1 Theoretical background

1.1 Gamma Radiation

During the transition between two different energetic states of a nucleus the energy difference is emitted in form of an electro magnetic wave. According to the energy above $200keV$ we call this gamma radiation. The interactions of such high energetic radiation with atoms has mostly a particle character. Therefor we call the photon of the radiation gamma quant.
Gamma radiation can be observed when after a particle radiation like $\beta - radiation$ the nucleus is in an exited state and relaxes to an energy state of lower energy.

1.2 Interaction of gamma radiation with mater

1.2.1 Photo effect

A gamma quant doing a photo effect is giving his complete energy to an electron of a most frequently inner shell. This electron leaves the atom and moves with a kinetic energy equal to:

$$E_{kin} = h\nu_0 - E_W \tag{1}$$

Where ν_0 is the energy of the gamma quant and E_W is the energy that the electron needs to quit the atom.
After the electron has left, electrons of higher energy states can take the state of the leaving electron emitting radiation of much lower energy than the gamma quant.

1.2.2 Compton effect

In this case the gamma quant is scattered at an electron of an outer shell. The scattering process can be described as an inelastic momentum transmission. Also here the scattered electron leaves the atom. The wavelength λ of the scattered gamma quant can be calculated as followed:

$$\lambda = \lambda_0 + \frac{h}{m_e c}(1 - cos(\theta)) \tag{2}$$

λ_0 being the initial wavelength, m_e is the rest mass of an electron and θ is the scattering angle of the gamma quant.

1.2.3 Pair production

For photons with an energy above $1,02MeV$ which is the rest energy of two electrons, there is the possibility, that the photon interacts with the electric field of an nucleus and materializes. In this case the energy is converted into one electron and one positron and the kinetic energy of those two particles.

1.2.4 Absorption

All these effects occur with a certain probability. Statistically we can say that the number of photons absorbed in a thin layer dx in a specific material is proportional to the distance x the photons traveled in the material. From this it follows for the intensity I of the radiation:

$$dI = I_0 \mu dx \rightarrow I(x) = I_0 e^{-\mu x} \tag{3}$$

Where μ is the absorption coefficient, depending on the absorbing material and the photon energy.
It is important to note, that this exponential behavior of absorption is a result of a more complex overlapping of the three interactions discussed above. Depending on the energy of the photon there is a certain probability for each of the three interactions to occur.

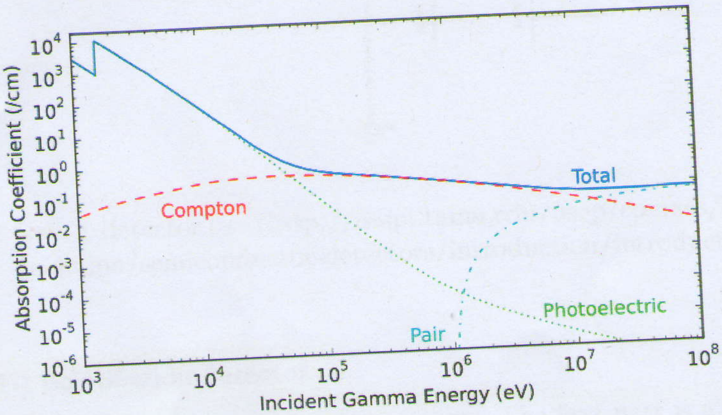

Abbildung 1: Absorption coefficient of Aluminum in dependence of photon energy (https://en.wikipedia.org/wiki/File:Al-gamma-xs.svg)

1.3 Gamma radiation detectors

Gamma radiation detectors are used to measure the energy of incoming photons. By different constructions scientists tried to minimize the dead time and the energy resolution of the detectors.

1.3.1 Ge detector

When gamma radiation is passing through the depletion region of an Ge(Li) p-n-junction, new electron-hole pairs are created. Due to the electric field in this region they are accelerated to the boarders of the region. Being amplified and measured, this current will be proportional to the energy of the incoming photon.
In order to built a good semiconductor detector one has to minimize the time that the

created electrons move in the region, to minimize the dead time of the detector. One has also to think about the size of the depletion region such that the whole energy can be absorbed. Since Ge has a very small band gap, it is important to cool the detector to reduce the offset current.

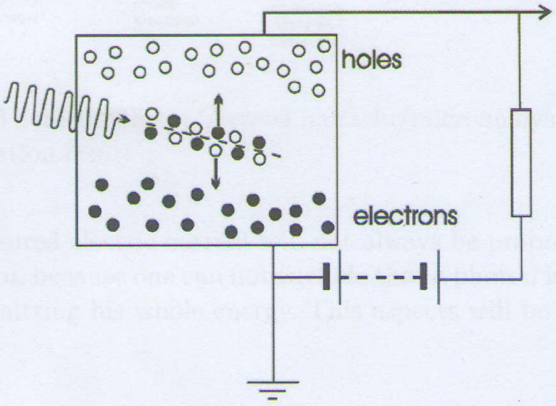

Abbildung 2: Ge detector (http://nsspi.tamu.edu/nsep/courses/basic-radiation-detection/semiconductor-detectors/introduction/introduction)

1.3.2 NaJ(Ti) Scintillation detector

The NaJ Scintillation detector consists of two parts. The first part is a Cristal in which the gamma radiation is absorbed. As a result of the interactions with atoms of the scintillator free electrons are created. While these electrons move through the Cristal they are slowed down under imitation of light.
This light is directed into the photomultiplier in which it creates photoelectrons. These photoelectrons are accelerated from dynode to dynode by an external voltage. In this way one gets out of a single photon a measurable current which is proportional to the the energy of incoming photon.

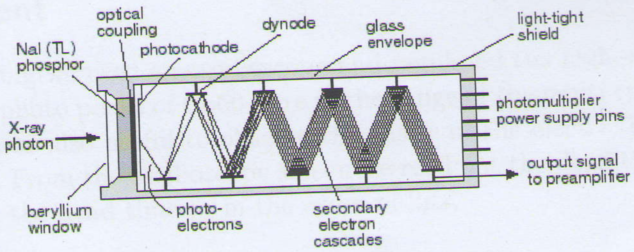

Abbildung 3: NaJ(Ti) detector (http://www4.nau.edu/microanalysis/Microprobe/WDS-Scintillation.html)

Obviously the measured electric current will not always be proportional to the energy of the incoming photon, because one can not exclude that a photon is leaving the detector again with out transmitting his whole energy. This aspects will be discussed below.

1.3.3 Data analysis

Since photons will enter the detectors frequently, it will by impossible to measure this currents manually. Therefor we use a device which is sorting the impulses by their hight and counting them in different channels.

The measured spectrum will have some characteristic sharp peaks which correspond to photons which are making a photo effect. Give their complete energy to the detector. These photo peaks are the most interesting for gamma spectrometry since they are giving informations about the energy states of the radiating nucleus.

Photons which are making Compton effects and leaving the detector with some energy will give rise to a continuous plateau of impulses. Due to (2) the transmitted energy is depending on the scattering angular:

$$\Delta E = \frac{(1-cos\theta)E_0^2}{m_ec^2+(1-cos\theta)E_0} \tag{4}$$

For a back scattering ($\theta = \pi/2$) we get the maximal energy:

$$\Delta E_{max} = \frac{2E_0^2}{m_ec^2+2E_0} \tag{5}$$

There is also the possibility that photons undergo a large angle Compton effect in the material isolating the detector and enter in the detector after wards. These photons create photo peaks with very low energy in the spectrum.

Finally photons doing pair production will give rise to two characteristic peaks: When the created positron hits an electron, two gamma quants with an energy equal to the electron rest energy will be created. If both of these photons interact through a photo effect the total energy will be equal to $1.02MeV$. If one of the photons escapes the detector it will only be the rest energy of one electron $0.5MeV$.

2 Measurement

To adjust the setting we used an oscilloscope and regulated the high voltage of the NaJ detector until the photo peaks of Co60 were in the range of the multi channel analysator. The oscilloscope was also useful to observe the shape of the electric impulses collected from the detector. From the oscilloscope screen we read out the dead time of the setting. We approximated the dead time to in the order of $2\mu s$.

From this point on the voltage was not modified any more. For calibration we took the spectra of Co60, Cs137 and Na22 and identified the characteristic photo peaks. After calibration we measured events with an energy equivalent to channels between channel 5904 and channel 6454 for different absorption materials and thicknesses. We started with the maximum absorption thickness in order to assure that the radiation will be significant enough to be measured.
The same calibration measurement was performed for the Ge(Li) detector. With this detector we made an one hour measurement of the Co60 spectrum.
Finally we compared the absorption of x-ray radiation and gamma radiation. For this task we summed over the counts of the peak around channel 156 and the peak around channel 408 of the Ba133 spectrum while using different absorbers.
The measurement notes are attached at the end of the document.

3 Results

The software we used had the feature to directly read out the full width at half maximum (FWHM) of an identified peak. Since the values of the FWHM that the software indicated seemed a bit small to us, we fitted the second photo peak of the Co60 spectrum with a Gaussian to verify if the measured FWHM's were meaningful. Gammaspektrometie

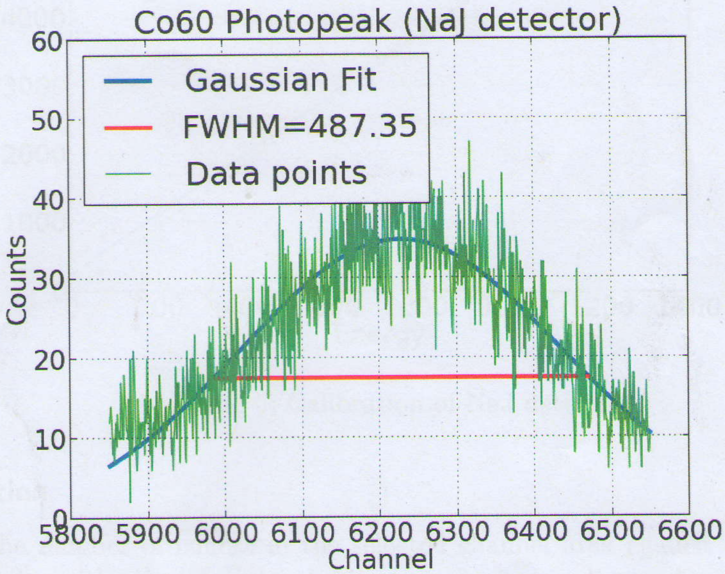

Abbildung 4: Second photo peak Co60 NaJ detector

Obviously the determined FWHM of 100 channels from the software are not confirmed by our fit, we therefor ignore the measured FWHM's. For this peak we calculate a channel resolution which is equivalent to the energy resolution of the setting:

$$\delta E = \frac{FWHM}{channelvalueofmaximum} = \frac{487.4}{6227.7} = 8\% \qquad (6)$$

For the calibration we used errors estimated while measuring. The calibration curve is a linear function. We observe an offset, since the function does not pass the origin.

$$channeln = (4.5 \pm 0.3) * energy/eV + (258 \pm 241) \qquad (7)$$

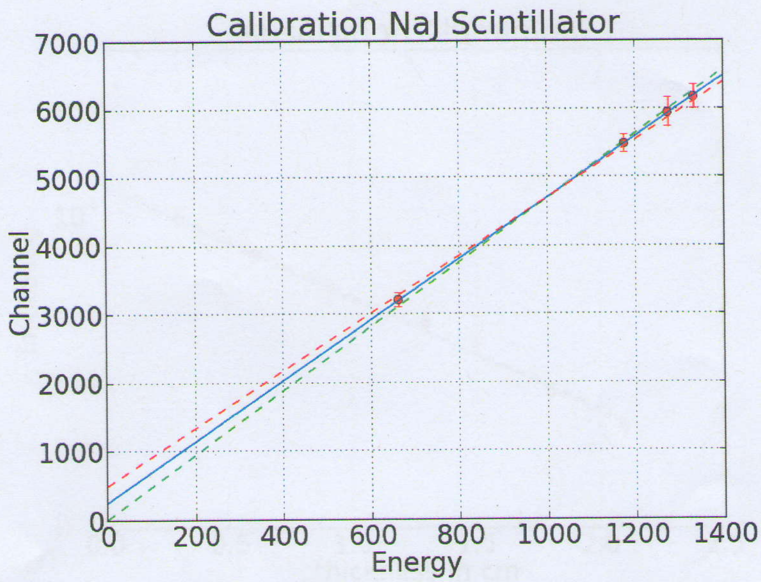

Abbildung 5: Calibration of NaJ detector

3.1 Absorption

We plotted the number of counts in the selected channel area against the absorption thickness on a logarithmic scale. The obtained graph shows a linear shape and out of an linear regression we get the absorption coefficient.

$$\mu_{Al}^{1.33MeV} = (0.127 \pm 0.006)\frac{1}{cm} \tag{8}$$

$$\mu_{Cu}^{1.33MeV} = (0.449 \pm 0.006)\frac{1}{cm} \tag{9}$$

$$\mu_{Pb}^{1.33MeV} = (0.644 \pm 0.009)\frac{1}{cm} \tag{10}$$

As expected the absorption coefficient rises with higher atomic numbers. Even though we measured longer for the Lead absorption, the radiation was to low to get results of the same precision as for the other measurements.

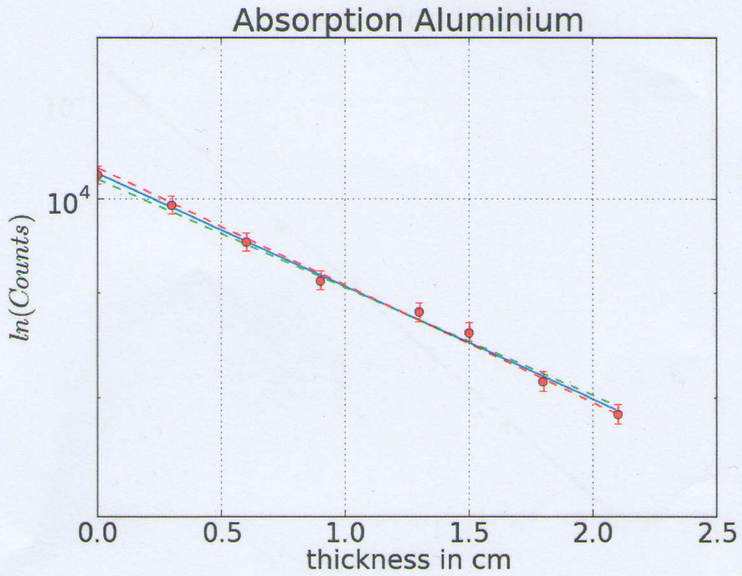

Abbildung 6: 120sec measurements

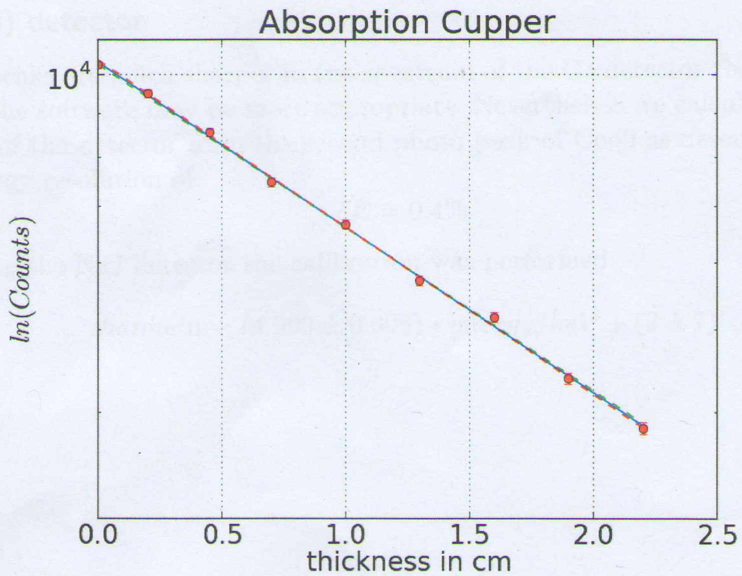

Abbildung 7: 120sec measurements

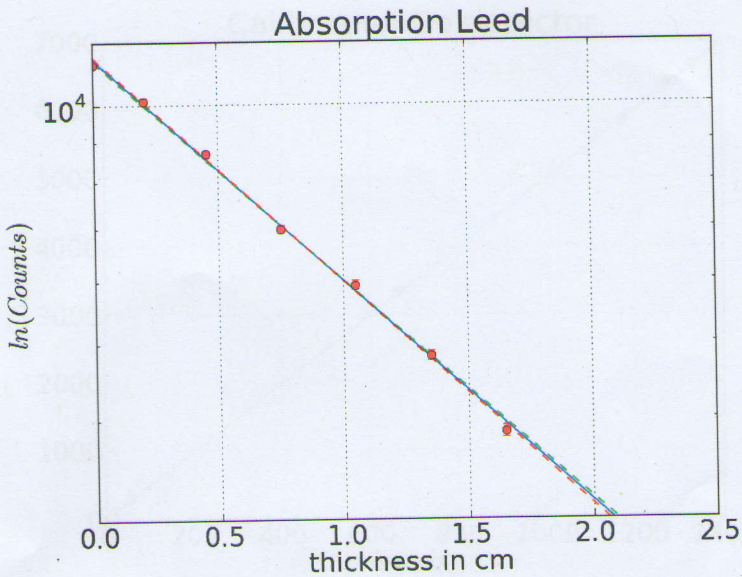

Abbildung 8: 200sec measurements

3.2 Ge(Li) detector

Since the peaks are much sharper in the spectrum of the Ge detector the FWHM determined by the software may be more appropriate. Nevertheless we calculated the energy resolution of the detector from the second photo peak of Co60 as described before and get an energy resolution of:

$$\delta E = 0.4\% \tag{11}$$

Similar to the NaJ detector the calibration was performed.

$$channeln = (4.999 \pm 0.008) * energy/keV + (3 \pm 7) \tag{12}$$

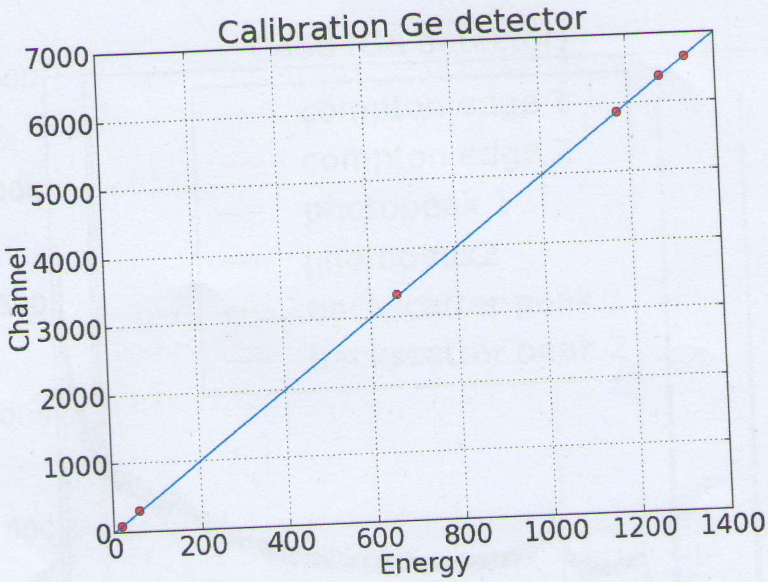

Abbildung 9: Calibration of Ge(Li) detector

The Co60 spectrum we recorded for 1 hour shows the characteristic peaks and plateaus discussed in the introduction. The error of the peak positions we determine from the spectrum results from the energy resolution.

$$\Delta E = E * \delta E \tag{13}$$

Out of (5) the theoretical values of the Compton edges are calculated. Since we know very little about the materials isolating the detector and the processes involved in the backscatter peaks there is no interest in the theoretical value of these peaks.

1. Photo peak 1 = $(1175 \pm 5)keV$ theory: $1173.2keV$
2. Photo peak 2 = $(1333 \pm 6)keV$ theory: $1332.5keV$
3. Compton edge 1 = $(958 \pm 4)keV$ theory: $963.4keV$
4. Compton edge 2 = $(1113 \pm 5)keV$ theory: $1118.1keV$
5. Backscatter peak 1 = $(77.0 \pm 0.3)keV$
6. Backscatter peak 2 = $(86.0 \pm 0.4)keV$

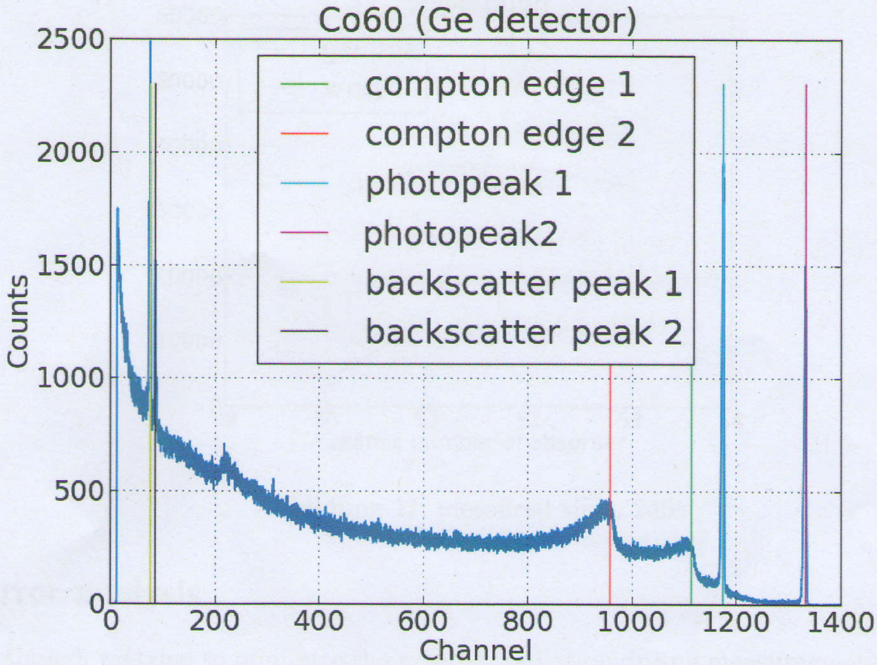

Abbildung 10: Co60 spectrum, 3600sec, Ge(Li) detector

3.2.1 X-ray absorption

To analyse the absorption of x-ray photons, we plotted the number of counts with the atomic number of the absorber.

While the gamma photons are absorbed in nearly the same rate by the different absorbers, the absorption of x-ray photons varies strongly and without any regularity.

Without absorption the x-ray peak was around 85000 counts high. So the different absorbers absorbed between 1/3 and 19/20 of the radiation.

The gamma peak was 46000 counts high without absorption and for the different absorbers not more than 1/3 of the radiation had been absorbed.

The rate of absorption for the gamma radiation follows nearly the trend of the ionization energies of the outer electrons of the absorbers (Sn might be an exception because of its half filled shell). We could therefor assume, that the main effects happening in the absorber is the Compton effect because it is concerned by the outer electrons. Since we don‘t see any similar trend for the x-ray radiation there might be different effects dominating for the different absorbers.

Nevertheless it is obvious, that x-ray photons are easier to absorb, than gamma photons.

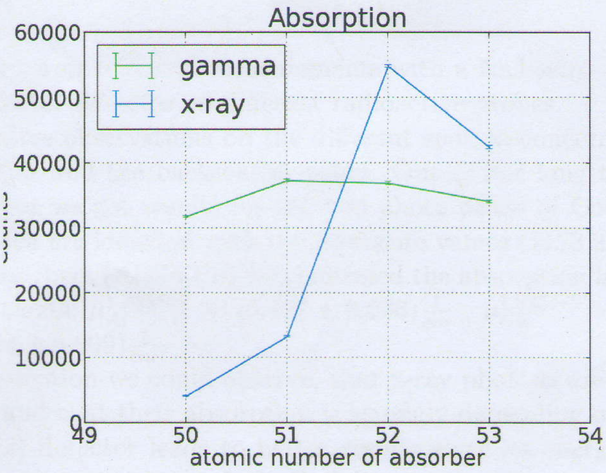

Abbildung 11: measured time: 240s

4 Error analysis

Even though we tried to minimize the external radiation during measurements, there is a background radiation we have to consider. This back ground is mainly in the low energy part of the spectrum which has a low interest for our measurements. In the region of the second photo peak ($1332.5keV$) we counted only 32 events in $180s$. For our absorption measurements and for the positioning of the peaks, the background radiation has no impact.
An other error source could be the dead time of our detectors. Using the oscilloscope we approximated the dead time of both detectors to be $2\mu s$. In our $3600s$ measurement we counted a total of 2464910 events, which leads us to 685 events per seconds or $1460\mu s$ per event. Compared to the dead time this is a long time period. Therefor we can ignore the dead time in the case of our low radiating probes.
Since our measurements are statistical the results get better with longer meas times. A specially for the absorption measurements we adjusted the time intervals such that we could still see an obvious peak in the spectrum. Nevertheless for some results, the measurement time was chosen to little.

5 Discussion

In this experiment we performed measurements with a NaJ scintillation detector and a Ge(Li) semiconductor detector on different radioactive probes.
We made qualitative observations on the different spectra concerning the photo peaks, the Compton edges and the backscatter peaks. Out of our long time measurement on the Ge(Li) detector we got results for the two photo peaks of Co60 ($1175 \pm 5keV$ and $1333 \pm 6keV$) which are identical with the literature values ($1173.2keV$ and $1332.5keV$).
For 3 different absorbers (Al,Cu,Pb) we confirmed the absorption law and calculated the absorption coefficients: $\mu_{Al}^{1.33MeV} = (0.127 \pm 0.006)\frac{1}{cm}$, $\mu_{Cu}^{1.33MeV} = (0.449 \pm 0.006)\frac{1}{cm}$, $\mu_{Pb}^{1.33MeV} = (0.644 \pm 0.009)\frac{1}{cm}$.
For the x-ray absorption we could observe, that x-ray photons are absorbed faster than gamma photons and that their absorption is strongly depending on the material.
Finally the Ge(Li) detector leads to better results since its energy resolution is about 0.4% while the energy resolution of our NaJ detector is 8%.

Literatur

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