CALCULATING SAFE HANDLING RADIATION DOSAGE LIMITS FROM NEUTRON ACTIVATION ANALYSIS

A.SINHA, J. PARGA AND S. LANDSBERGER

NUCLEAR ENGINEERING TEACHING LAB

THE UNIVERSITY OF TEXAS AT AUSTIN

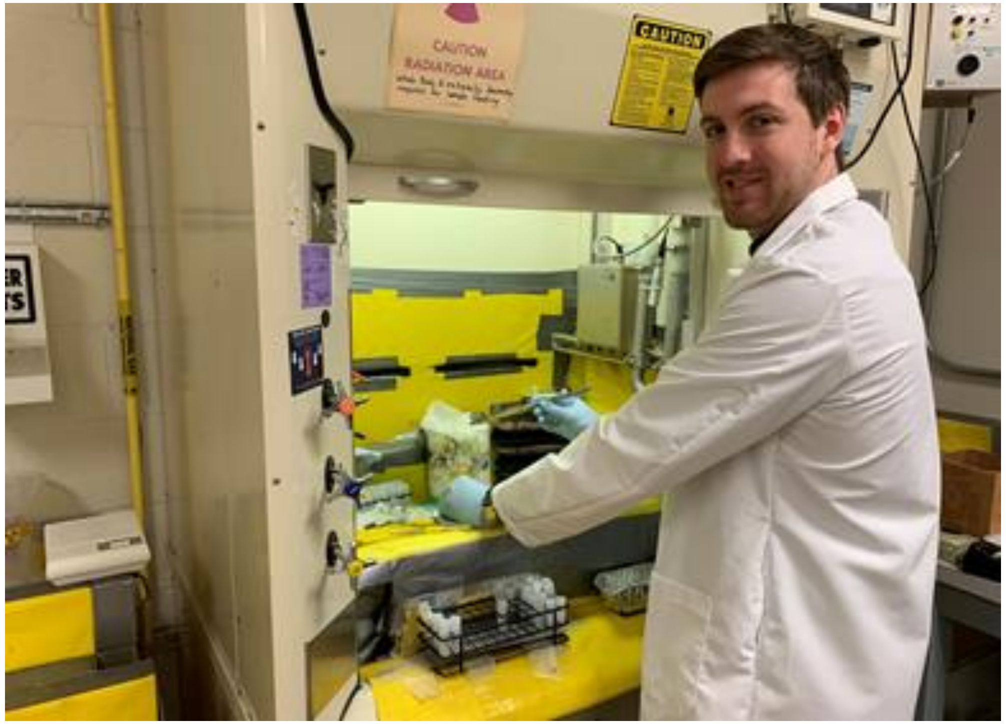
Motivation

- Typical laboratory deals with one or two types of radiation (well characterized)
- Neutron Activation Analysis (NAA) can contain large variety of radioactive isotopes
- Each isotope has varying half-lives and different strength gamma rays and beta particles
- Literature review found little to no work quantifying mixed beta and gamma fields in multi isotope samples

Nuclear Engineering Teaching Laboratory

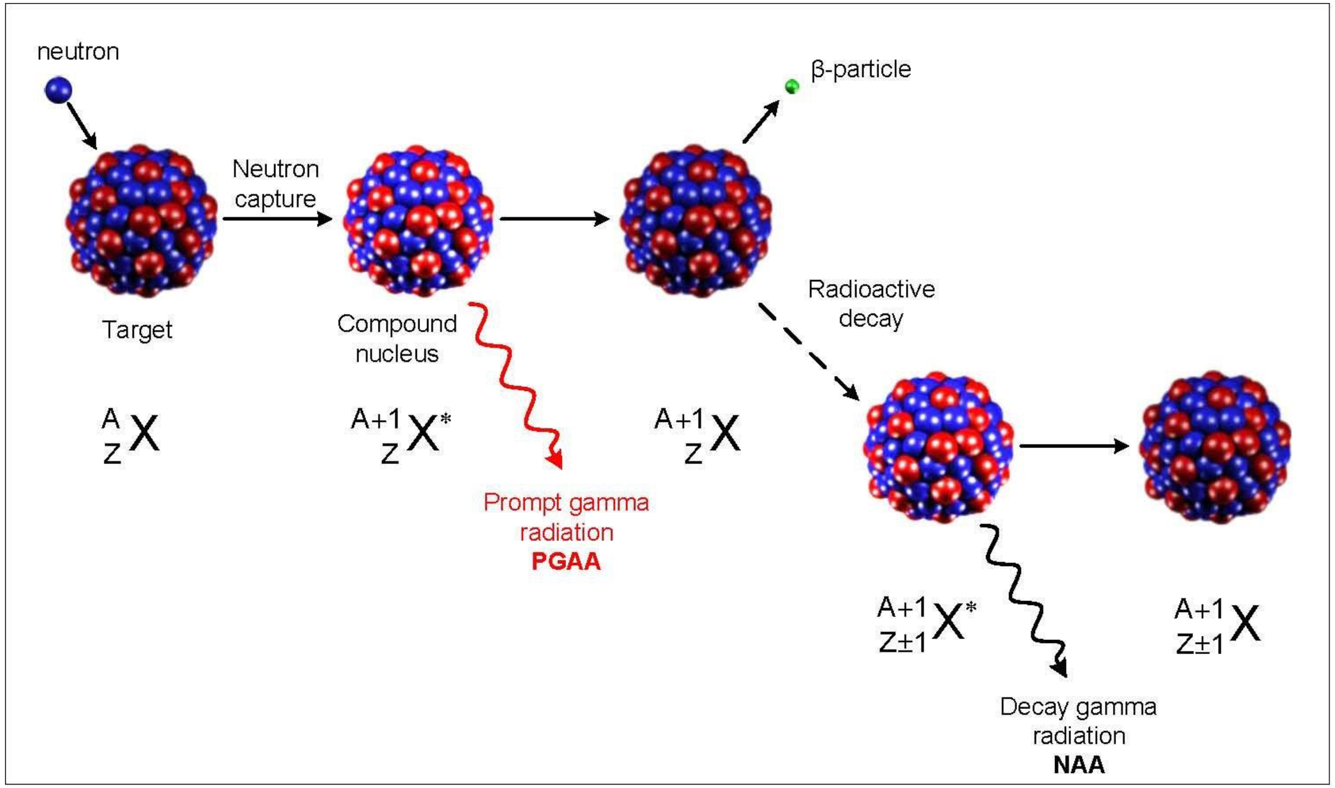
- Operates the newest TRIGA Mark II university reactor in the USA
- Reactor has in-core irradiation facilities and five beam ports with steady state operation at power levels up to 1.0 MW or pulsing up to 1.5 GW for 10 microseconds
- Maximum neutron flux of 2×10^{13} n/cm^2s^{-1} can be achieved
- The flexibility allows the reactor to be used for numerous NAA experiments at varying reactor power, neutron flux, and time

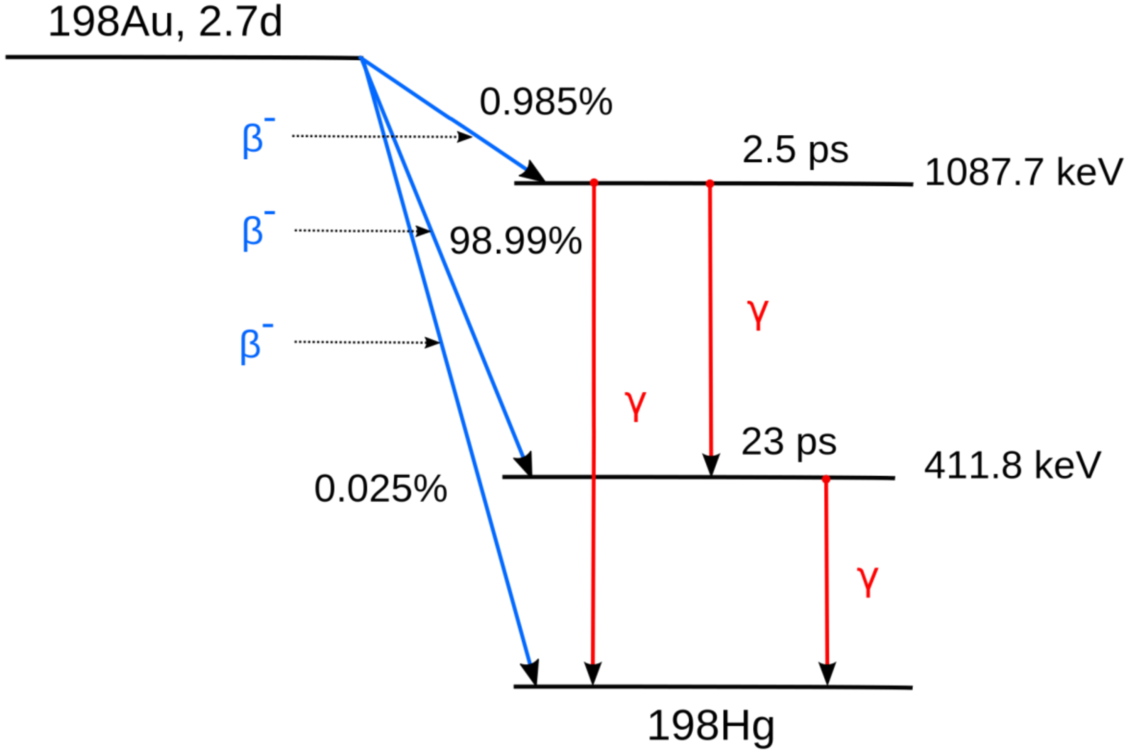
NAA Facility



PGAA Facility

Neutron Activation Analysis





Common Short Lived Isotopes

Element	Isotope	Half-life	γ -rays (keV)
Ag	^{110}Ag	24.6 sec	657.8
Al	^{28}Al	2.24 min	1778.9
Ba	^{139}Ba	83.2 min	165.9
Br	^{80}Br	17.7 min	616.2
Br	^{80m}Br	4.42 hr	37.1
Ca	^{49}Ca	8.7 min	3084.4
Cl	^{38}Cl	37.3 min	1642.4, 2167.5
Co	^{60m}Co	10.48 min	58.6
Cu	^{66}Cu	5.1 min	1039.4
Dy	^{165}Dy	2.33 hr	94.7
F	^{20}F	11.0 sec	1633.8

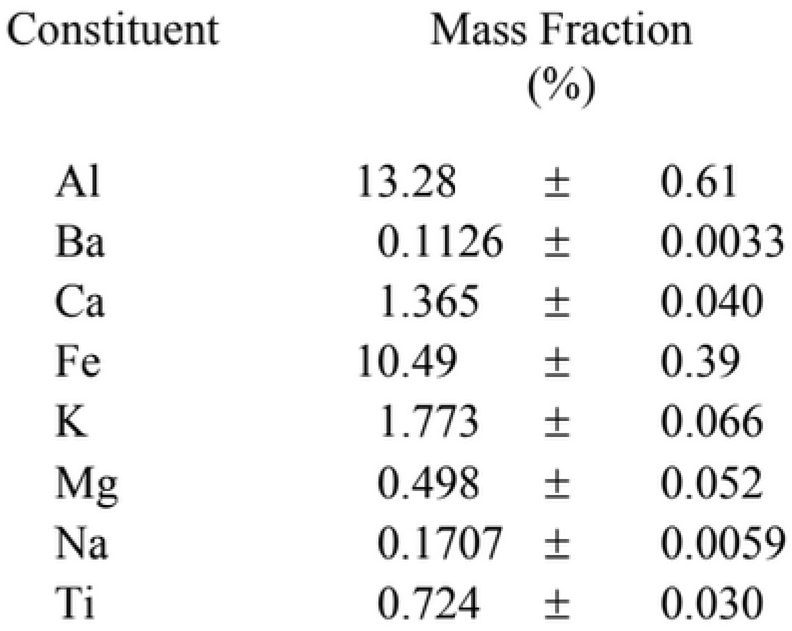
Element	Isotope	Half-life	γ -rays (keV)
I	^{128}I	25.0 min	442.3
In	^{116m}In	54.2 min	416.9, 1097.3
K	^{42}K	12.36 hr	1524.7
Mg	^{27}Mg	9.45 min	843.8, 1014.4
Mn	^{56}Mn	2.58 hr	846.7, 1810.7
Na	^{24}Na	15.0 hr	1368.6, 2754.1
Se	^{77m}Se	17.4 sec	161.7
Sb	^{122m}Sb	4.15 min	61.5
Si(n,p)	^{29}Al	6.6 min	1273.0
Sr	^{87m}Sr	2.81 hr	388.4
Ti	^{51}Ti	5.8 min	320.1
U	^{239}U	23.5 min	74.6
V	^{52}V	3.76 min	1434.1

Python Analysis Overview

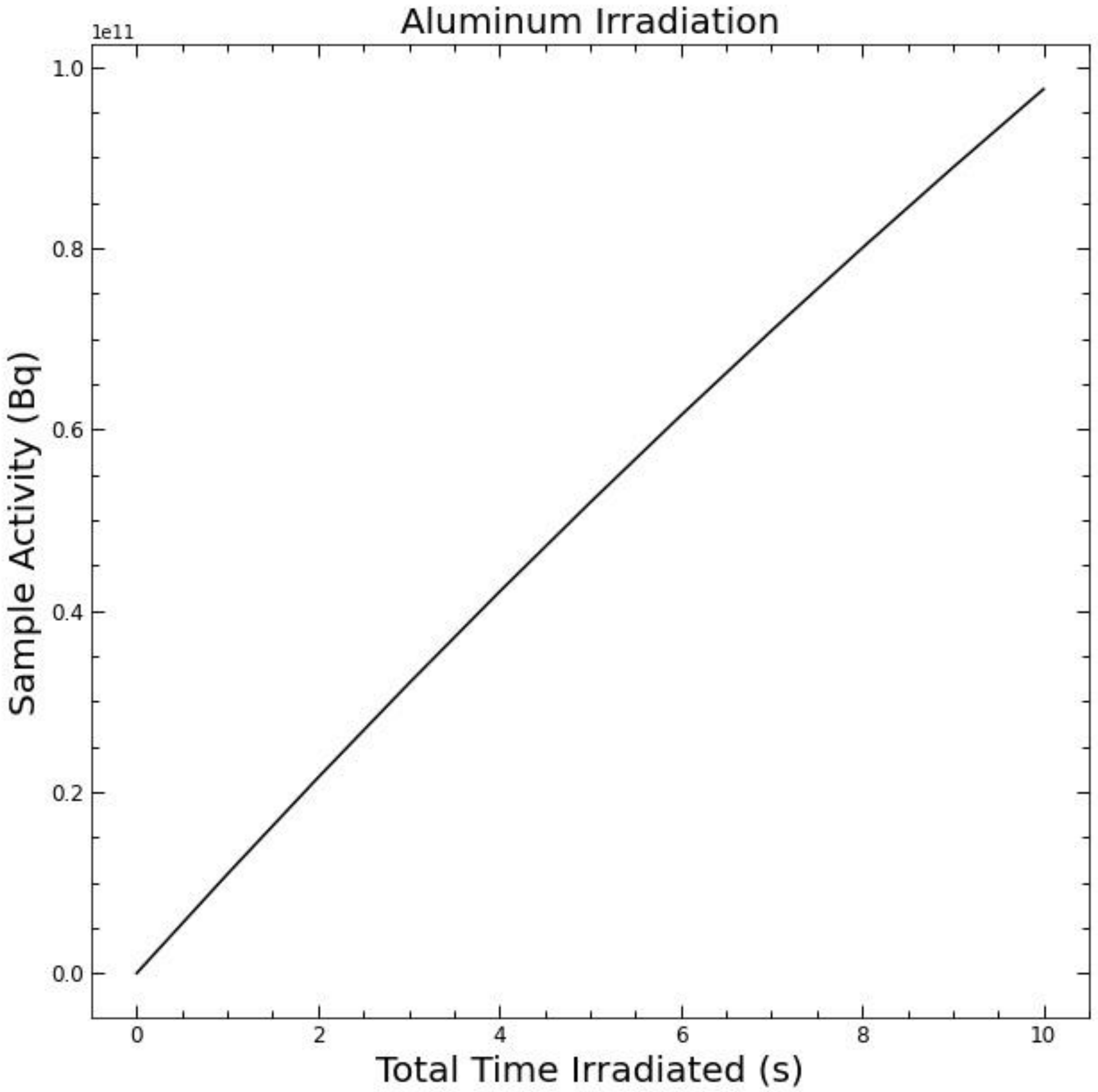
- The purpose of the pipeline being written was to take an input of the mass of a sample and then output the total radiation dosage an operator would experience.

- This study was tested using a sample of the fly ash from the NIST Materials Index but can be recoded with the isotope % by mass for any sample.

NIST Standard Reference Materials 1633C used in this Dose Calculation

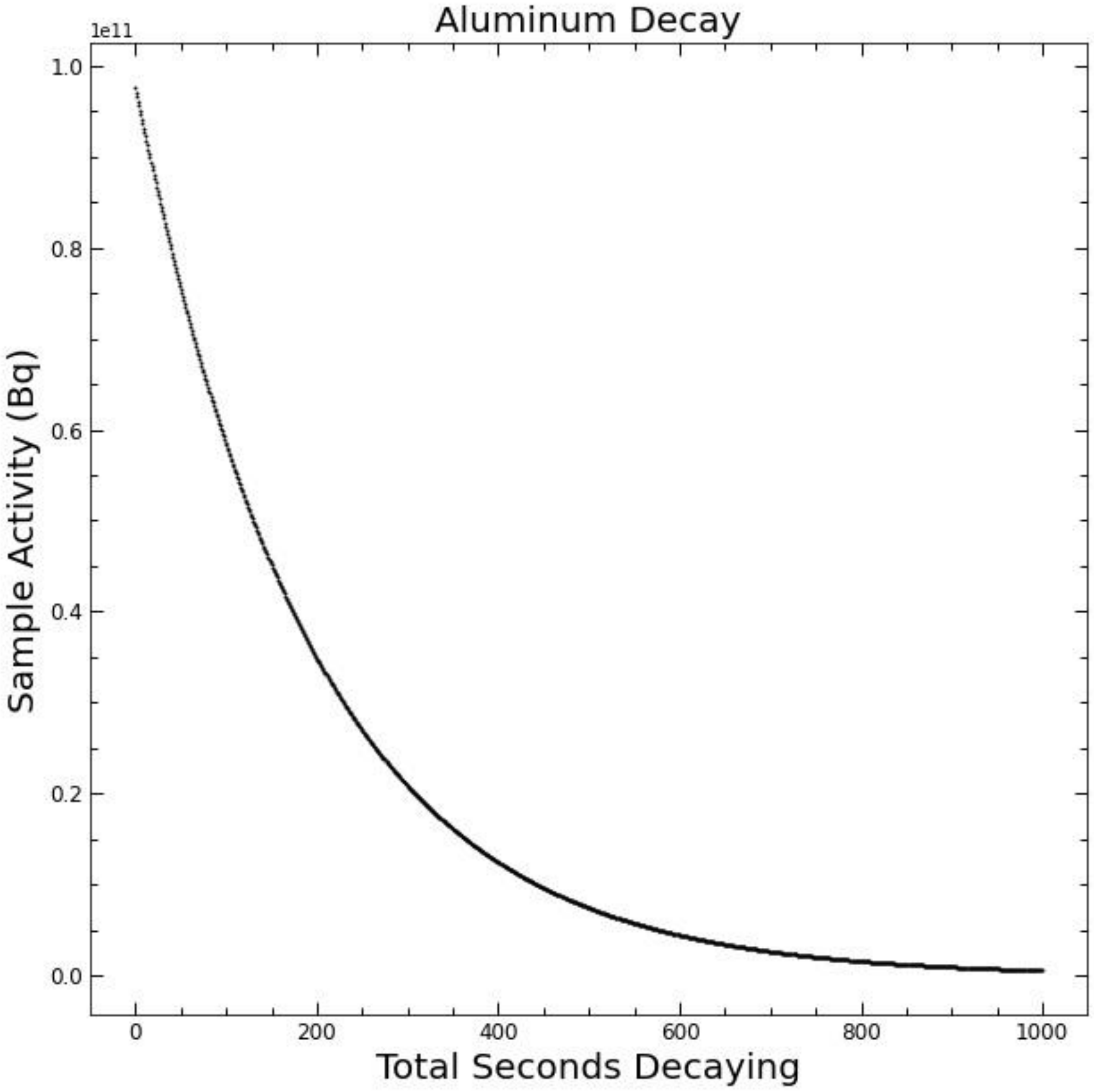


Constituent	Mass Fraction (%)		
Al	13.28	±	0.61
Ba	0.1126	±	0.0033
Ca	1.365	±	0.040
Fe	10.49	±	0.39
K	1.773	±	0.066
Mg	0.498	±	0.052
Na	0.1707	±	0.0059
Ti	0.724	±	0.030



Step 1: Irradiation

- Aluminum was chosen as the sample element to use due to the fact that of all the isotopes included in the NIST Table it was the most short lived
- The equation used for the irradiation graph:
- $For\ t \leq 10\ seconds$: $N(t_{irr}) = \frac{R}{\lambda}(1 - e^{-\lambda t_{irr}})$

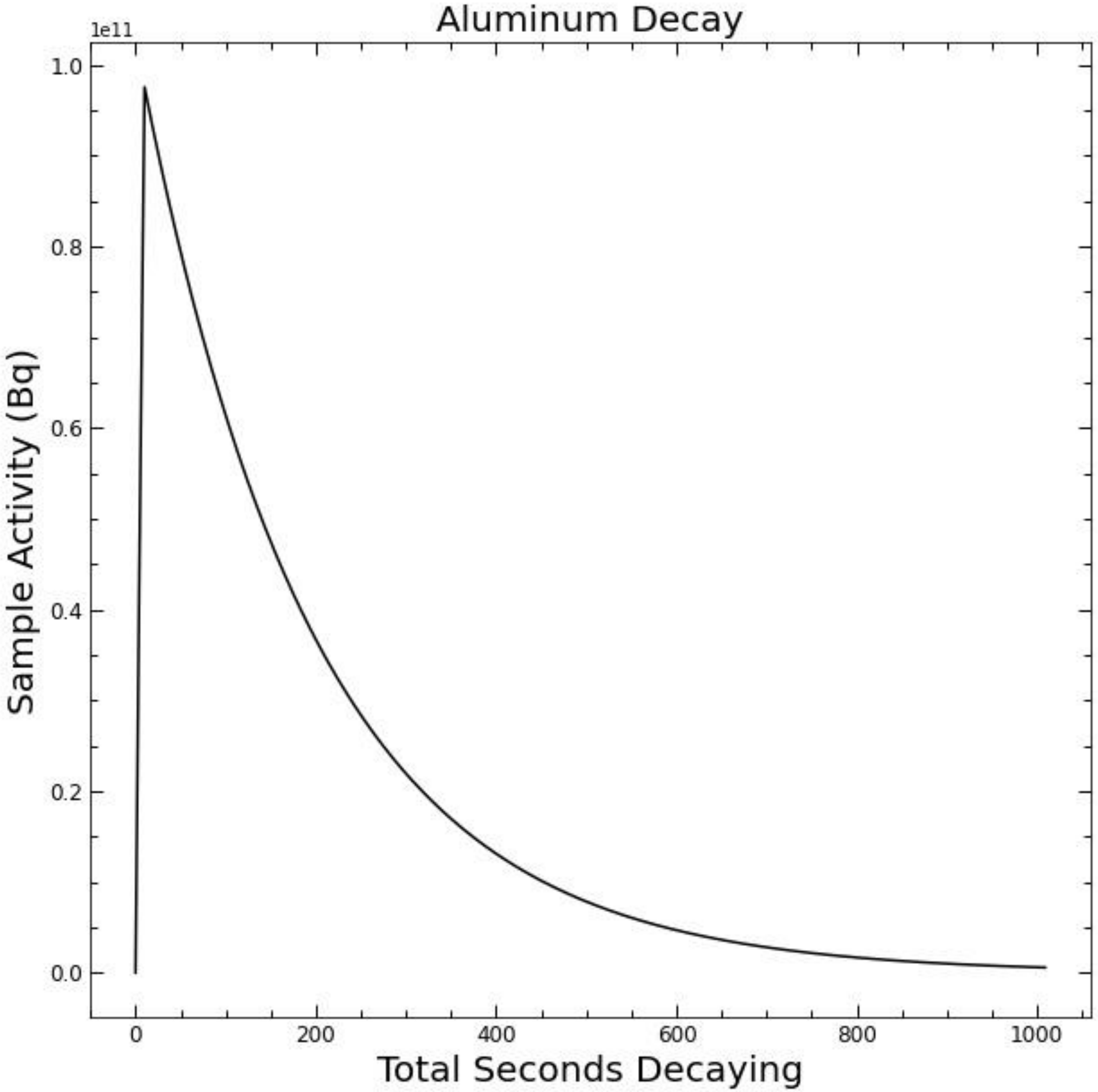


Step 2: Decay Activity

- The equation used for the decay graph:

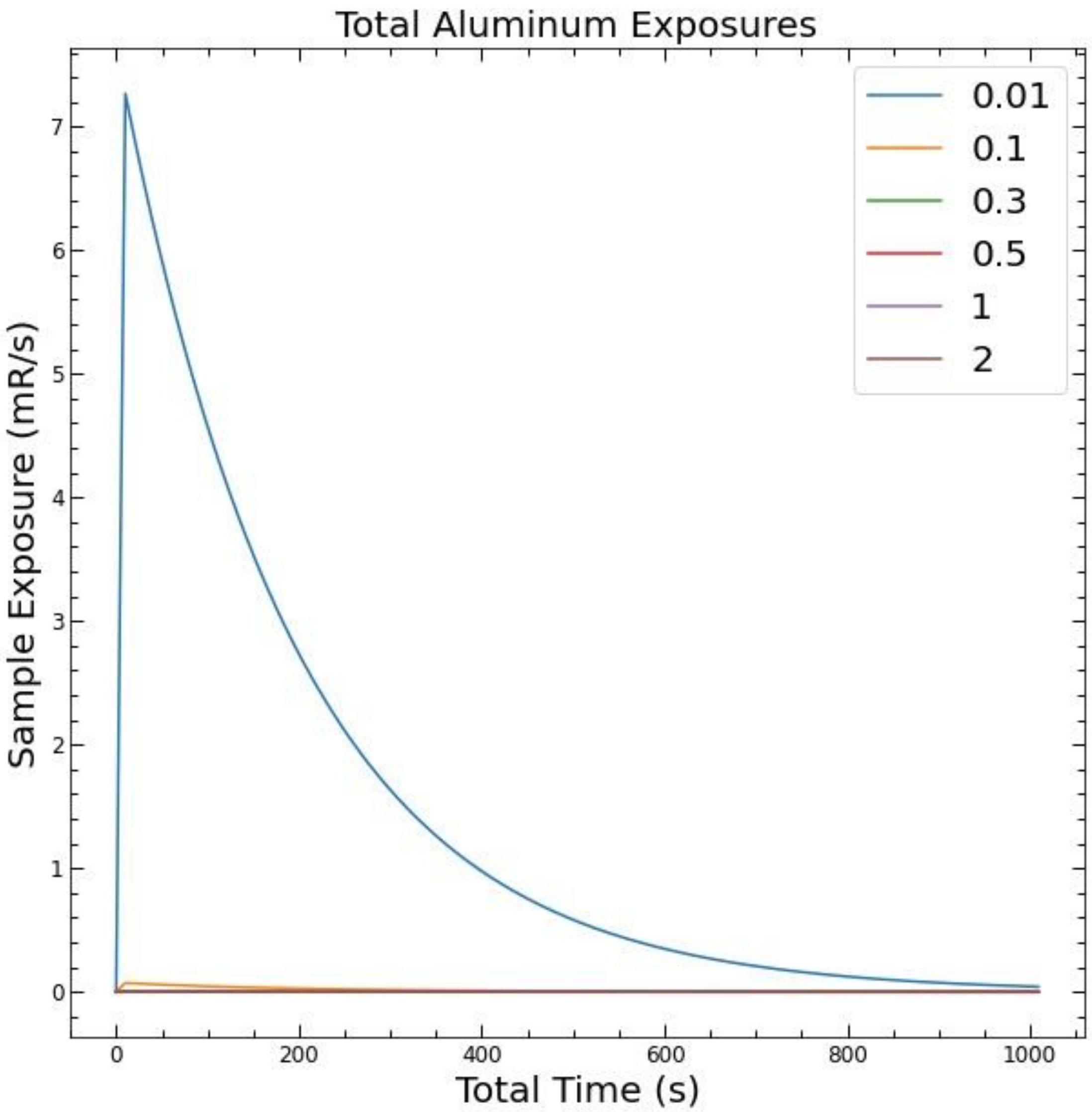
$$For\ t > 10\ seconds:\ N(t_{irr}) = \frac{R}{\lambda}\left(1 - e^{-\lambda t_{irr}}\right)e^{-\lambda t_{decay}}$$

- For each sample, a standard time of 1000 seconds was chosen to give a depiction of the activity of each sample over time.



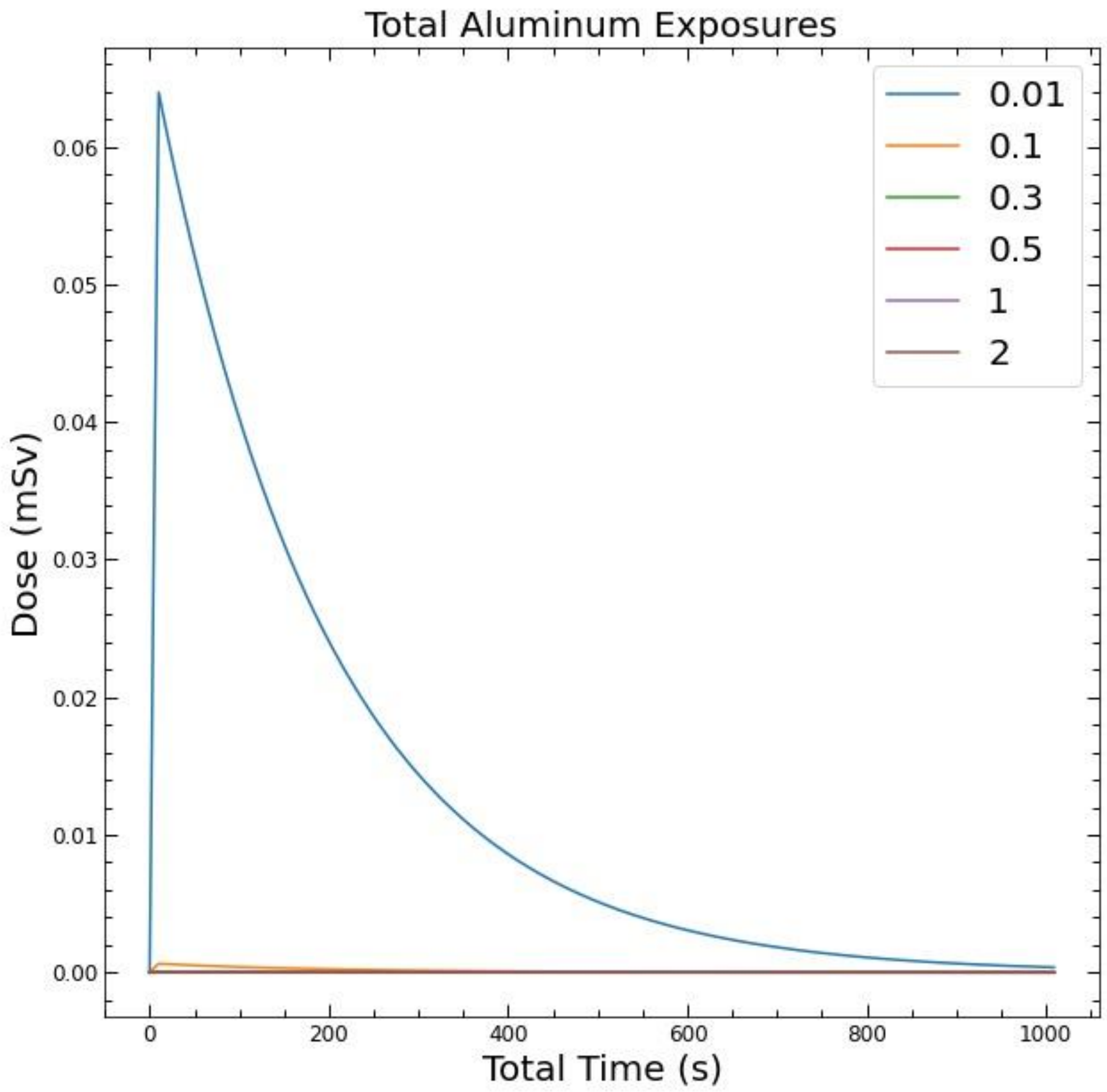
Step 3: Putting it together

- For each element, the irradiation and decay graphs were put together to show the total activity of each element



Step 4: Exposure at Distances

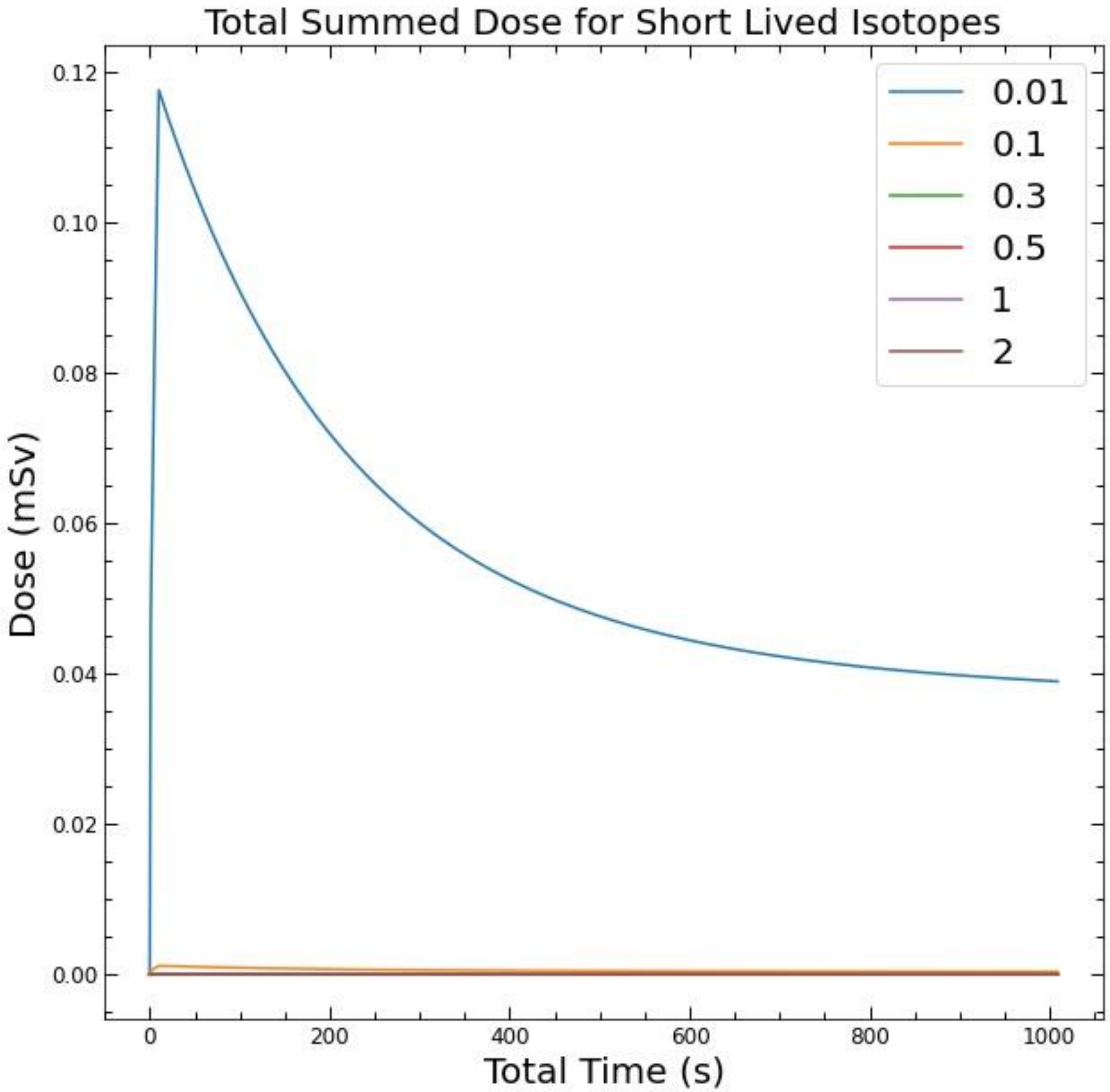
- Distances in the legend measured in meters
- From the activity, the following equation (adjusting for units):
- $R/hr = \frac{6CEf}{d^2}$
- This was used to calculate the exposure from each sample



Step 5: Dosage

- Distances in the legend measured in meters
- The exposure was then converted to dose rates

- Originally it was calculated using mrem but was then converted to mSieverts



Summation of Dosage

- Lastly, the dosages from each isotope were summed together to form an approximation of the total dosage a human would experience.
- As is evident in the plot, while at 0.01 m the dosage is substantial, at even 0.3 m the total dose experienced at the peak is approaching zero.

Results

- The results of this project indicate that calculating the overall exposure and dosage rates from a sample while performing neutron activation analysis is possible using Python.

- Furthermore this study shows that at neutron flux of 4.5×10^{12} $n \cdot cm^{-2} s^{-1}$ the effective dose rate in the air decreases significantly between 0.01 and 0.1 meters from the source, with the former peaking at 0.12 mSv for an aluminum sample but is less than 0.005 mSv at 1 meter.

- The data outputted from the analysis agreed with what would normally be expected experimentally from such a sample, so as of now this analysis method is a viable option.

Next Steps

- However, currently the model only supports dose rates in the air.

- The obvious next step would be to develop a model of the human hand, specifically incorporating the tissue and bone.

- This would no doubt allow for a more complete analysis regarding safe dosage limits.

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