The Effect of Shielding on the Detection Probability of Nuclear Material Outside of Regulatory Control

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Abstract

Detecting nuclear material outside of regulatory control is a key part of nuclear security efforts. The purpose of this project was to look at the effect of polyethylene and lead shielding on the detection probability of nuclear materials, using Californium-252 and a liquid organic scintillator Radiation Portal Monitor developed by KTH Royal Institute of Technology. To assess this, five types of particle events were detected: single γ-photons, single neutrons, γ-γ coincidences, γ-neutron coincidences and neutron-neutron coincidences. These were detected during five hour measurements, one for the bare source and one for each type of shielding. The results confirmed previous knowledge about radiation shielding - the polyethylene decreased the neutron radiation more and the lead decreased gamma radiation more - and were promising regarding the ability of the RPM to detect shielded sources.

Acknowledgements

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Contents

1 Introduction

Nuclear and radioactive materials, used in the wrong way, can have catastrophic effects on health, environment and political stability. Therefore, nonproliferation of such materials is of high priority.

1.1 Nuclear Security and Radiation Portal Monitors

The International Atomic Energy Agency (IAEA) defines nuclear security as "The prevention and detection of, and response to, theft, sabotage, unauthorized access, illegal transfer or other malicious acts involving nuclear material, other radioactive substances or their associated facilities." in their safety glossary [1]. This is different from nuclear safety, which mainly concerns the prevention and mitigation of accidents, and from nuclear safeguards, which is the means by which IAEA verifies states' commitment to peaceful use of nuclear material [2].

One important part of nuclear security is the detection of nuclear and radioactive materials in places where these might be unlawfully transported, for example sea- and airports, mail centres and border crossings. This is commonly done using Radiation Portal Monitors (RPMs). These passive radiation detection devices look for radiation, mainly gamma and neutrons, while persons, objects and vehicles are passing through them, and alert if the radiations levels surpass a predefined threshold. Previous RPM systems have only had the ability to alert the presence of the material, but scientists at the KTH Royal Institute of Technology have recently developed a way to also discern its precise location. This negates the need for inspectors to manually verify it. [3]

Some of the materials that are most commonly looked for by RPMs are weapons-grade nuclear materials, such as plutonium and uranium, and substances that could be used in radiological dispersion devices (RDDs). The latter uses conventional explosives to disperse radioactive, but non-fissile, materials throughout a larger area. These materials have been main targets of nuclear security efforts due to their possible use in acts of terrorism. [3]

1.2 Fission and Its Products

In the fission process a heavy nucleus splits into two lighter nuclei, usually combined with the release of gamma photons and/or neutrons. This can be induced by neutron bombardment, or it can happen naturally through so called spontaneous fission. In theory, all heavy nuclei should be susceptible to spontaneous fission, but only the heaviest manage to overcome the potential barrier that is created by the distortion of the nucleus.[4] Generally, spontaneous fission happens for nuclei with an atomic number above 230 [5].

Other than the two lighter nuclei created during fission, it is also very common to have one or more gamma rays as a fission product. Gamma rays are a type of electromagnetic radiation, meaning it consists of photons, and typically has energies around 0, 1-10 MeV. If these gamma rays are emitted during the actual fission they are called prompt gammas. Gamma rays can also occur as radiation from the decay of the two fission fragments, and are then called delayed gammas. Many spontaneous fission events, especially those of nuclei heavier than uranium, also emit several prompt neutrons, and their fission fragments may emit delayed neutrons. [6]

For most fissile materials it is not uncommon that one fission event releases multiple gamma photons, neutrons or both at the same time. These events are called coincidences: γ-γ if it is two photons, γ-neutron if it is one of each and neutron-neutron if it is two neutrons. These events can be detected by all types of detectors, with good enough time resolution, by registering the time between each particle detection and grouping together those with small enough differences. Since photons and neutrons have very different mass and travel at very different speeds, γ-neutron coincidences are expected to have the largest mean time difference of all types of coincidences. Knowledge about coincidences can help discern the location of a source, since the coincidence time differences will vary depending on the distance to the detectors. [7]

1.3 Interactions With Matter by Gamma Rays and Neutrons

Due to their large differences in characteristics, gamma photons and neutrons interact with matter in very different ways. Generally though, almost all of their respective interactions are in some way affected by the energy of the incident particle and the atomic number Z of the absorber material.

1.3.1 Gamma Rays

Gamma photons have a large amount of possible interactions with matter, but the three most significant in radiation detection are *photoelectric effect*, *Compton scattering* and *pair production*. All of these processes involve the transfer of energy from photons to electrons, and can therefore all be used for detection of radiation, since this relies on charged particles. [4]

During the photoelectric effect, a gamma photon transfers all of its energy to a bound electron in an atom. Subsequently, the photon is annihilated, and an electron is ejected from the atom with the kinetic energy E_{e^-}. The energy is described by equation (1)

$$E_{e^-} = hv - E_b \tag{1}$$

where hv is the energy of the incident photon and E_b is the binding energy of the electron in its original shell. This process is the most prevalent mode of interaction for low energy gamma rays, and the probability of it also increases with a high atomic number Z of the absorber material. This is firstly due to the large amounts of electrons present in these. Secondly, the interaction commonly happens with electrons of the inner shells and these have a high binding energy for atoms with a high Z number, which increases the probability of photoelectric effect since it relies on tightly bound electrons to be able to transfer all of the photons energy and avoid scattering. Roughly, the probability of photoelectric effect, τ, can be described by equation (2)

$$\tau \approx \text{constant} \cdot \frac{Z^n}{E_\gamma^{3.5}} \tag{2}$$

where Z is the atomic number of the absorber material, n varies between 4 and 5, and E_γ is the incident photon energy. [4]

Compton scattering can happen both with bound and loose electrons. In this interaction, an incident gamma photon deposits part of its energy to an electron through a collision. The amount of energy that is transferred is dependent on the angle between the scattered photon and its initial trajectory, and reaches its peak when the photon is completely back-scattered. In the observed energy spectrum of a detector, these varying energies can be seen as the Compton continuum, where the maximum energy is called the Compton edge. This interaction is most abundant for mid-energy photons and is therefore the predominant process through which the gammas of most common radioisotopes interact with matter. Like photoelectric effect it also increases in probability with higher Z of the absorber material. [4]

Pair production happens for high energy gamma photons. Specifically, it requires that the energy of the photon exceeds what corresponds to the rest mass of two electrons ($\approx$ 1.02 MeV), and it remains uncommon until they surpass that by some additional MeV. During the interaction, which takes place in the coulomb field of a nucleus, the photon disappears and an electron-positron replaces it. Any excess energy goes toward kinetic energy. The positron is soon thereafter annihilated with a free electron, producing two 511 keV gamma photons. [4]

The probability of each interaction, in relation to the incident photon energy and the atomic number Z of the absorber material is illustrated in figure 1. The left line indicates the instances in which photoelectric effect and Compton scattering is equally likely, and the right line represents the times where Compton scattering and pair production is equally likely.

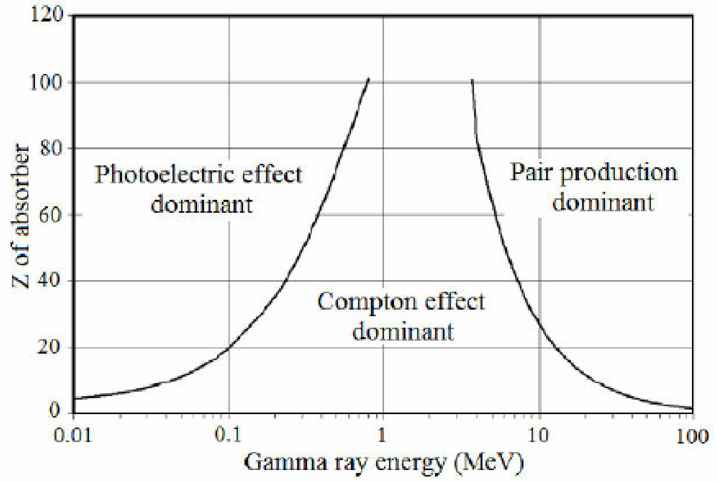

Figure 1: The relative importance of different gamma ray interactions, depending on photon energy and atomic number of absorber material. [8].

1.3.2 Neutrons

During all types of interactions between neutrons and matter, the interaction happens with the nucleus of the atom rather than the electrons. Similarly to gamma photons, the type of interaction that is most likely is dependent on the kinetic energy of the incident particle.

For slow neutrons, those with lower energy than 0.5 eV, the significant types of interactions are elastic scattering and neutron-induced nuclear reactions. In the case of neutrons, the elastic scattering is defined as a process in which the total kinetic energy of the system is not changed. In other words, any energy that the neutron loses becomes kinetic energy in the recoil nucleus. Just like in Compton scattering, the energy of the neutron and recoil nucleus depends on the angle of the collision and is highest when the neutron is completely back-scattered. Due to the low energy, however, even complete back-scattering is not enough to get a recoil nucleus with a easily detectable energy. [4]

For detection of slow neutrons, the most important type of interaction is neutron-induced nuclear reactions, also called absorption reactions since the incident neutron is completely absorbed and a compound nucleus is formed instead. For most materials, the radiative capture reaction is most common. In this, the compound nucleus decays through one or more gamma rays and is therefore written as (n, γ). Since the decay product is gamma photons, this is not very useful for detection purposes. Instead, reactions such as (n, α), (n, p) and (n, fission) are more preferred due to their charged decay products. [4]

The probability of neutron-induced nuclear reactions decrease as neutron energy increases. Instead, scattering reactions become more important and probable. Elastic scattering of fast neutrons is very good for detection purposes since a significant amount of energy can be transferred. With fast neutrons of sufficiently high energy, the possibility for inelastic scattering also appears. In the case of neutrons, this means that the collision excites the recoil nucleus, which then de-excites with the emission of a gamma ray. During inelastic scattering, the neutron loses more energy than it would have during an elastic scattering. This is good for shielding purposes but bad for detection since more energy than necessary ends up with an undetectable particle. [4]

For elastic scattering, independent of neutron energy, the interaction is more useful for shielding and detection with lower atomic number Z of the absorber material. This is due to these atoms having a nucleus mass more similar to the mass of a neutron, which allows more of the kinetic energy to be transferred to the recoil nucleus during the collision. [4]

1.4 Attenuation and Shielding

Attenuation is the decreasing intensity of a type of radiation while it travels through a material. This is dependent on different things depending on the type of radiation and the material it interacts with, but generally has a correlation to the sum of the probabilities of different matter interactions.

1.4.1 Gamma Ray Attenuation

As described in 1.3.1, gamma photons can interact with matter in three main ways: photoelectric effect, Compton scattering and pair production. The probability of photoelectric effect for a certain material and incident photon energy is described by τ, the Compton scattering probability by σ and the pair production probability by κ. The sum of these probabilities, seen in equation (3),

$$\mu = \tau(\text{photoelectric}) + \sigma(\text{Compton}) + \kappa(\text{pair}) \tag{3}$$

is called the linear attenuation coefficient, and describes the probability per unit length that a gamma photon is lost from the total radiation when traveling through a material. When picking a material for shielding gammas, the best choice is to pick something with a high linear attenuation coefficient. Generally, this always means something with a high atomic number, like lead. [4]

1.4.2 Neutron Attenuation

The probability of an interaction between neutrons and a material is usually described by the nuclear cross section, σ. The nuclear cross section somewhat dependent on the area around a nucleas in which a certain interaction can happen and, therefore, it has the unit barn (b), which is defined as 10^{-28} m^2. The cross section is different for each type of interaction, and also depends on the speed of the neutron and the stability of the target nucleus. Like with gamma rays, the total probability of interaction, or total cross section σ_{tot}, is the sum of the probability of each type of interaction, as shown in equation (4), [9]

$$\sigma_{\text{tot}} = \sigma_{\text{elastic scatter}} + \sigma_{\text{inelastic}} + \sigma_{\text{fission}} \cdots \tag{4}$$

The cross section σ is sometimes also called the microscopic cross section, meaning it describes the attenuation properties of a single nucleus. When looking at an entire material it is more practical to look at the macroscopic cross section, Σ. This is defined as

$$\Sigma_{\text{tot}} = \text{N} \cdot \sigma_{\text{tot}} \tag{5}$$

where N is the total atom density of the material. When choosing a neutron shielding material, the best ones are generally those with high atom density but low atomic number, or with a large fraction of atom with low atomic number. Many organic materials, like polymer plastics, fit this description due to their large fraction of hydrogen atoms. [9]

1.5 Organic Scintillators

Scintillation detectors utilize that some materials have the ability to emit detectable light, so called scintillation light, when hit by charged particle radiation. For the purpose of radiation detectors, the material should preferably also have some other qualities like being transparent to the wavelength of the scintillation light, having a linear conversion from kinetic energy to the energy of the light and producing very short bursts of light so that the detector will get good time resolution. In most organic scintillators the scintillation mechanism relies on specific types of electron energy level structures that appear in some materials. The scintillation works by exciting the electron into any one of a large number of possible states, with specific energy levels and very fine spacing between them. The light is then emitted during the de-excitation. [4]

Liquid organic scintillators are produced by dissolving an organic scintillator material in a suitable solvent. Sometimes there is also a third ingredient, added to shift the wavelength into something more appropriate for the detection. The liquid is usually encapsulated with something like glass or metal so that it can be treated like a solid scintillator. [4]

Independent of material, the scintillation light is very weak and requires some sort of extra device to amplify it into a detectable electrical current. In this experiment, and in most others, this is done with a photo-multiplier (PM) tube. The PM consists of two main parts: a photo-cathode and an electron multiplier structure. The photo-cathode converts the light photons into low energy electrons and the multiplier structure accelerates and increases the number of electrons so that they become a detectable current. This is done linearly so that the number of detected electrons is proportional to the initial light photons. [4]

With most organic scintillators, the majority of the scintillation light is emitted very quickly and very shortly after the radiation hits the material. This is called prompt fluorescence. In many cases there is also a more long-lived component called delayed fluorescence. How much of the light is emitted as delayed fluorescence and how long the delayed fluorescence last often depends on the type of radiation. Therefore, the detected distribution of scintillation light intensity over time can be used to discriminate between gamma rays and neutrons. This is called pulse shape discrimination (PSD), and is also what enables some detectors to track coincidences. [4]

In the case of the KTH Royal Institute of Technology RPM the scintillator liquid is EJ-309, which has properties like good PSD abilities, low toxicity and low fire hazard.

1.6 Aim

The aim of this project was to study the effects of shielding on the detection probability of nuclear materials, using californium-252 and the organic scintillator RPM developed by the KTH Royal Institute of Technology. For this purpose, two different materials were used - polyethelene (PE-1000) and lead - to be able to compare differences between the effects of neutron shielding and gamma shielding.

2 Method

For all measurements, the RPM from the KTH Royal Institute of Technology was set up with 4 detectors on each side, spread out in a zigzag pattern, as can be seen in figure 2. This setup differs from previous published studies with said RPM, where the detectors were placed in a 2-by-2 square pattern on each side, and was done to spread out the detectors over a larger area. In theory, this improves the detection abilities of the RPM since a larger percentage of the emitted particles could be detected. The RPM inside has a width (direction of y-axis) of 1 m, a height (z-axis) of 2 m and a depth (x-axis) of $0,5$ m. The detectors themselves are 127 mm diameter $\cdot$ 127 mm length cylindrical liquid organic scintillators (EJ-309). In all graphs or tables where detector number is mentioned, detectors 0-3 refer to the detectors on the left side, starting with 0 on the bottom and going upwards, and 4-7 refer to the detectors on the right side starting with 4 at the bottom.

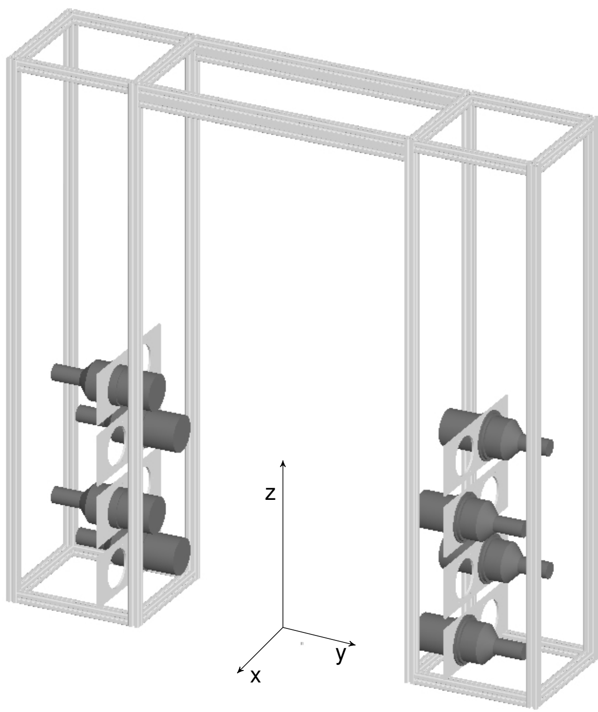

Figure 2: Illustration of RPM setup

The source material used in all measurements was a californium-252 sample with a mass of approximately $2,4 \cdot 10^{-9}$ g, encased in a ceramic cylinder with $4,6$ mm diameter and 6 mm height. Californium-252 decays with around $3,1\%$ spontaneous fission. The source, at this point in time, had a total activity of around $41,7$ kBq and a neutron activity of around $5,61$ kBq.

2.1 Measurements

The first measurement was carried out using the bare source, to have something to compare the shielded measurements with. For this, an aluminium beam was placed on top of the RPM, parallel to the x-axis. A piece of fishing line, with a $0,5$ kg weight tied to the other end, was tied to the beam. The source was then taped to the fishing line, with the center of the source located at the coordinates (x,y,z)=(0,0,52) cm, which along the z-axis is exactly in the middle of the detectors. A five hour measurement was carried out, and the input was processed using the CoMPASS DAQ software to discern and document all events (single gammas, single neutrons, gamma-gamma coincidences, gamma-neutron coincidences and neutron-neutron coincidences).

The second measurement was done like the first one, but with polyethylene (PE-100) shielding in the form of a cylinder. The cylinder had a cylinder shaped hole inside of it, just wide enough to fit the source, reaching down to $4,2$ cm from the bottom, where the source was placed. The actual PE had a thickness of 4 cm and the height of the entire cylinder was $8,3$ cm. The cylinder was placed on top of an aluminium beam (standing, parallel to the z-axis) so that the center of the source was once again at the coordinates (x,y,z)=(0,0,52) cm. The third measurement followed the same process, this time with the source taped to the fishing line again and lead shielding, in the form of $5 \cdot 10 \cdot 20$ cm blocks, placed around it so that there was 5 cm shielding in all directions.

The last measurement was done exactly like the first one but with the beam, fishing line and source placed so that the center of the source was at the coordinates (x,y,z)=(0,30,52) cm. This measurement was done to look at any differences between the data from this measurement and from when the bare source was placed in the center. This, in combination with the measurements of the shielded source, could give some implications about the effect of shielding on the RPMs ability to detect location.

2.2 Data Processing

All the data recorded by CoMPASS was later processed using a C++ code and the CERN ROOT software to sort the events into their respective categories, create histograms for each type of event and each combination of detectors and finally extract the data in numbers from said histograms. For some of the measurements, like total single gamma counts, the counts were divided by the measurement time to acquire a count rate (s^{-1}).

3 Results

Tables 1 and 2 show the total count rates of single gammas and single neutrons respectively, for each detector. The data was derived form tables 6 and 7, which can be seen in appendix A. As the tables show, the gamma count rate decreased slightly, in all detectors, from the polyethylene shielding and more from the lead shielding. The neutron count rate decreased slightly from the lead shielding and more from the PE shielding. For the measurement with the bare source at coordinates (x,y,z)=(0,30,52) cm, there is a clear increase in count rate for the two detectors closest to the source (5 and 6), both for gammas and neutrons, and a clear decrease in count rate for all detectors on the left side, especially for neutrons but also gamma photons.

Table 1: Total single γ count rate for all detectors.

Detector	No shielding	PE shielding	Lead Shielding	(0,30,52)
0	338,4877778	328,5455556	288,0561111	312,5311111
1	337,2444444	328,1322222	278,52	302,4866667
2	330,3888889	318,975	267,6077778	278,4294444
3	317,4155556	308,0583333	269,4361111	293,9861111
4	342,6922222	329,1016667	286,2866667	372,9633333
5	341,0488889	328,0472222	275,6394444	493,4422222
6	337,9694444	325,015	274,2477778	497,9272222
7	322,4694444	310,5327778	272,1538889	381,2122222

Table 2: Total single neutron count rate for all detectors.

Detector	No shielding	PE shielding	Lead Shielding	(0,30,52)
0	8,504944444	4,360722222	6,494222222	4,532833333
1	9,528611111	5,518611111	8,237611111	4,614444444
2	9,372	5,423611111	7,991333333	4,245722222
3	7,672666667	4,067444444	6,216833333	4,176555556
4	8,557388889	4,277222222	6,067888889	17,73455556
5	9,8504444449	5,603333333	8,391	35,14544444
6	9,478944444	5,398277778	8,283111111	34,66288889
7	7,944166667	4,055944444	6,448888889	17,75461111

The recorded γ-neutron coincidence counts, per each ns time difference between the γ-photon and neutron, can be seen in the histograms in figure 3. Numbers extracted from said histogram, the total amount of entries, the mean time difference and the variance of the time difference, can be seen in table 3. As both the histogram and the table shows, both the PE shielding and the lead shielding decreased the total amount of entries, but the decrease was much larger for lead. The numbers also show a slight implication that the lead shielding increases the mean time difference.

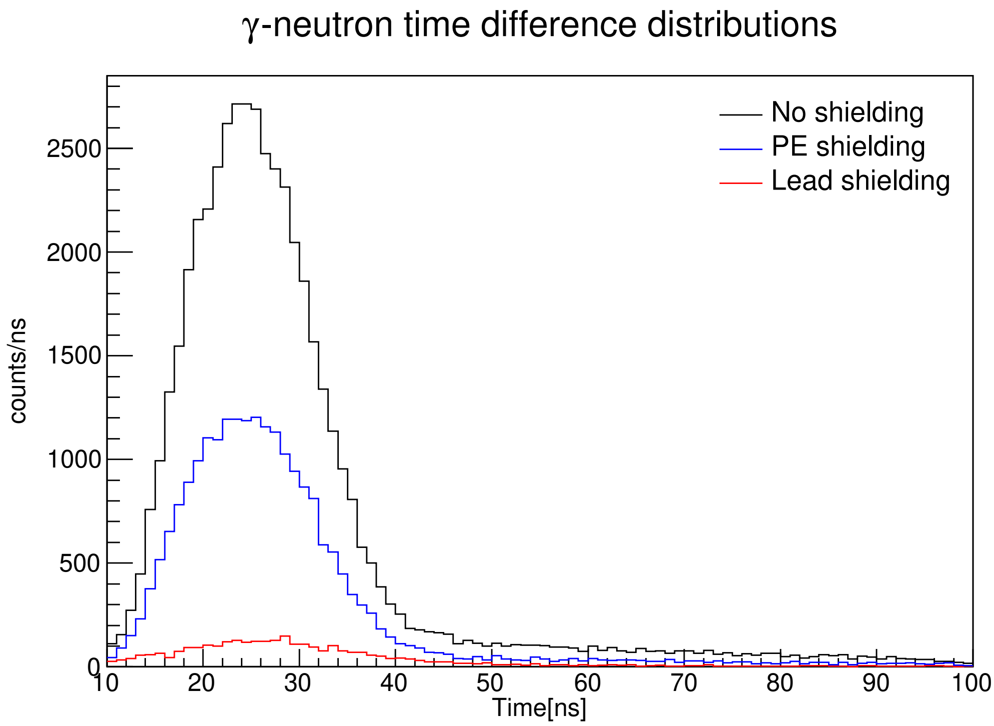

Figure 3: Time difference distribution for γ-neutron coincidences in all detectors.

Table 3: γ-neutron coincidence entries for all measurements.

	No shielding	**PE shielding**	**Lead shielding**
Entries	51452	23690	4288
Mean time difference	28,6587	27,989	31,0769
Variance	178,745	157,677	225,099

The neutron-neutron time difference distribution histograms can be seen in figure 4, and the corresponding table of compiled numbers for each histogram can be seen in table 4. Both the graph and the numbers show that PE shielding had the most effect on decreasing the number of counts, but the lead also had some. Any variation between the mean time differences is too small to imply a systematic trend.

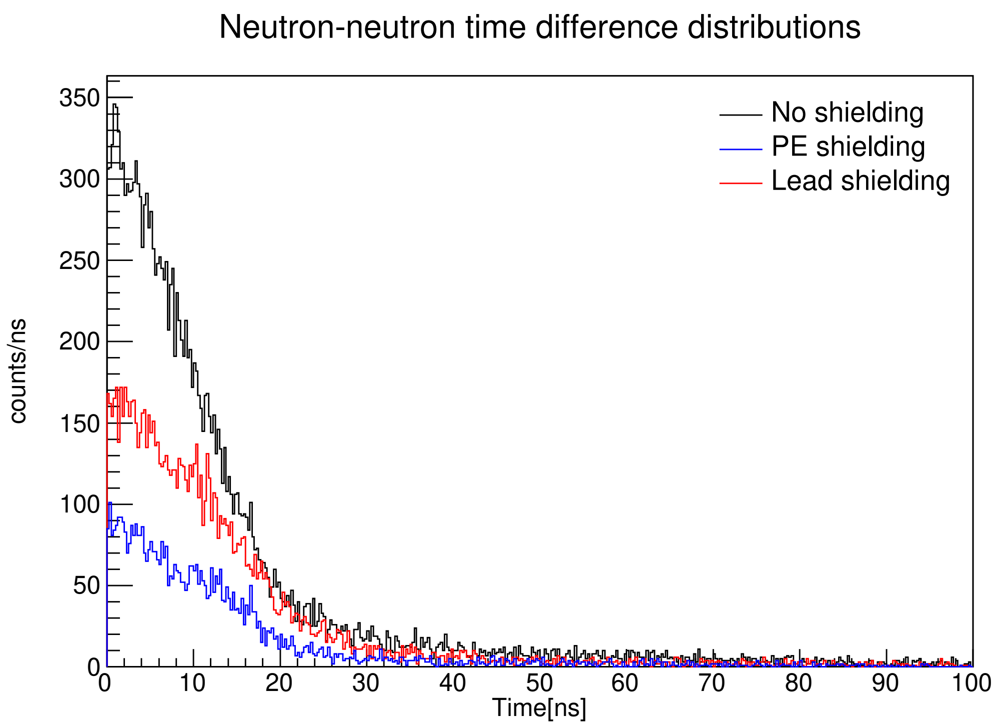

Figure 4: Time difference distribution for neutron-neutron coincidences in all detectors.

Table 4: Neutron-neutron coincidence entries for all measurements.

	No shielding	**PE shielding**	**Lead shielding**
Entries	17789	5289	10629
Mean time difference	13,0633	13,3295	13,4498
Variance	259,126	238,801	232,558

Figure 5 shows the histograms for the γ-γ coincidence time difference distributions for all measurements, and table 5 shows the corresponding numbers. As far as decreasing counts, PE was somewhat effective and lead more effective. For these numbers there is also, like with the γ-neutron coincidences, a clear difference in the time differences between the measurement without shielding and the one with lead shielding. However, the difference shows up mostly in the graph this time rather than the numbers. While the mean time difference is practically the same, the graph shows that this mean was reached in different ways for the two measurements. For the lead shielding, the peak of the distribution is much closer to the mean, and the shielding therefore seems to have caused a larger decrease of the coincidences with the shortest time differences than for the rest.

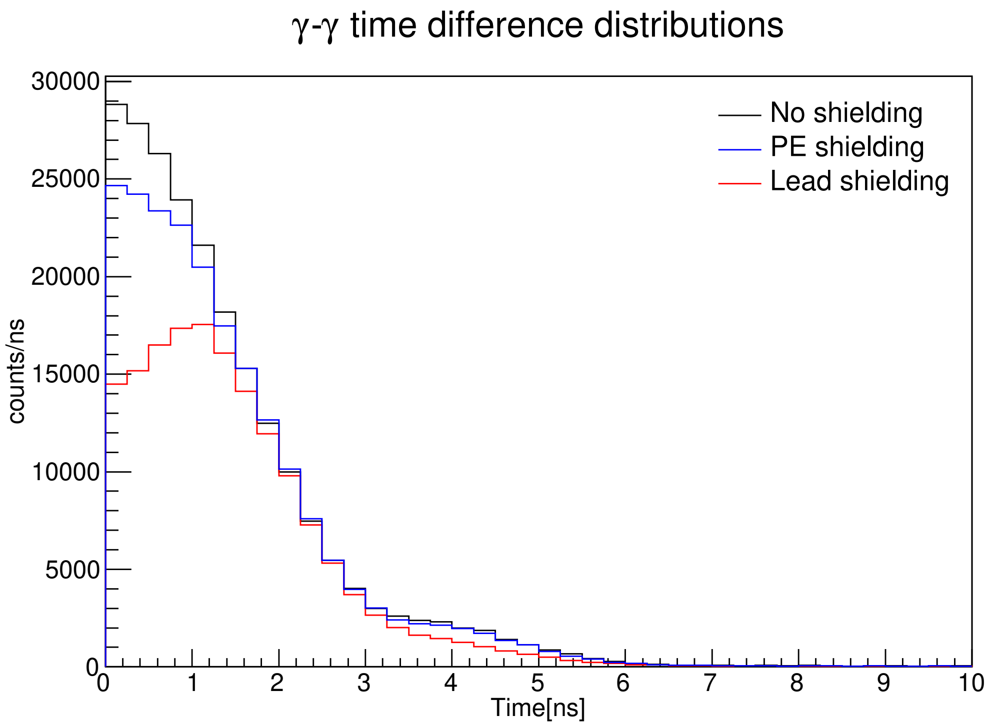

Figure 5: Time difference distribution for γ-γ coincidences in all detectors.

Table 5: γ-γ coincidence entries for all measurements.

	No shielding	**PE shielding**	**Lead shielding**
Entries	234124	217614	169642
Mean time difference	1,553	1,55709	1,5809
Variance	5,0198	4,3692	3,2802

For the last set of graphs, seen in figure 6, the results of the measurement with the bare source in the position (x,y,z)=(0,30,52) cm is compared with the results of the measurement with the bare source in the position (x,y,z)=(0,0,52) cm. It is important to note that instead of the y-axis displaying total counts, like in previous graphs, these display the percentage of the counts, and that the y-axis range is not the same on every graph.

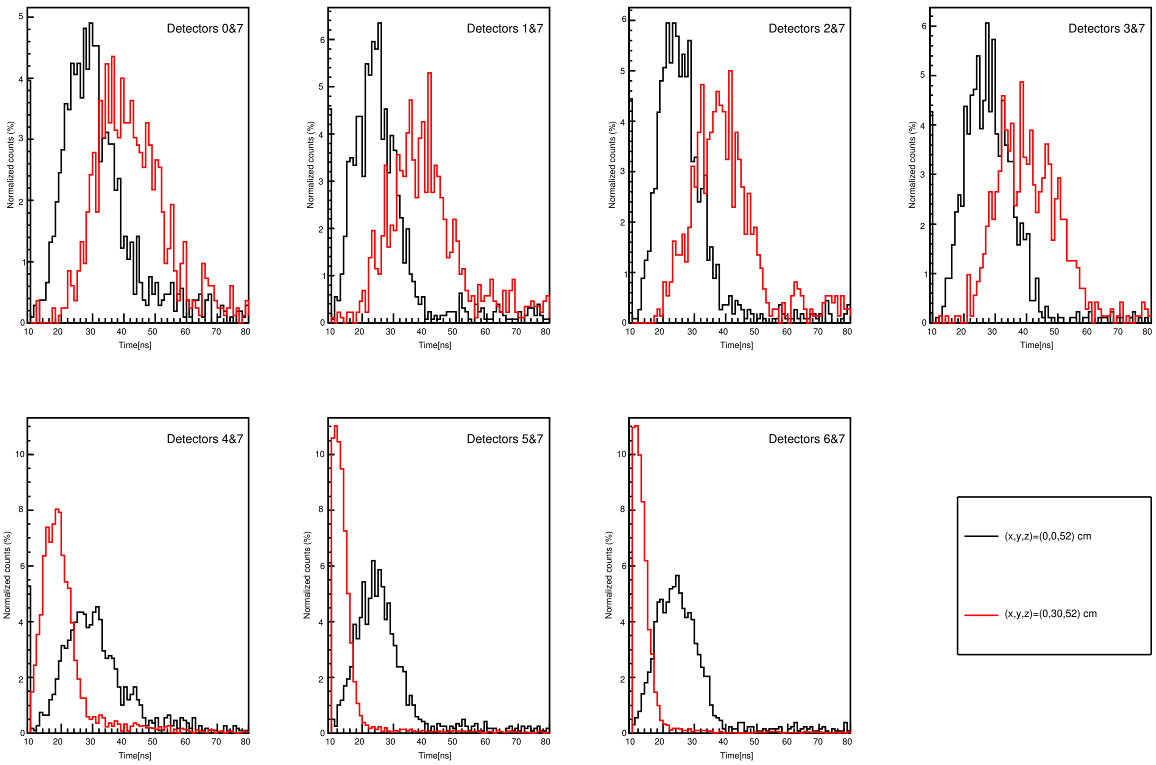

Figure 6: γ-neutron time difference distributions for two different source positions. Each panel corresponds to the time difference between the detection of a neutron in one detector and the corresponding detection of a γ-photon in detector 7.

The graphs shows a very clear difference between the two source positions, with the detectors on the right side (4-6) having a much shorter mean time difference and the counts for those being much more concentrated around the mean, for the position (x,y,z)=(0,30,52). Subsequently, the detectors on the left (0-3) display the opposite - longer mean time differences and a wider range of time differences. The graphs also shows a similar sentiment to that of tables 1 and 2; the amount of counts is larger for the detectors on the right side (4-7), and lower for the ones on the left (0-3), instead of being close to evenly distributed.

4 Discussion

The results show, both graphs and tables, that the shielding affected the radiation detection in the way that would be expected. The polyethylene shielding was more effective in decreasing neutron counts and count rates, while lead was more effective in decreasing the gamma radiation, but both lead and PE had some effect on both. More importantly though, neither type of shielding seems to decrease the count rate to the point where the RPM is no longer effective at detecting the source. However, the measurements done during this study were very long and in a real world application the RPM would have to do its job a lot faster, often even on moving sources. This warrants further research into the effects of shielding on shorter measurements, to assure that the RPM is still effective in those scenarios.

One interesting aspect of the results, albeit not entirely unexpected, was the change in coincidence time differences for γ-γ and γ-neutron. Lead seemed to increase the mean time difference for both of these, or at least decrease the amount of counts for the really low time differences.

As far as the measurements with the source moved to (x,y,z)=(0,30,52) cm goes, the results also show what is expected. The graphs show shorter time differences and larger amounts of coincidence counts for the detector combinations on the right side of the RPM (the side the source was closer to), and the opposite for the detectors on the left side.

The same is evident for single gamma photon and neutron counts.

Based on the results from this study, an interesting prediction can be made for the detection abilities for non-centered source positions. The combined results that different positions cause different coincidence time differences, and that lead shielding possibly changes time differences as well, means that the source localization abilities of the RPM might be distinctly lower for shielded sources. At least, it might hinder the detection of smaller changes in position. This area needs further study, preferably in combination with shorter measurement times to simulate more realistic conditions.

4.1 Conclusion

In conclusion, this study mainly confirmed previous knowledge on the effects on shielding on gamma and neutron radiation. It also showed promising results for the ability of the RPM to detect shielded elements, but lacks the possibility to accurately predict how this might work with more realistic conditions like shorter measurements and non-centered sources.

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A More Data

The following two tables represent the total amount of single gamma and neutron entries, for each detection during each measurement. This is the raw data used to derive the count rates seen in tables 1 and 2.

Table 6: Total single gamma entries for all detectors.

Detector	No shielding	PE shielding	Lead Shielding	(0,30,52)
0	6092780	5913820	5185010	5625560
1	6070400	5906380	5013360	5444760
2	5947000	5741550	4816940	5011730
3	5713480	5545050	4849850	5291750
4	6168460	5923830	5153160	6713340
5	6138880	5904850	4961510	8881960
6	6083450	5850270	4936460	8962690
7	5804450	5589590	4898770	6861820

Table 7: Total single neutron entries for all detectors.

Detector	No shielding	PE shielding	Lead Shielding	(0,30,52)
0	153089	78493	116896	81591
1	171515	99335	148277	83060
2	168696	97625	143844	76423
3	138108	73214	111903	75178
4	154033	76990	109222	319222
5	177308	100860	151038	632618
6	170621	97169	149096	623932
7	142995	73007	116080	623932

The following sixteen tables show the γ-γ, γ-neutron and neutron-neutron coincidence entries, their mean time difference and the time difference variance for all measurements.

Table 8: Coincidences for all combinations of detectors.

Detectors	Entries gg	Mean gg	Variance gg	Entries nn	Mean nn
1-0	21371.0	-0.229547	3.37691	265.0	15.6944
2-0	10794.0	0.538108	5.94652	218.0	16.3776
3-0	5460.0	0.0434308	11.134	171.0	14.6522
4-0	2605.0	0.221849	20.0858	215.0	13.4452
5-0	3067.0	0.299645	18.5031	216.0	16.0107
6-0	3051.0	-0.239793	17.5154	211.0	12.9862
7-0	2560.0	-0.0173996	20.3814	263.0	11.6305
0-1	21371.0	0.229547	3.37691	522.0	13.2829
2-1	19963.0	0.818278	3.13654	430.0	10.7061
3-1	10304.0	0.314152	5.81802	332.0	12.7712
4-1	3037.0	0.540936	19.0378	391.0	13.6424
5-1	3380.0	0.567303	16.9321	417.0	12.3156
6-1	3473.0	0.209932	16.4002	413.0	10.8718
7-1	2906.0	0.283491	18.3737	428.0	12.0301
0-2	10794.0	-0.538108	5.94652	360.0	13.8481
1-2	19963.0	-0.818278	3.13654	362.0	11.7452
3-2	19554.0	-0.431918	3.2799	437.0	12.709
4-2	2964.0	-0.311323	20.2477	480.0	12.8576
5-2	3303.0	-0.184521	17.5227	412.0	13.3545
6-2	3331.0	-0.619047	15.2306	331.0	11.7693
7-2	2844.0	-0.45622	17.4642	293.0	12.8055
0-3	5460.0	-0.0434308	11.134	182.0	16.0915
1-3	10304.0	-0.314152	5.81802	170.0	15.6102
2-3	19554.0	0.431918	3.2799	222.0	14.4773
4-3	2447.0	0.147432	21.0197	312.0	12.6682
5-3	2819.0	0.205027	15.799	246.0	11.3446
6-3	2814.0	-0.213979	18.3719	182.0	14.7142
7-3	2365.0	-0.128075	18.7498	171.0	18.3163

Table 9: Coincidences for all combinations of detectors.

Detectors	Entries gg	Mean gg	Variance gg	Entries nn	Mean nn
0-4	2605.0	-0.221849	20.0858	209.0	13.4791
1-4	3037.0	-0.540936	19.0378	182.0	10.2358
2-4	2964.0	0.311323	20.2477	249.0	15.3913
3-4	2447.0	-0.147432	21.0197	259.0	11.6109
5-4	21649.0	0.137276	3.12998	282.0	13.6994
6-4	10981.0	-0.310892	6.13314	199.0	16.1219
7-4	5595.0	-0.414441	10.7407	220.0	17.6102
0-5	3067.0	-0.299645	18.5031	406.0	12.9376
1-5	3381.0	-0.574529	17.1036	388.0	12.0437
2-5	3303.0	0.184521	17.5227	413.0	11.0607
3-5	2819.0	-0.205027	15.799	432.0	12.9708
4-5	21649.0	-0.137276	3.12998	508.0	13.0519
6-5	21076.0	-0.420966	3.75936	448.0	11.7869
7-5	10721.0	-0.424944	5.99951	341.0	13.0587
0-6	3051.0	0.239793	17.5154	503.0	13.1282
1-6	3473.0	-0.209932	16.4002	400.0	11.6793
2-6	3331.0	0.619047	15.2306	395.0	12.0819
3-6	2814.0	0.213979	18.3719	329.0	15.1376
4-6	10981.0	0.310892	6.13314	417.0	13.4178
5-6	21076.0	0.420966	3.75936	389.0	12.6351
7-6	19862.0	0.0375821	2.91549	491.0	14.2542
0-7	2561.0	0.007631	20.6178	342.0	12.5405
1-7	2906.0	-0.283491	18.3737	274.0	11.7453
2-7	2844.0	0.45622	17.4642	203.0	11.6838
3-7	2365.0	0.128075	18.7498	178.0	13.9319
4-7	5595.0	0.414441	10.7407	215.0	14.166
5-7	10721.0	0.424944	5.99951	218.0	13.011
6-7	19862.0	-0.0375821	2.91549	235.0	11.8808

Table 10: Coincidences for all combinations of detectors.

Detectors	Variance nn	Entries ng	Mean ng	Variance ng
1-0	352.552	876.0	26.3573	162.356
2-0	371.086	788.0	27.0157	155.359
3-0	359.931	627.0	30.5685	179.109
4-0	269.845	735.0	30.9203	127.34
5-0	442.308	868.0	26.9408	174.714
6-0	334.699	847.0	26.3079	167.254
7-0	276.821	682.0	29.3535	150.018
0-1	118.784	923.0	31.9756	154.345
2-1	162.027	1065.0	27.7564	202.202
3-1	156.887	805.0	30.6935	169.729
4-1	230.978	942.0	31.8582	147.162
5-1	305.238	1116.0	28.3047	186.227
6-1	249.312	1025.0	27.3975	213.269
7-1	232.734	877.0	28.69	142.627
0-2	258.963	874.0	30.9699	162.831
1-2	183.183	1017.0	26.6093	175.298
3-2	203.37	841.0	29.5752	144.401
4-2	222.731	901.0	31.9281	189.727
5-2	329.661	1067.0	27.2842	203.001
6-2	284.581	1067.0	26.1145	177.14
7-2	285.363	844.0	29.0219	155.444
0-3	313.217	712.0	31.6849	187.467
1-3	332.509	810.0	26.1448	175.985
2-3	351.337	759.0	27.9917	214.922
4-3	284.106	707.0	31.078	152.951
5-3	259.976	857.0	26.9232	158.46
6-3	405.573	789.0	26.1728	170.477
7-3	573.548	625.0	28.9684	180.036

Table 11: Coincidences for all combinations of detectors.

Detectors	Variance nn	Entries ng	Mean ng	Variance ng
0-4	248.379	678.0	31.0807	175.531
1-4	162.229	825.0	27.1592	209.911
2-4	461.367	808.0	26.4721	182.589
3-4	240.894	699.0	30.639	218.472
5-4	266.292	851.0	26.977	171.124
6-4	424.414	811.0	26.7524	207.22
7-4	433.092	626.0	29.1029	177.421
0-5	202.538	965.0	31.3343	157.846
1-5	266.216	1018.0	26.8232	167.942
2-5	230.538	1127.0	27.3672	193.344
3-5	269.713	847.0	29.3769	167.461
4-5	142.179	960.0	31.7726	183.955
6-5	210.51	1081.0	26.2207	178.506
7-5	230.926	873.0	29.1946	165.904
0-6	200.441	1019.0	31.3031	160.351
1-6	235.697	1019.0	27.0151	182.333
2-6	275.128	1057.0	27.4538	175.985
3-6	373.952	831.0	31.1247	227.803
4-6	149.782	950.0	31.4664	150.465
5-6	219.858	1055.0	27.0766	170.09
7-6	244.49	869.0	29.2429	163.033
0-7	205.875	749.0	31.2303	157.224
1-7	228.177	893.0	27.2196	190.831
2-7	291.417	789.0	27.59	190.093
3-7	300.175	648.0	28.5829	105.433
4-7	189.063	759.0	31.349	171.928
5-7	247.102	824.0	27.2243	183.092
6-7	225.188	856.0	27.0257	192.368

Table 12: Coincidences for all combinations of detectors, with PE shielding.

Detectors	Entries gg	Mean gg	Variance gg	Entries nn	Mean nn
1-0	20935.0	-0.234202	3.04583	97.0	13.27
2-0	10592.0	0.508457	5.55233	76.0	16.1613
3-0	5075.0	0.0939937	9.53818	39.0	14.0423
4-0	2111.0	0.286922	21.0699	61.0	13.0457
5-0	2649.0	0.319433	17.3957	52.0	15.2508
6-0	2138.0	-0.169394	18.064	73.0	11.5604
7-0	2067.0	0.121695	21.7064	64.0	10.137
0-1	20935.0	0.234202	3.04583	173.0	14.842
2-1	19432.0	0.868891	2.52956	158.0	12.2688
3-1	9977.0	0.311413	5.58748	105.0	14.5682
4-1	2537.0	0.510907	17.3249	93.0	13.2359
5-1	2600.0	0.500082	17.4826	121.0	10.8931
6-1	2823.0	0.19822	17.4823	111.0	10.8671
7-1	2332.0	0.322508	18.0773	117.0	11.2607
0-2	10592.0	-0.508457	5.55233	124.0	14.5226
1-2	19432.0	-0.868891	2.52956	161.0	12.1619
3-2	19374.0	-0.468305	2.80398	159.0	12.9388
4-2	2065.0	-0.158806	19.6499	96.0	13.2789
5-2	2767.0	-0.125743	16.9282	112.0	11.6813
6-2	2687.0	-0.47825	16.5906	97.0	12.2718
7-2	2319.0	-0.506533	18.5695	91.0	13.3326
0-3	5075.0	-0.0939937	9.53818	62.0	13.7166
1-3	9977.0	-0.311413	5.58748	50.0	13.2083
2-3	19374.0	0.468305	2.80398	68.0	13.8701
4-3	2011.0	0.158218	23.7283	70.0	13.2775
5-3	2282.0	0.335108	17.6106	55.0	10.7008
6-3	2370.0	-0.447738	18.0747	56.0	12.4072
7-3	1988.0	-0.261652	21.012	47.0	18.5326

Table 13: Coincidences for all combinations of detectors, with PE shielding.

Detectors	Entries gg	Mean gg	Variance gg	Entries nn	Mean nn
0-4	2111.0	-0.286922	21.0699	53.0	17.1256
1-4	2537.0	-0.510907	17.3249	55.0	14.4343
2-4	2065.0	0.158806	19.6499	52.0	10.6477
3-4	2011.0	-0.158218	23.7283	84.0	11.7884
5-4	20735.0	0.139421	2.81012	90.0	16.1678
6-4	10457.0	-0.329767	6.40056	62.0	16.6543
7-4	4949.0	-0.315605	11.1965	54.0	21.0188
0-5	2649.0	-0.319433	17.3957	89.0	14.4668
1-5	2600.0	-0.500082	17.4826	124.0	9.66858
2-5	2767.0	0.125743	16.9282	111.0	9.89941
3-5	2282.0	-0.335108	17.6106	127.0	13.8513
4-5	20735.0	-0.139421	2.81012	171.0	12.1513
6-5	20220.0	-0.452827	3.20401	166.0	12.491
7-5	10058.0	-0.50688	5.06674	122.0	16.2153
0-6	2138.0	0.169394	18.064	142.0	16.0796
1-6	2823.0	-0.19822	17.4823	122.0	10.5634
2-6	2687.0	0.47825	16.5906	99.0	15.5229
3-6	2370.0	0.447738	18.0747	109.0	14.3468
4-6	10457.0	0.329767	6.40056	119.0	15.9753
5-6	20220.0	0.452827	3.20401	156.0	12.8847
7-6	19598.0	0.0211783	2.79523	165.0	13.6642
0-7	2067.0	-0.121695	21.7064	71.0	12.5131
1-7	2332.0	-0.322508	18.0773	66.0	12.7072
2-7	2319.0	0.506533	18.5695	53.0	14.6652
3-7	1988.0	0.261652	21.012	39.0	9.41538
4-7	4949.0	0.315605	11.1965	52.0	14.165
5-7	10058.0	0.50688	5.06674	59.0	12.0732
6-7	19598.0	-0.0211783	2.79523	87.0	15.8453

Table 14: Coincidences for all combinations of detectors, with PE shielding.

Detectors	Variance nn	Entries ng	Mean ng	Variance ng
1-0	215.492	434.0	25.5506	158.443
2-0	256.817	414.0	27.0337	179.489
3-0	294.233	248.0	29.2799	139.852
4-0	246.924	294.0	31.1519	181.749
5-0	463.651	391.0	26.585	169.819
6-0	275.665	362.0	26.0701	135.466
7-0	115.778	303.0	28.1785	112.675
0-1	165.786	443.0	31.0113	135.356
2-1	151.177	510.0	27.1337	162.92
3-1	275.865	415.0	30.2527	175.83
4-1	203.829	369.0	30.9061	157.73
5-1	166.486	523.0	27.8969	174.172
6-1	200.606	531.0	25.9429	132.242
7-1	163.216	374.0	29.9179	154.043
0-2	188.385	406.0	30.2979	143.888
1-2	175.206	526.0	25.5682	140.876
3-2	120.253	384.0	29.2738	157.283
4-2	234.565	372.0	30.6625	162.833
5-2	205.611	514.0	26.6033	154.865
6-2	246.561	546.0	25.6874	142.118
7-2	343.348	346.0	29.9047	195.314
0-3	225.001	312.0	30.7036	166.847
1-3	179.746	369.0	26.7768	191.425
2-3	156.799	372.0	27.0979	159.395
4-3	364.887	305.0	31.5299	187.542
5-3	316.051	374.0	26.1831	144.753
6-3	395.386	377.0	25.6938	149.948
7-3	468.261	277.0	28.8725	139.978

Table 15: Coincidences for all combinations of detectors, with PE shielding.

Detectors	Variance nn	Entries ng	Mean ng	Variance ng
0-4	297.277	281.0	30.6325	132.499
1-4	446.612	366.0	26.2823	173.235
2-4	237.526	409.0	25.2152	111.68
3-4	220.848	291.0	29.2336	142.449
5-4	302.736	410.0	26.6232	165.977
6-4	412.437	371.0	25.218	144.562
7-4	569.618	276.0	28.8187	158.564
0-5	293.903	386.0	30.3233	127.487
1-5	177.117	528.0	25.9636	155.232
2-5	162.781	514.0	26.0445	170.459
3-5	354.333	345.0	28.8424	155.314
4-5	86.3208	430.0	29.8558	158.744
6-5	178.283	549.0	25.7196	133.679
7-5	300.125	409.0	28.7035	145.738
0-6	259.461	423.0	30.8074	153.329
1-6	179.208	516.0	26.4412	138.919
2-6	338.998	529.0	26.6531	144.236
3-6	320.483	391.0	29.6078	123.282
4-6	254.613	446.0	31.8054	147.105
5-6	185.129	571.0	26.6095	142.621
7-6	141.31	413.0	30.0957	166.102
0-7	212.359	287.0	30.8671	136.702
1-7	329.486	407.0	26.7754	164.602
2-7	412.339	393.0	26.4196	163.498
3-7	48.5503	278.0	28.9836	142.457
4-7	162.679	268.0	31.05	138.658
5-7	230.883	399.0	27.4933	179.659
6-7	324.692	370.0	26.655	188.214

Table 16: Coincidences for all combinations of detectors, with lead sheilding.

Detectors	Entries gg	Mean gg	Variance gg	Entries nn	Mean nn
1-0	19149.0	-0.213172	2.56843	164.0	13.7128
2-0	8970.0	0.637693	4.40423	140.0	14.5493
3-0	4088.0	0.238673	10.5699	109.0	14.4444
4-0	1323.0	0.107346	23.1279	120.0	15.4142
5-0	1124.0	0.620846	24.9086	134.0	11.6678
6-0	349.0	0.0589226	51.9704	119.0	12.886
7-0	965.0	-0.211813	34.3412	129.0	14.0036
0-1	19149.0	0.213172	2.56843	285.0	14.4508
2-1	17588.0	0.853841	2.5585	279.0	14.274
3-1	8684.0	0.335211	4.62438	200.0	15.1138
4-1	1139.0	0.152126	28.3893	199.0	13.5166
5-1	352.0	0.00315909	52.7396	246.0	10.7452
6-1	843.0	0.147752	33.6909	239.0	11.2677
7-1	269.0	1.42301	61.7865	253.0	13.0219
0-2	8970.0	-0.637693	4.40423	206.0	15.1235
1-2	17588.0	-0.853841	2.5585	231.0	12.5374
3-2	17157.0	-0.483714	2.45602	250.0	13.4936
4-2	317.0	-1.12543	46.2884	203.0	14.3011
5-2	1004.0	-0.196352	30.9143	259.0	11.8119
6-2	313.0	0.152505	55.8206	203.0	13.5532
7-2	1078.0	-0.765448	28.3429	209.0	14.4034
0-3	4088.0	-0.238673	10.5699	130.0	14.1474
1-3	8684.0	-0.335211	4.62438	156.0	15.7522
2-3	17157.0	0.483714	2.45602	176.0	11.664
4-3	657.0	0.00644901	36.7549	154.0	13.1988
5-3	277.0	-0.178534	43.1662	141.0	12.6543
6-3	1077.0	0.0531318	27.2295	110.0	12.1107
7-3	1142.0	-0.216164	29.2042	115.0	14.2169

Table 17: Coincidences for all combinations of detectors, with lead sheilding.

Detectors	Entries gg	Mean gg	Variance gg	Entries nn	Mean nn
0-4	1323.0	-0.107346	23.1279	127.0	16.5235
1-4	1139.0	-0.152126	28.3893	109.0	13.8527
2-4	317.0	1.12543	46.2884	104.0	13.5163
3-4	657.0	-0.00644901	36.7549	119.0	12.5247
5-4	18717.0	0.14179	2.434	171.0	12.8248
6-4	9164.0	-0.320886	4.65862	120.0	14.1203
7-4	4013.0	-0.36527	10.3174	107.0	16.883
0-5	1124.0	-0.620846	24.9086	224.0	13.2548
1-5	352.0	-0.00315909	52.7396	243.0	11.7707
2-5	1004.0	0.196352	30.9143	277.0	11.6875
3-5	277.0	0.178534	43.1662	205.0	11.8951
4-5	18717.0	-0.14179	2.434	286.0	15.3933
6-5	18183.0	-0.482961	2.42242	244.0	11.971
7-5	8576.0	-0.546426	4.7404	260.0	14.7676
0-6	349.0	-0.0589226	51.9704	248.0	14.1228
1-6	843.0	-0.147752	33.6909	266.0	12.5054
2-6	313.0	-0.152505	55.8206	294.0	12.7
3-6	1077.0	-0.0531318	27.2295	201.0	13.8529
4-6	9164.0	0.320886	4.65862	245.0	14.7553
5-6	18183.0	0.482961	2.42242	328.0	13.2297
7-6	17403.0	-0.0281605	2.40705	301.0	13.3068
0-7	965.0	0.211813	34.3412	155.0	15.8673
1-7	269.0	-1.42301	61.7865	146.0	12.8966
2-7	1078.0	0.765448	28.3429	141.0	11.4024
3-7	1142.0	0.216164	29.2042	131.0	14.2387
4-7	4013.0	0.36527	10.3174	128.0	14.6395
5-7	8576.0	0.546426	4.7404	139.0	14.2866
6-7	17403.0	0.0281605	2.40705	147.0	11.9442

Table 18: Coincidences for all combinations of detectors, with lead shielding.

Detectors	Variance nn	Entries ng	Mean ng	Variance ng
1-0	266.359	47.0	24.4865	107.108
2-0	212.792	63.0	27.006	114.862
3-0	308.295	38.0	34.0204	260.198
4-0	317.882	34.0	32.0298	215.378
5-0	296.259	41.0	28.026	207.754
6-0	324.44	32.0	29.5496	183.5
7-0	301.946	39.0	32.0578	125.944
0-1	138.067	66.0	32.2726	219.385
2-1	276.594	68.0	29.5246	173.889
3-1	247.354	56.0	32.8585	162.1
4-1	137.262	60.0	35.3901	220.428
5-1	128.547	75.0	26.8753	116.626
6-1	185.436	80.0	31.6429	260.045
7-1	204.082	60.0	32.1379	140.103
0-2	241.159	73.0	31.851	255.644
1-2	207.393	85.0	27.508	161.141
3-2	161.205	59.0	31.115	156.807
4-2	219.995	44.0	36.5478	259.346
5-2	194.667	77.0	31.073	356.91
6-2	315.776	61.0	27.7415	170.095
7-2	270.846	45.0	33.358	172.38
0-3	170.064	50.0	33.6387	149.033
1-3	343.213	43.0	27.1866	117.709
2-3	151.602	58.0	31.4287	249.753
4-3	282.436	40.0	35.0894	324.862
5-3	319.658	62.0	28.4076	186.317
6-3	163.947	50.0	31.9343	349.505
7-3	320.83	31.0	35.5047	258.472

Table 19: Coincidences for all combinations of detectors, with lead shielding.

Detectors	Variance nn	Entries ng	Mean ng	Variance ng
0-4	298.969	36.0	33.9284	323.249
1-4	278.586	47.0	28.6242	199.309
2-4	262.204	32.0	32.8643	457.529
3-4	219.13	36.0	30.736	83.4442
5-4	227.359	33.0	29.3858	117.929
6-4	328.648	53.0	31.1365	264.412
7-4	325.884	27.0	36.2735	342.163
0-5	181.74	56.0	35.0908	211.324
1-5	186.814	73.0	32.6419	242.985
2-5	232.656	68.0	30.2498	260.884
3-5	158.826	56.0	32.9953	197.414
4-5	224.003	76.0	29.1874	140.117
6-5	200.309	81.0	26.144	210.657
7-5	261.043	54.0	29.1251	242.971
0-6	200.814	57.0	31.4558	133.752
1-6	251.936	77.0	30.8479	288.499
2-6	271.617	67.0	30.8471	320.197
3-6	250.273	58.0	36.4205	330.793
4-6	150.735	59.0	32.7079	168.621
5-6	243.703	78.0	34.1292	341.047
7-6	149.066	74.0	32.1416	253.176
0-7	358.92	36.0	31.1026	200.103
1-7	226.546	49.0	28.246	246.847
2-7	281.091	41.0	28.3351	83.6601
3-7	276.21	37.0	32.7365	149.959
4-7	244.702	35.0	35.5675	315.289
5-7	234.472	54.0	29.9059	198.428
6-7	225.846	63.0	29.525	192.196

Table 20: Coincidences for all combinations of detectors, (x,y,z)=(0,30,52).

Detectors	**Entries gg**	**Mean gg**	**Variance gg**	**Entries nn**	**Mean nn**
1-0	19759.0	-0.234656	2.78908	102.0	18.7135
2-0	8828.0	0.733689	5.28368	69.0	18.066
3-0	4330.0	0.102909	10.4308	65.0	25.5539
4-0	2705.0	-0.359292	22.3191	22.0	22.5954
5-0	4354.0	-0.910497	15.0749	28.0	23.7291
6-0	4450.0	-1.42052	15.515	38.0	29.7044
7-0	2666.0	-0.895415	18.9427	17.0	26.6454
0-1	19759.0	0.234656	2.78908	135.0	15.7911
2-1	16994.0	0.968022	2.74502	81.0	15.5258
3-1	8936.0	0.324935	5.44804	102.0	17.0928
4-1	2775.0	-0.259276	21.8673	30.0	22.5034
5-1	4582.0	-0.785212	15.6908	22.0	26.3775
6-1	4646.0	-1.13645	15.3598	24.0	32.8852
7-1	2667.0	-0.563103	19.0999	26.0	32.4325
0-2	8828.0	-0.733689	5.28368	84.0	18.0593
1-2	16994.0	-0.968022	2.74502	94.0	15.8862
3-2	17034.0	-0.62989	2.65546	109.0	16.4951
4-2	2518.0	-1.04822	19.573	37.0	14.4115
5-2	4387.0	-1.67889	13.2243	40.0	23.4188
6-2	4174.0	-2.12214	12.6647	23.0	25.2301
7-2	2592.0	-1.53997	17.8493	23.0	37.8996
0-3	4330.0	-0.102909	10.4308	54.0	19.4306
1-3	8936.0	-0.324935	5.44804	65.0	16.9922
2-3	17034.0	0.62989	2.65546	68.0	14.5411
4-3	2496.0	-0.508218	23.8784	33.0	15.9935
5-3	4167.0	-1.00887	16.3703	26.0	30.3899
6-3	4181.0	-1.57784	14.9303	11.0	40.1879
7-3	2591.0	-1.01506	18.4745	27.0	39.5338

Table 21: Coincidences for all combinations of detectors, (x,y,z)=(0,30,52).

Detectors	Entries gg	Mean gg	Variance gg	Entries nn	Mean nn
0-4	2705.0	0.359292	22.3191	362.0	27.535
1-4	2775.0	0.259276	21.8673	433.0	24.2349
2-4	2517.0	1.0387	19.3528	458.0	24.6859
3-4	2496.0	0.508218	23.8784	514.0	25.0753
5-4	33463.0	-0.22254	5.43332	824.0	12.4925
6-4	22620.0	-0.820643	7.97202	500.0	17.3435
7-4	10425.0	-0.526518	10.8898	781.0	11.037
0-5	4354.0	0.910497	15.0749	938.0	34.2758
1-5	4582.0	0.785212	15.6908	1158.0	29.677
2-5	4387.0	1.67889	13.2243	1139.0	29.5531
3-5	4167.0	1.00887	16.3703	1219.0	31.0464
4-5	33463.0	0.22254	5.43332	4380.0	11.2644
6-5	49235.0	-0.490668	5.39466	3592.0	7.4281
7-5	23277.0	-0.25546	7.47536	2951.0	11.0703
0-6	4450.0	1.42052	15.515	1322.0	33.2091
1-6	4646.0	1.13645	15.3598	1232.0	30.8155
2-6	4174.0	2.12214	12.6647	1146.0	30.7372
3-6	4181.0	1.57784	14.9303	885.0	33.1422
4-6	22620.0	0.820643	7.97202	2906.0	12.6053
5-6	49235.0	0.490668	5.39466	4308.0	7.86243
7-6	34918.0	0.184703	4.59502	4272.0	10.3212
0-7	2666.0	0.895415	18.9427	556.0	26.227
1-7	2667.0	0.563103	19.0999	490.0	25.3762
2-7	2592.0	1.53997	17.8493	386.0	25.4977
3-7	2591.0	1.01506	18.4745	373.0	30.132
4-7	10425.0	0.526518	10.8898	1033.0	11.1759
5-7	23277.0	0.25546	7.47536	649.0	13.0305
6-7	34918.0	-0.184703	4.59502	760.0	10.8705

Table 22: Coincidences for all combinations of detectors,(x,y,z)=(0,30,52).

Detectors	Variance nn	Entries ng	Mean ng	Variance ng
1-0	334.15	190.0	36.9441	154.09
2-0	289.769	154.0	40.7883	239.583
3-0	608.747	154.0	38.7994	170.515
4-0	402.608	683.0	19.2795	95.5803
5-0	580.727	807.0	16.6081	191.674
6-0	713.456	692.0	15.3167	134.017
7-0	450.054	685.0	19.6814	184.077
0-1	190.2	203.0	42.6564	188.765
2-1	157.713	181.0	39.3348	204.771
3-1	264.277	170.0	41.5401	154.038
4-1	469.948	759.0	20.2031	107.024
5-1	565.789	936.0	16.186	149.508
6-1	699.756	816.0	15.997	160.71
7-1	689.783	749.0	19.6403	159.737
0-2	183.455	185.0	41.9462	225.876
1-2	317.543	155.0	37.7084	187.583
3-2	221.45	153.0	40.0506	221.254
4-2	309.253	698.0	19.1747	105.514
5-2	360.794	697.0	17.2439	203.592
6-2	486.322	590.0	16.2774	173.406
7-2	884.927	614.0	18.074	108.047
0-3	309.167	183.0	42.4636	168.602
1-3	157.615	180.0	41.5107	296.43
2-3	213.763	171.0	41.0256	235.312
4-3	200.784	667.0	19.7067	120.178
5-3	610.173	724.0	16.7177	178.858
6-3	587.852	586.0	17.6277	255.158
7-3	987.39	626.0	19.0056	137.951

Table 23: Coincidences for all combinations of detectors, (x,y,z)=(0,30,52).

Detectors	Variance nn	Entries ng	Mean ng	Variance ng
0-4	248.837	757.0	43.9651	203.507
1-4	311.617	757.0	41.3641	224.22
2-4	295.912	709.0	40.7903	204.797
3-4	261.431	684.0	42.0972	189.938
5-4	283.195	4173.0	15.5963	117.545
6-4	423.873	3693.0	15.0086	103.755
7-4	303.743	2966.0	19.352	116.21
0-5	232.424	1746.0	43.8642	175.122
1-5	225.26	1735.0	41.0399	192.96
2-5	214.502	1590.0	41.3297	213.406
3-5	207.091	1500.0	42.701	179.76
4-5	107.953	7197.0	21.0199	108.559
6-5	151.536	9050.0	15.0786	103.592
7-5	178.466	6884.0	19.3016	97.6013
0-6	202.283	1882.0	43.8875	164.1
1-6	243.749	1868.0	41.704	225.147
2-6	240.664	1650.0	42.2388	218.221
3-6	254.017	1601.0	43.1134	195.46
4-6	154.03	7156.0	21.5997	113.871
5-6	147.278	10897.0	15.7087	104.557
7-6	105.585	7270.0	20.1351	117.885
0-7	224.578	803.0	43.5664	171.8
1-7	261.608	849.0	41.7892	207.663
2-7	254.401	721.0	41.9128	218.253
3-7	342.892	702.0	43.23	213.153
4-7	195.588	3353.0	21.2433	104.569
5-7	310.031	4922.0	15.5715	105.184
6-7	246.504	4451.0	14.7575	78.5854