over 5 MeV. Except for the X-rays between 20keV and 60 keV, the gamma sensitivity is basically independent of the drift thickness. Subsequently for each of the drift thicknesses, an energy threshold is applied that cuts away 5$\%$, 10$\%$ and 25$\%$ of the conversion electron signal. This threshold has been derived from the percentiles in figure 5.2(b). Figure 5.6(b) shows that only a high threshold that cuts away 25$\%$ of the conversion electron signal significantly reduces the gamma sensitivity to X-rays below 100 keV, and to gammas above 1 GeV. Whereas without a threshold the sensitivity in this range is 10^{-2}, the 25$\%$ threshold reduces it to $5 \cdot 10^{-3}$ for the X-rays and 10^{-3} for the fast gammas. Gammas with an energy between 1 MeV and 100 MeV are already considerably affected by the 5$\%$ and 10$\%$ thresholds.

If possible, the gamma background at the NMX instruments should be reduced and adapted to the sensitivity of the detectors. Especially X-rays under 100 keV should be avoided. Under these conditions, a gamma threshold that reduces the conversion electron signal by 5$\%$ is realistic. For the most common gamma energy range of 100 keV up to 10 MeV the resulting gamma sensitivity amounts to $2 \cdot 10^{-3}$.

Measurements using a 5$\%$ threshold confirmed a gamma sensitivity of $2 \cdot 10^{-3}$ for 511 keV and 1274.5 keV gammas from a ^{511}Na source, and a gamma sensitivity of $6 \cdot 10^{-3}$ for 59.5 keV gammas from a ^{241}Am source. The results from measurements and simulations

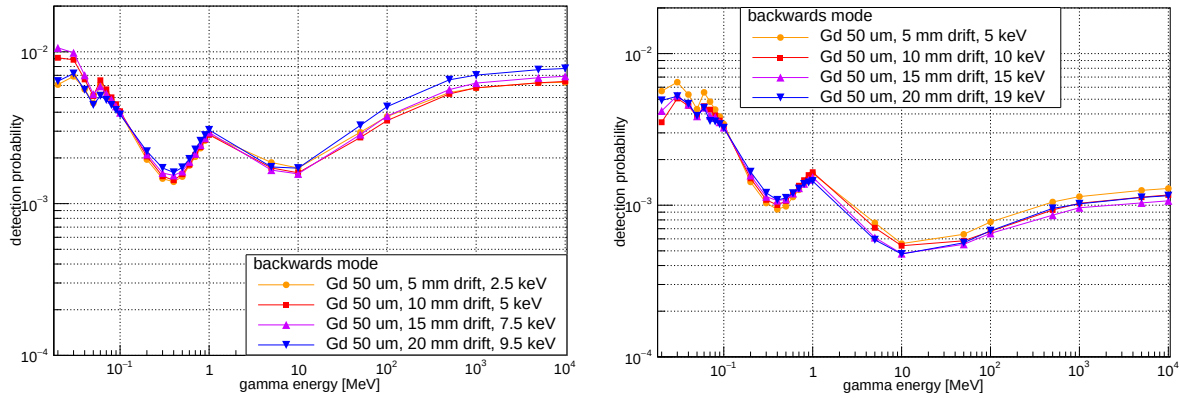


(a) Without threshold

(b) 5 % energy threshold

Figure 5.5. *Gamma detection probability for 50 μm converter thickness without a threshold and after the application of a threshold that cuts away 5% of the conversion electron detection efficiency.*

suggest that Boron should be used as shielding material and material for the beam dump. The Boron neutron capture reaction produces with a probability of 94 % a 478 keV gamma. This is preferable to obtaining multiple high energy gammas (MeV range) from Cadmium or Gadolinium shielding, since the gamma sensitivity to the 478 keV gamma is lower than the sensitivity to gammas in the MeV range.



(a) 10 % energy threshold

(b) 25 % energy threshold

Figure 5.6. *Gamma detection probability for 50 μm converter thickness after the application of a threshold that cuts away 10% or 25% of the conversion electron detection efficiency.*

5.3 Studies of enriched Gd converters

Natural Gadolinium powder, sputter targets and foils can be obtained from several suppliers. Enriched ^{157}Gd and ^{155}Gd on the other hand is difficult to obtain [20]. The initial detector for the NMX instrument at ESS, Lund, Sweden, will be constructed using a natural Gadolinium converter. However, in view of a potential future performance upgrade of the detector during the operations phase, it is desirable to investigate the viability of an enriched Gadolinium cathode.

CERN and ESS are in contact with the Swedish company Neonest AB [21] that offers enriched ^{157}Gd as metallic powder. Enriched ^{155}Gd is only available as oxide in powder form, and would have first to be converted to a metal. Therefore and due to the higher detection efficiency attainable with ^{157}Gd, the focus lies on enriched ^{157}Gd. Isotope enriched materials are strategic supplies. Whilst China is the main producer of rare-earth elements, it does not isotope enrich them. There are worldwide two historical producers of isotope enriched Gd: The US and Russia. In the US production has now ceased, but there is a remaining stockpile available for strategic use, and managed as part of the strategic isotope supply coordinated by the US Department of Energy. There is little information on the size of the Russian stockpile, but the enriched Gd offered by Neonest AB originally comes from Russia. Prices are ca 5 USD/mg for small quantities. As there is almost no demand for the isotope enriched material, this availability should remain into the near future.

To create a converter from the metallic ^{157}Gd powder, the powder has to be melted and an ingot has to be produced. This ingot can then be rolled into a foil. Companies like Goodfellow [22] that roll Gadolinium foils usually start from large rectangular ingots. Due to the high price of the enriched Gd, the production of a large ingot is out of the budget scope for this project. Presently a collaboration is ongoing with Goodfellow to test the melting of 5 g of natural Gd powder to produce an ingot. If the manufacturing of the ingot works, two ingots will be produced to assess the risk of production with this valuable material. From one of them a 10 μm thick foil will be rolled, from the other one a 25μm thick foil. If the melting tests and the rolling of the foils are successful, another experiment will determine the minimum amount of Gd powder necessary to produce a foil. Assuming only relatively small losses during the production process, the experiment will then be repeated with this amount of enriched Gd powder from Neonest AB. The aim is to obtain a small enriched Gd cathode that can be used to measure the achievable detection efficiency and to refine the simulation. Depending on the results of these measurements, the use of enriched Gd converters will be considered as an upgrade option for the NMX detectors. The exact amount of material needed depends on the losses during the fabrication process of the cathodes, but amounts in any case to at least 220 g of enriched Gd.

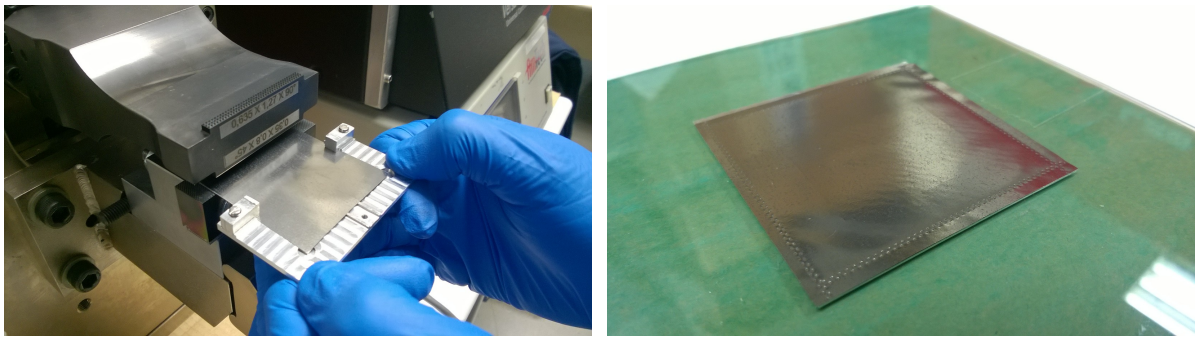
5.4 Manufacturing of large Gd cathode

For the small 10 x 10 cm^2 detector prototypes, the Gd cathodes were produced at CERN, as part of its activities in BrightnESS WP4, by glueing a 10 x 10 cm^2 Gd foil produced by Goodfellow to a frame. Goodfellow rolls Gd foils in the standard thicknesses of 10μm, 25μm, 50μm, 100μm and 250μm. Taking into consideration the detection efficiency, gamma sensitivity and robustness of the detector design, the preferred converter thickness is 10μm or 25μm. Since it is not trivial to create a Gd coating of such a thickness, foil production methods are preferred. Foil production also offers a higher material efficiency than physical vapour deposition methods, which first require the production of a sputter target. With regard to the elevated cost of enriched Gd material, this is especially relevant for the production of enriched Gd cathodes. Thin coatings of Gadolinium also have the tendency to oxidize through. This process can be arrested by applying a capping layer of ZrN to the coating [24]. Oxidization studies of foils on the other hand show that foils only oxidise at the surface. An oxidization layer of a few 100 nm thickness is quickly formed, subsequently the foils remain stable over decades.

The maximum available foil size in 10μm and 25μm thickness is 10 x 20 cm^2. To produce a 60 x 60 cm^2 cathode, 18 pieces of 10 x 20 cm^2 foils or 36 pieces of 10 x 10 cm^2 foils have to be joined. To achieve maximum mechanical stability and durability, the idea is to produce a

grid-like 60 x 60 cm^2 Aluminium frame with 36 openings of 9.5 x 9.5 cm^2. The 36 pieces of the 10 x 10 cm^2 Gd foils are then welded to the frame.

Ultrasonic welding tests were carried out at branches of Branson Ultrasonics in Geneva and Barcelona [23]. Ultrasonic welding of Gadolinium is novel and unstudied. Whereas 10μm thick Gd foils could not be welded without destroying the foil, figure 5.7(a) shows the successful welding of a 25μm thick Gd foil to a Al support. Attempts to weld Gd to Gd have not been successful. Figure 5.7(b) shows the finished cathode. As next step measurements with the welded cathode are foreseen to check whether the weld has an influence on detection efficiency and position resolution. Subsequently the welding of a larger size cathode composed of several quadratic foils in planned. The tests so far show that ultrasonic welding can create a build-able and durable 60 x 60 cm^2 natural Gd cathode of a suitable thickness. This cathode meets the requirements for the detector for the NMX instrument and is feasible and affordable.



(a) Ultrasonic welding

(b) Welded Gd cathode

Figure 5.7. *Ultrasonic welding of a Gd foil to an Aluminium frame.*

Summary & Conclusion

The development of Gadolinium based GEM detectors for the NMX instrument at ESS, Lund, Sweden is funded by the European Union through the BrightnESS project. Simulations and first measurements demonstrate that the Gd-GEM will be able to successfully tackle the position resolution challenge. A position resolution of around 200μm is achievable. Large progress has been made in the understanding of the properties of Gd converters, leading to the determination of the appropriate converter and drift thickness. This constitutes the framework for the final design of the converter. The GEANT4 simulation of the relevant properties of Gd is only partially reliable, and needs tuning. Some experimental results are available to be used from the literature. The gamma background will be higher than for a ^{10}B or ^{3}He based detector, but with around 10^{-3} depending on the incoming gamma energy still acceptable. This meets the detector requirements for the NMX instrument.

The strategic availability of enriched Gadolinium has been investigated, as a potential future upgrade of the detectors. Two potential suppliers have been identified, and 2 industrial collaborations with Goodfellow and Neonest AB are ongoing to study the cost-efficient manufacturing of enriched Gd converters.

Ultrasonic welding using a machine by Branson Ultrasonics has been identified as suitable technology to produce a 60 x 60 cm^2 natural Gd cathode. Welding Gd is novel. A mechanically reliable and affordable cathode can be produced in this manner.

The complete work on Gd converters is presently being summarised for a future journal publication on this topic.

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