Gamma ray coincidence and angular correlation

CNNAUA001

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Introduction and Theory

When 22Na decays it decays via beta minus decay, which releases a positron. This annihilates with an electron and then two 511keV gamma rays (gammas) are emitted in directly opposite directions. This advantageous decay is used in the medical field in scans called positron emission tomogrophy (PET)[2]. If two detectors are placed directly opposite each other, one can tell exactly where the decay took place, therefore this is useful for medical imaging and having detectors placed in multiple places means a 3D graph can be produced. For this reason, accurate detectors are needed.

Aim

To determine the coincidence gamma spectra for 22Na and analyse it. To determine how the angular correlation effects the count rate for 22Na. From data to determine the absolute efficiency of the NaI crystal. To determine the activity of 60Co.

Apparatus and Method

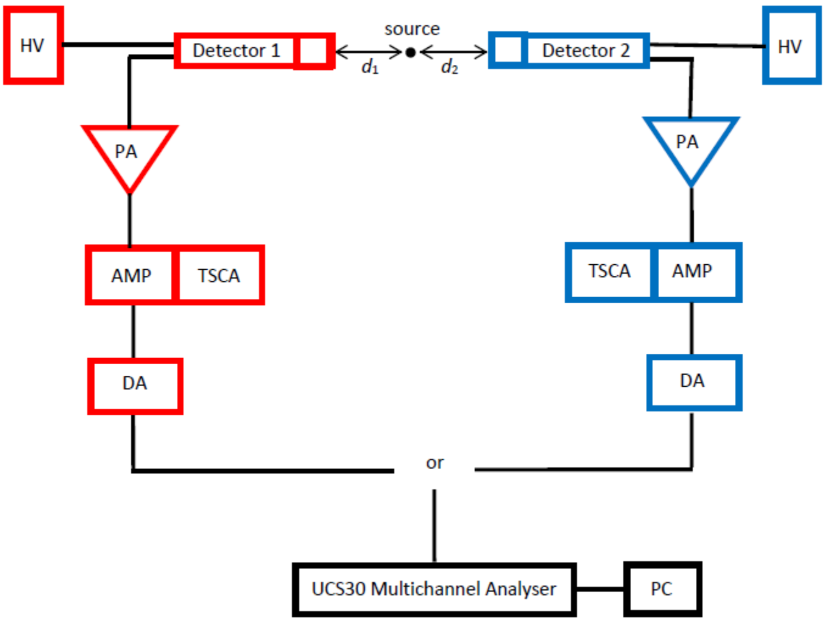

Figure 1: This image shows the setup of the experiment

Two detectors detector 1 (Red) and detector 2 (blue) were connected to high voltage power supplies. They were then connected to preamplifiers which feeds the signal to the amplifier and TSCA, which chooses the window of the detectors. These were fed to two delay amplifiers which then went into a multichannel analyser which then uploaded the data to the PC. After this was done, measurements were taken in order to get data to calibrate the detectors

Coincident Gamma Spectra

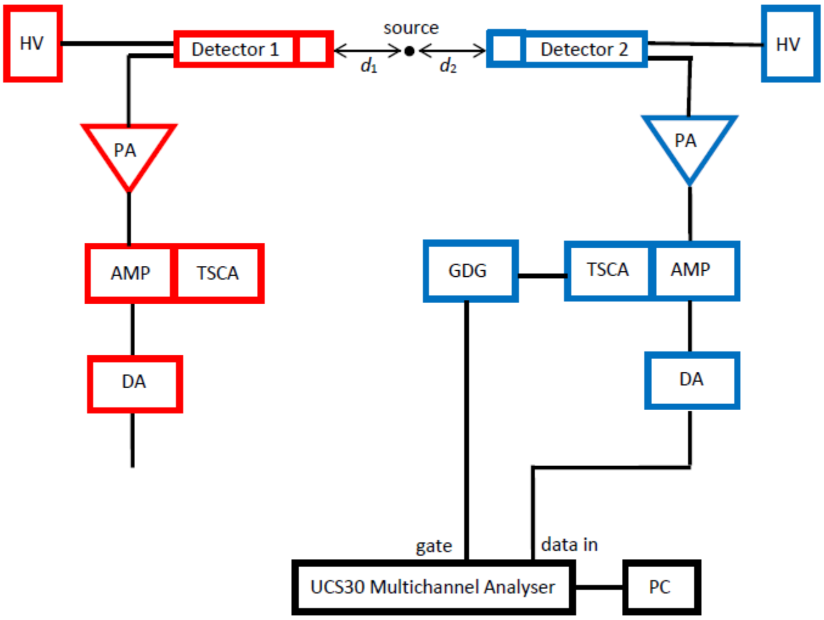

Figure 2: This image shows the setup for the second part of the experiment

A gate and delay generator was put into the system in order to sync the two detectors. In order to fix the delay between communication between the two detectors by setting a $2.5\mu s$ delay. The distance between the two detectors are both set to 15cm. For the first spectrum the TSCA were set to a wide window, so it recorded all the energies.

Angular Correlation Measurements

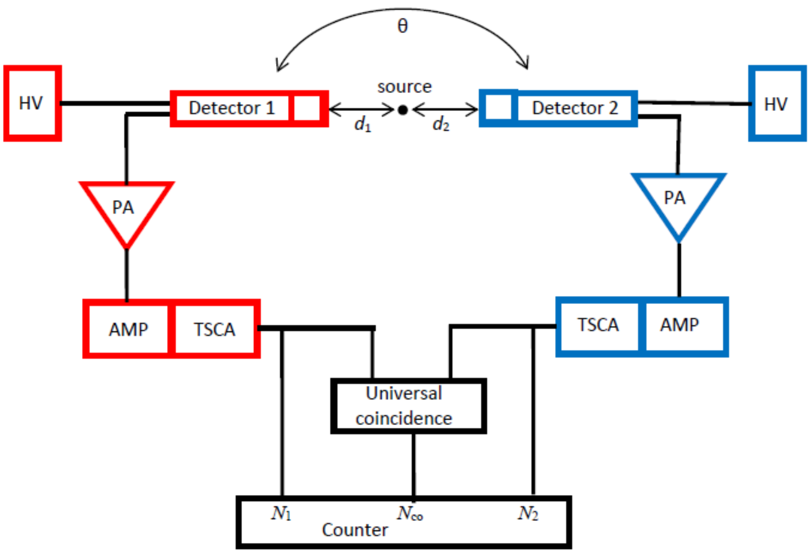

Figure 3: This image shows the setup of the angular scanning of the experiment

For the next part we use 22Na, the experiment was set up as seen above, and the angle θ is what is being changed. For the first part the angle was changed and the distance between the source and the detectors were both 15cm and both windows were wide open. For the second part both detectors were set to only detect 511 keV gammas and the distance between the source and detector was the same as before. For the third part the distance between detector 1 and the source remained 15cm and the distance between detector 2 and the soucre increased to 30cm and the TSCA windows were wide open.

Activity of 60Co Source

For this part of the experiment both detectors were placed 180 degrees apart and only 22Na was used. The setup was the same as above. The one detector was 8cm away from the source and the other was 24cm from the source and then readings were taken to obtain table (1).

Calibration Data

For this section the same setup as in Figure (1) and the source used was 60Co, where the distance between the detectors and the source were both 15cm. The TSCA windows were wide open and the time that the counts were recorded was 1200s.

Code for Analysing the Data

Once the data was gathered for each source in the first part of the experiment for the calibration, the graphs were plotted and around the photopeaks, a gaussian was curvefitted in order to determine the μ value and its uncertainty. These photopeaks were then linked to certain energies acquired from the Nudat2 library[1][3]. Then these points were plotted and a line of best fit was plotted in order to determine the calibration factor which was the gradient of the line, and this value was used when converting from channel number to energy for the data in the rest of the experiment. This process was done from data acquired by both red and blue detectors.

Data

N_1	253901	Both TSCA windows wide open
N_2	79100	
N_{co}	12607	
N_1	115940	Tight window on 0.511 MeV photopeaks on both TSCAs
N_2	32444	
N_{co}	7871	
N_1	258432	Tight window on 0.511 MeV photopeaks on TSCA 2 (blue) only
N_2	31578	
N_{co}	12236	

Table 1: This table shows number of counts for each detector and for both as well as the TSCA setting of the detectors

N_1	231123	Both TSCA windows wide open
N_2	223368	
N_{co}	4582	

Table 2: This table shows the data to determine the activity of 60Co

Graphs

Calibration

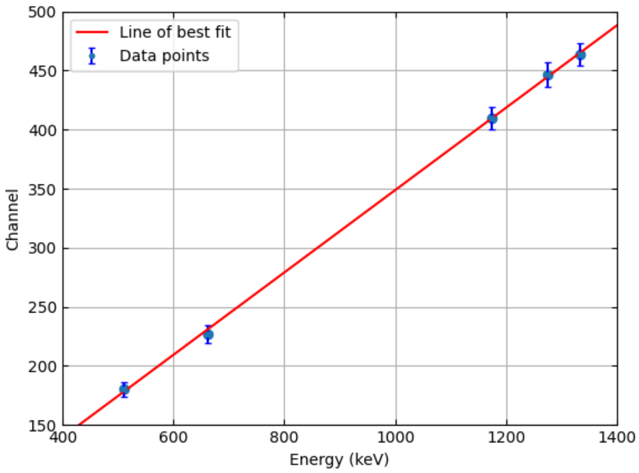

Figure 4: This graph shows the energy calibration of the data from the blue detector with gradient 0.349 ± 0.004

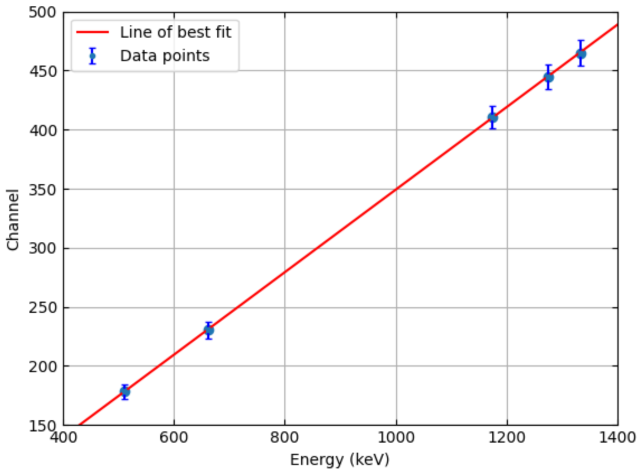

Figure 5: This graph shows the energy calibration of the data from the red detector with gradient 0.349 ± 0.001

Coincident Gamma Spectra

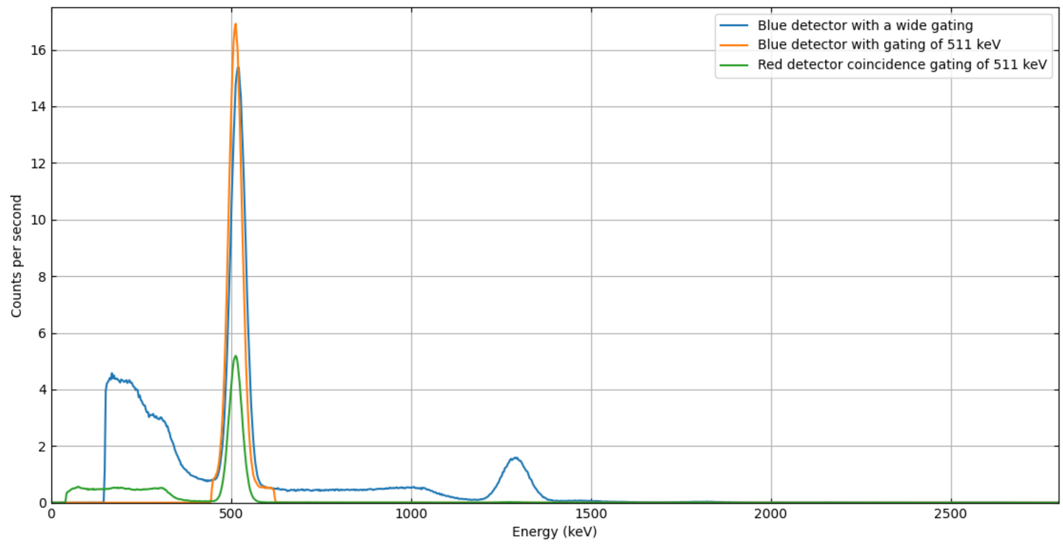

Figure 6: This graph shows the gated and non gated detections from detector 1 and 2 for 22Na

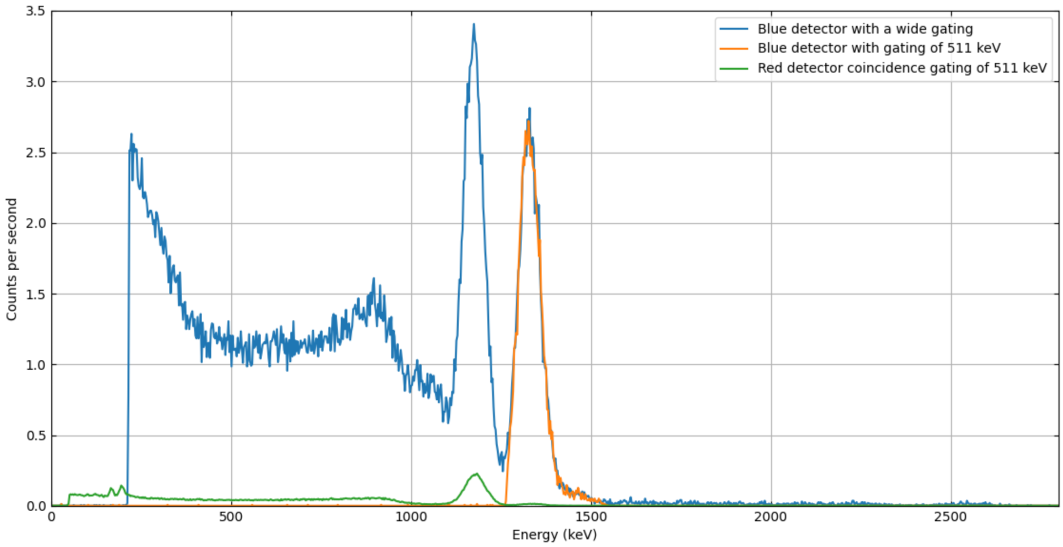

Figure 7: This graph shows the gated and non gated detections from detector 1 and 2 for 60Co

Angular Correlation Measurements

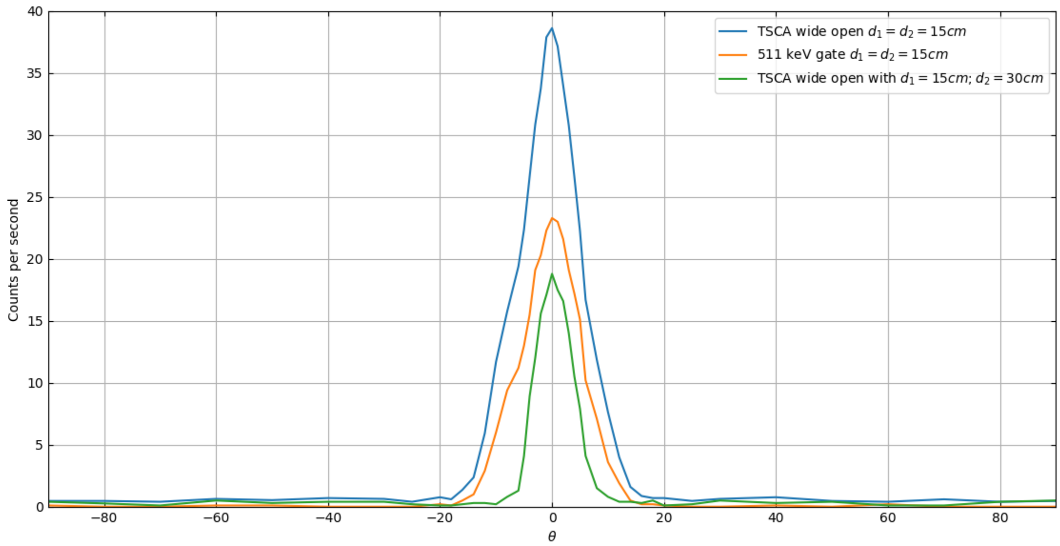

Figure 8: This graph shows the angular scans of 22Na

Calculations

Absolute Efficiency Determination

When considering table (1) and thinking about the definition of efficiency being the number of gamma rays detected divided by the total number of gamma rays emitted by the source it is wise to choose the efficiency to be N_{Co}/N_2. As N_2 is the number of counts from the blue detector which is further away from the source than the red detector, it will pick up more of the actual gamma rays emitted by annihilation and less gamma rays that were emitted from a different decay or source due to annihilation gamma rays being emitted in the opposite direction. Therefore N_2 is considered to be the number of annihilation gamma rays emitted. N_{Co} is the number of gamma rays that are detected by both detectors and therefore can be taken as the number of gamma rays detected by the detector. Therefore the absolute efficiency $\varepsilon_1(0.5) = N_{Co}/N_2$. As the distribution is Poissonian, the uncertainty on each N value is $\sqrt{N}$. Using the second set of data where both windows are gated in 511 keV gammas the absolute efficiency is:

$$\varepsilon_1(0.5) = \frac{7871}{32444}$$

$$\therefore \varepsilon_1(0.5) = 0.2426 \tag{1}$$

And then in percentage form:

$$\varepsilon_1(0.5) = 24.26 \pm 0.30\% \tag{2}$$

Activity of the 60Co source

In order to determine the activity of the 60Co source we use the equation:

$$D = \frac{R_1 R_2}{R_{Co}} \tag{3}$$

where R_1 and R_2 are the count rates and R_{Co} is given by:

$$R_{Co} = R_1 \varepsilon_2 \tag{4}$$

where ε_2 is the efficiency of detector 2. When looking at table (2), and noting that it was recorded in a time interval of $t = 1200s$. The count rate is the number of counts divided by the total time the detector was open, then the count rates are:

$$R_1 = N_1/t = 231123/1200 = 192.603$$
$$R_2 = N_2/t = 223368/1200 = 186.140$$

$$R_{Co} = R_1\varepsilon_2$$
$$\therefore R_{Co} = R_1\Big(\frac{N_{Co}}{N_2}\Big)$$
$$\therefore R_{Co} = (192.603)\Big(\frac{4582}{223368}\Big)$$
$$\therefore R_{Co} = 3.951$$

Then substituting into the equation for activity:

$$D = \frac{R_1R_2}{R_{Co}}$$
$$\therefore D = \frac{(192.603)(186.140)}{(3.951)}$$
$$\therefore D = 9073.9 \pm 234.7Bq$$

Uncertainty Analysis

Uncertainty of the absolute efficiency

As the data points from table (1) are counts they follow a Poisson distribution and therefore their uncertainty is given by $\sqrt{N}$. Then propagating uncertainty using:

$$u(\varepsilon_1) = \varepsilon_1\sqrt{\Big(\frac{u(N_{Co})}{N_{Co}}\Big)^2 + \Big(-1\frac{u(N_2)}{N_2}\Big)^2} \tag{5}$$

We get the uncertainty of ε_1 to be:

$$\therefore u(\varepsilon_1) = \varepsilon_1\sqrt{\Big(\frac{\sqrt{N_{Co}}}{N_{Co}}\Big)^2 + \Big(\frac{\sqrt{N_2}}{N_2}\Big)^2}$$
$$\therefore u(\varepsilon_1) = (0.2426)\sqrt{\Big(\frac{\sqrt{7871}}{7871}\Big)^2 + \Big(\frac{32444}{32444}\Big)^2}$$

$$\therefore u(\varepsilon_1) = 0.0030 = 0.30\% \tag{6}$$

Uncertainty of the activity of the 60Co source

As in the section above the uncertainty of the number of counts is $\sqrt{N}$. First getting the uncertainty of R_1, R_2 and R_{Co}:

$$u(R_1) = \sqrt{231123} = 480.7525$$
$$u(R_2) = \sqrt{223368} = 472.6182$$
$$u(N_{Co}) = \sqrt{4582} = 67.6904$$

Now to calculate the uncertainty of R_{Co}:

$$u(N_{Co}/N_2) = (N_{Co}/N_2)\sqrt{\Big(\frac{u(N_{Co})}{N_{Co}}\Big)^2 + \Big(\frac{u(N_2)}{N_2}\Big)^2}$$
$$\therefore u(N_{Co}/N_2) = (4582/223368)\sqrt{\Big(\frac{67.6904}{4582}\Big)^2 + \Big(\frac{472.6182}{223368}\Big)^2}$$
$$\therefore u(N_{Co}/N_2) = 5.2886 \times 10^{-4}$$

Then:

$$u(R_{Co}) = (R_1)(N_{Co}/N_2)\sqrt{\Big(\frac{u(R_1)}{R_1}\Big)^2 + \Big(\frac{u(N_{Co}/N_2)}{(N_{Co}/N_2)}\Big)^2}$$
$$\therefore u(R_{Co}) = 122.630$$

Then getting the uncertainty of D:

$$u(R_1R_2) = (R_1R_2)\sqrt{\Big(\frac{u(R_1)}{R_1}\Big)^2 + \Big(\frac{u(R_2)}{R_2}\Big)^2}$$

$$\therefore u(R_1R_2) = 1.531 \times 10^8$$

Then:

$$u(D) = (R_1R_2/R_{Co})\sqrt{\Big(\frac{u(R_1R_2)}{R_1R_2}\Big)^2 + \Big(\frac{u(R_{Co})}{R_{Co}}\Big)^2}$$

$$\therefore u(D) = 281634.2234$$

Then dividing by the total time:

$$\therefore u(D) = 234.695 Bq$$

Interpretation and Discussion

Coincident Gamma Spectra

22Na:

Looking at figure (6) the orange graph shows the 511 keV photons detected by the blue detector, and it is seen that this has a higher count per second than the blue graph which is when the blue detector has a wide window, so it detects all energies of photons entering the detector, this means that every second it is detecting more noise such as from Compton scattering than when the detector is gated, this results in it detecting less 511 keV gammas per second than the blue graph. The green graph shows the counts per second of 511 keV gammas when they are detected in the blue detector and then the red detector with a wide window it detects a gamma hitting it at the same time, for this reason we still detect some noise, as is seen from the small Compton continuum, and it detects 511 keV gammas as well however not as much due to the fact that it detects all events coming in to the red detector resulting in the green graph's peak being less than the blue graphs peak.

60Co:

Looking at figure (7), the blue graph shows the photons detected at all energies, for this reason we see all of the peaks and Compton continuum, for this reason the peaks are higher than for the green graph. The orange graph are the photons detected at 1.33 MeV. The reason that the peak of this graph is lower than the peak of the blue graph, as was the case in the previous case with 22Na, is because unlike 22Na, 60Co does not produce annihilation gammas, it produces a 1.33 MeV and a 1.17 MeV gamma at the same time, for this reason as the detector is gated it detects less 1.33 MeV photons.

Angular Correlation measurements

In figure (8) it can be seen that as the angle between the detectors increases, as in as the angle that the detector moves away from its original position, the counts of gammas per second decreases for all 3 graphs. This is due to the fact that the detector is no longer detecting the annihilation gammas that leave the source and move directly towards the detectors. The green graph shows the distance between the source and the blue detector increasing and we observe a decrease in the maximum count rate value, meaning that there are less gamma rays being detected. The orange graph shows the TSCA windows tight on 511 keV photopeaks and we see that the maximum count rate is higher than the green graph, meaning when the distance increases, data is being missed. The orange graph is also less than the blue graph, and the blue graph was obtained when the windows of the detector were wide open, meaning it could detect a wide range of gammas either coming from the source or the background.

Determining the Absolute Efficiency

The absolute efficiency was taken from table (1) where the second set of data was chosen. This was because both of the TSCAs had tight windows and gated on 511 keV and therefore only detected the 511 keV gammas which means when determining the efficiency we can neglect the data that comes in the form of Compton scattering, thereby determining the efficiency of the detector to be: $24.26 \pm 0.30\%$

The activity of the 60Co source

Using table (2) the activity of 60Co was found to be $9073.9 \pm 234.7 Bq$. Convering from curies to becquerel, we see that the activity has decreased on the 60Co source, this is due to the fact that the source has been active since 2010.

Conclusion

In conclusion it was seen that when the TSCA are open then more noise is attained which when looking at the efficiency of a detector we want to reduce, therefore setting the TSCA to detect certain energies of gammas is the best way to do this. It was seen that when the detectors are placed directly in front of and behind the source the maximum amount of gammas were detected. The absolute efficiency of the 22Na source was found to be $24.26 \pm 0.30\%$ and the activity of the 60Co source was found to be $9073.9 \pm 234.7 Bq$.

References

[1] M. Shamsuzzoha Basunia. *Decay Radiation Results, Dataset 1.* URL: `https://www.nndc.bnl.gov/nudat2/decaysearchdirect.jsp?nuc=22NA&unc=nds`. (accessed:16.9.2021).

[2] Prof. Andy Buffler. *Gamma ray coincidence and angular correlation Do-at-home version.* URL: `https://vula.uct.ac.za/access/content/group/275677d7-258c-4507-b368-7cb674c91ca0/Laboratory/Lab%5C%206%5C%20Gamma%5C%20coincidence/PHY3004W_gglab_instructions_do_at_home_2021.pdf`. (accessed:16.9.2021).

[3] E. Browne J. K. Tuli. *Decay Radiation Results, Dataset 3.* URL: `https://www.nndc.bnl.gov/nudat2/decaysearchdirect.jsp?nuc=60CO&unc=nds`. (accessed:16.9.2021).