

Non-destructive photon activation analysis in Paleontology

Tyler C. Borgwardt

South Dakota School of Mines and Technology

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Benefits of Photon Activation Analysis

- Broad spectrum, typically 30+ elements can be identified
- Low sensitivity, varies by element but ppm level sensitivities are typical
- If used correctly, can be non-destructive
- Equipment needed is widely available and will likely increase in availability in the future
- Can analyze large samples (100's of grams without any special techniques, kilograms or more with some slight modifications)
- Penetrates deep into samples, making it useful for bulk analysis

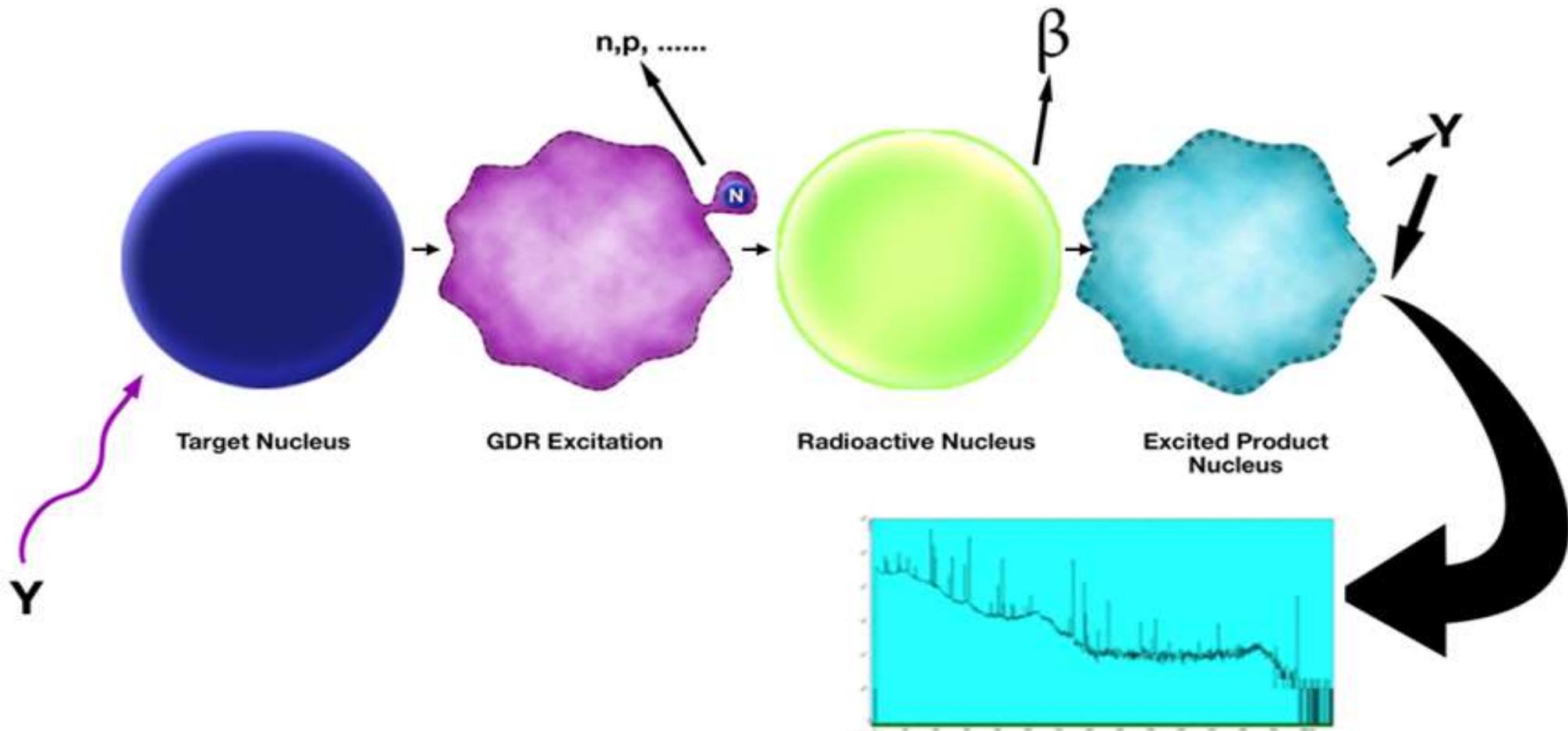
How to use non-destructively

- Keep energies at the lower end of the typical range for the technique (~ 20 MeV). This prevents damage to the internal structure.
- Use external monitor method. This eliminates any sort of destructive alteration in order to add an internal monitor.
- Group samples by size/shape to reduce uncertainties (samples can't be altered to create more uniform geometries)
- Avoid samples with organic components, as this technique is inherently destructive to organic material

Photon Activation Analysis – Physics

- Gamma rays (high energy light, γ) are used to create radioactivity and are also measured to identify elements and calculate concentrations.
- Nuclei of atoms absorb these gamma rays and become energetic, they release this energy by ejecting a neutron, proton, or combination of those two.
- Ejecting a neutron/proton, often makes the resulting nucleus radioactive, which after some time, depending on the half-life, decays, typically giving off a unique set of gamma rays that can be measured and used to identify what the original element was.

Photon Activation Analysis – Physics



Photon Activation Analysis – How it works

- The source of gamma rays for creating radioactivity in the sample is a particle accelerator, that accelerates electrons
- The electrons hit a heavy metal target and create photons through bremsstrahlung radiation

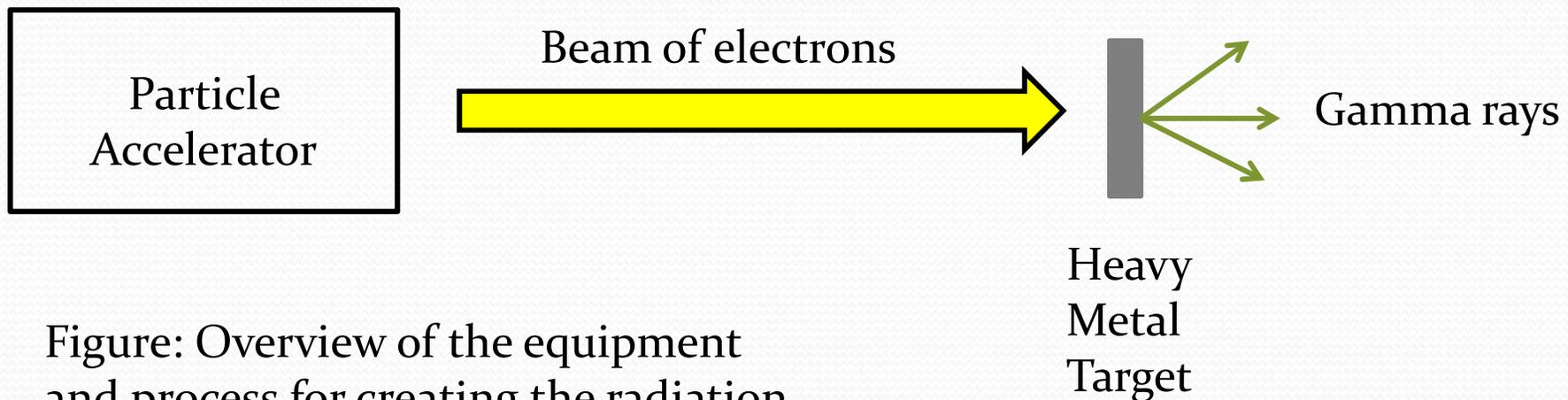


Figure: Overview of the equipment and process for creating the radiation source for photon activation analysis

Example Irradiation Setup

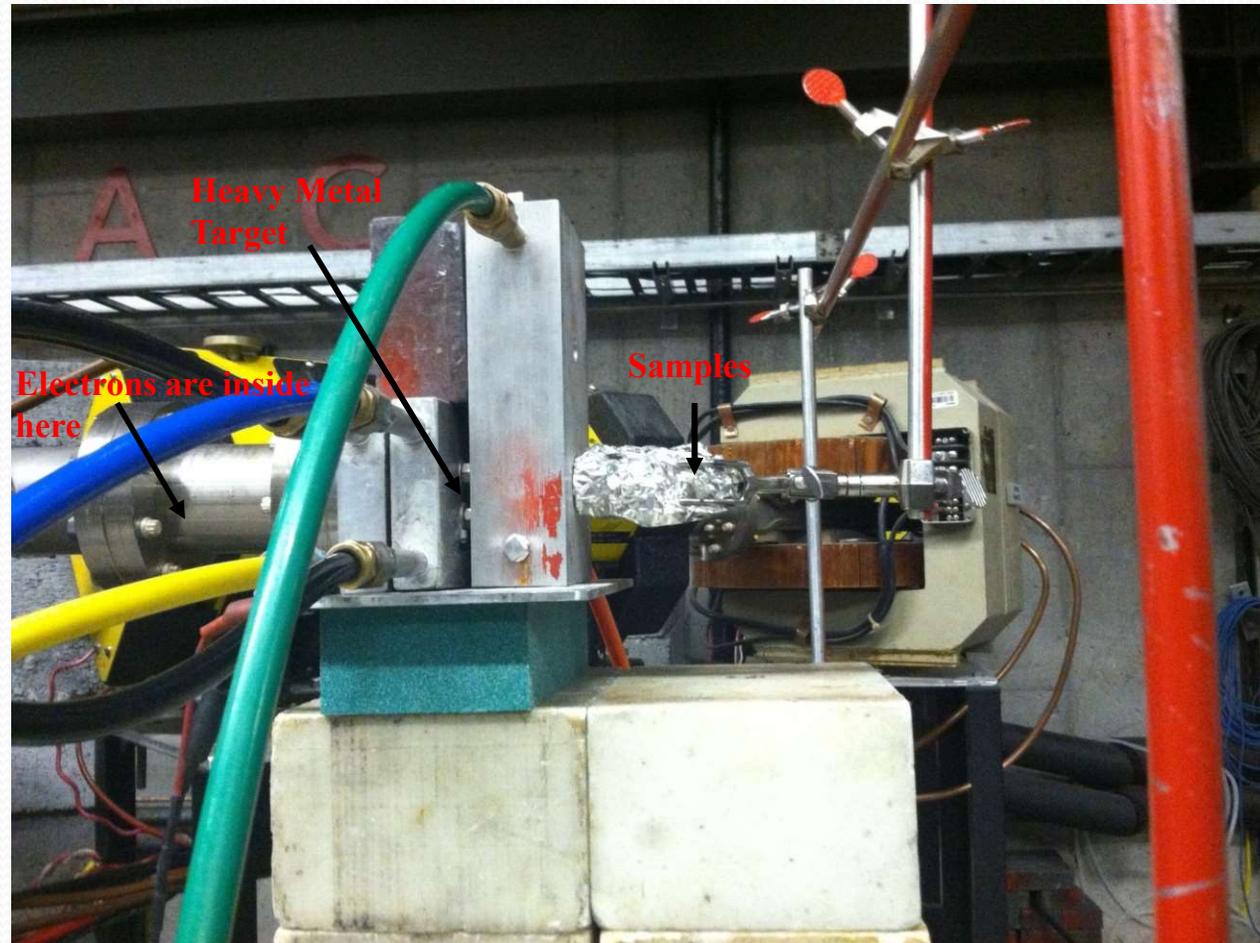


Figure: Image of the end of the irradiation setup. Image from (Borgwardt, 2014)

Bremsstrahlung Radiation

- Electrons (e^-) interact with the electric charge of the nucleus, in order for energy conservation to hold, they release a gamma ray

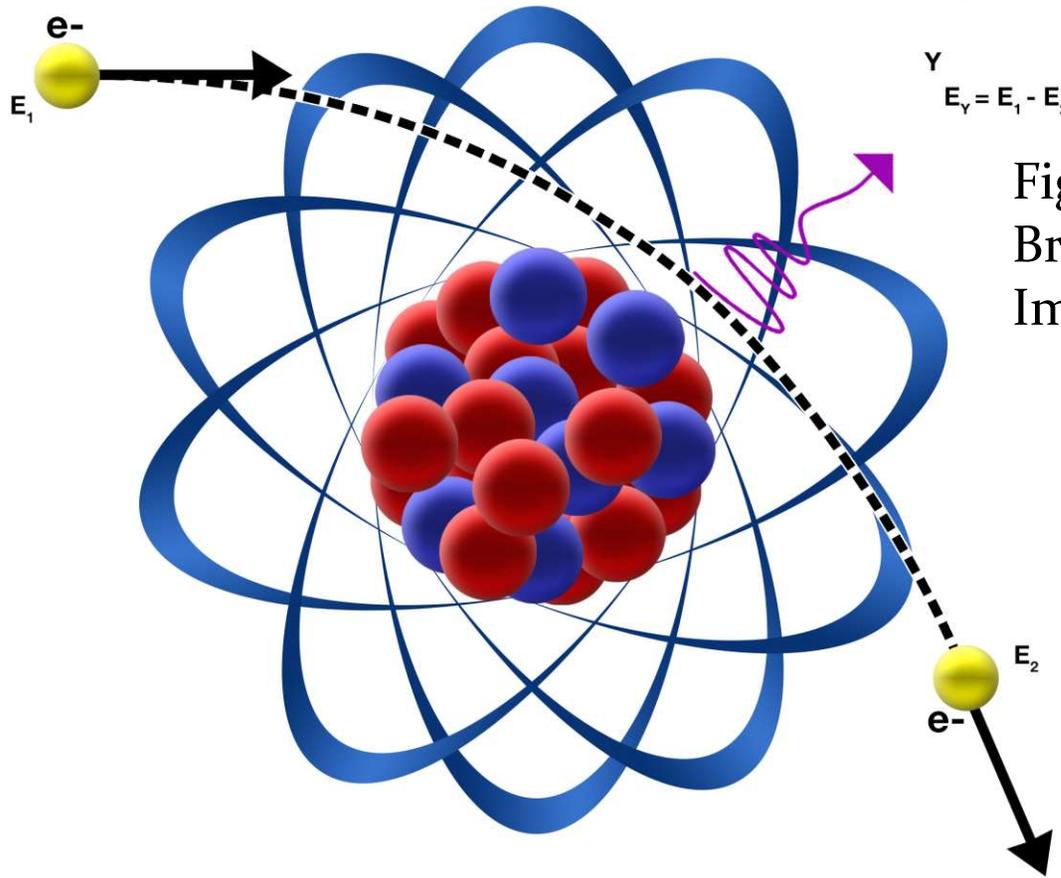


Figure: Illustration of the Bremsstrahlung radiation process. Image from (Borgwardt, 2014)

Sample Preparation

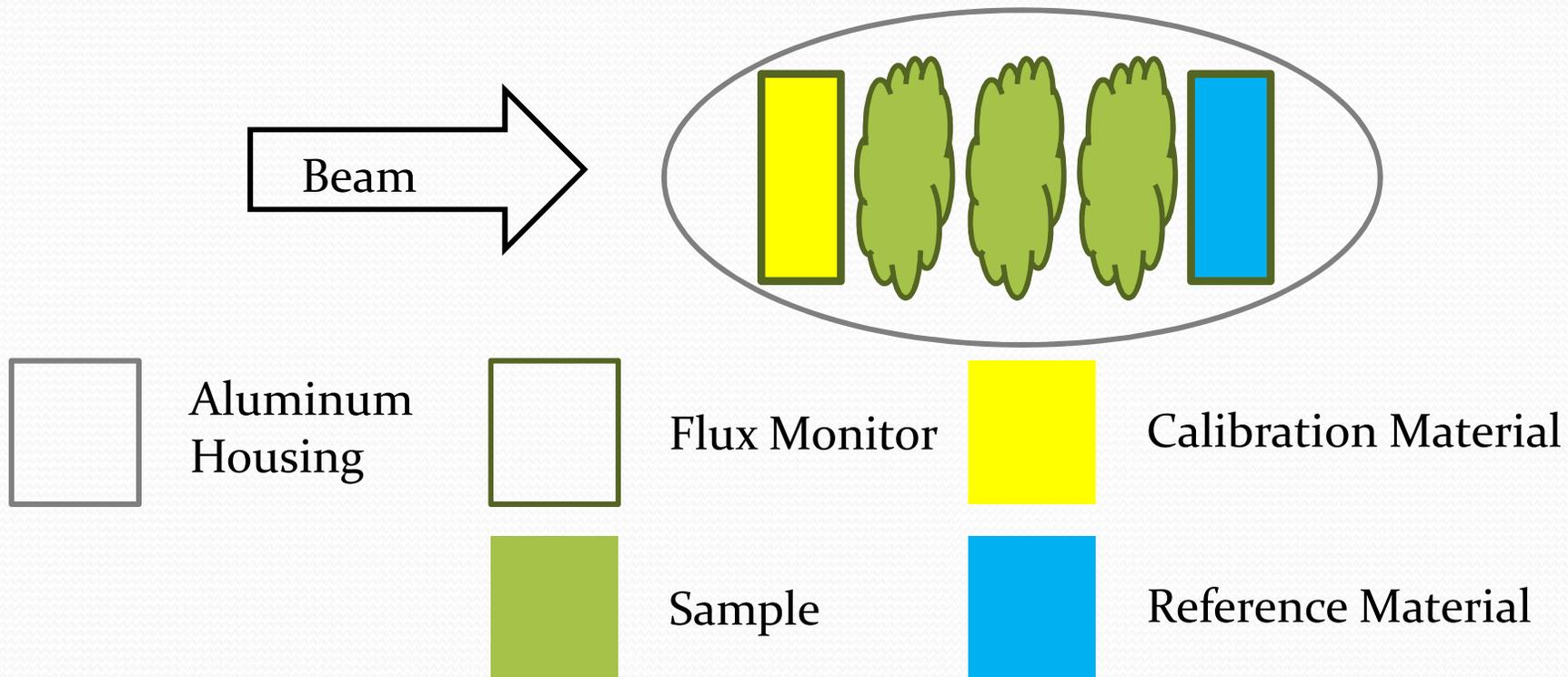
- Typical fossil handling procedures should be used. Gloves should be worn to prevent contamination, careful handling to avoid damage to the sample
- For non-destructive analysis, no sampling, chemical separation, or altering of sample should be done



Figure: Flaking of a fragile sample due to improper handling. Image from (Borgwardt, 2014)

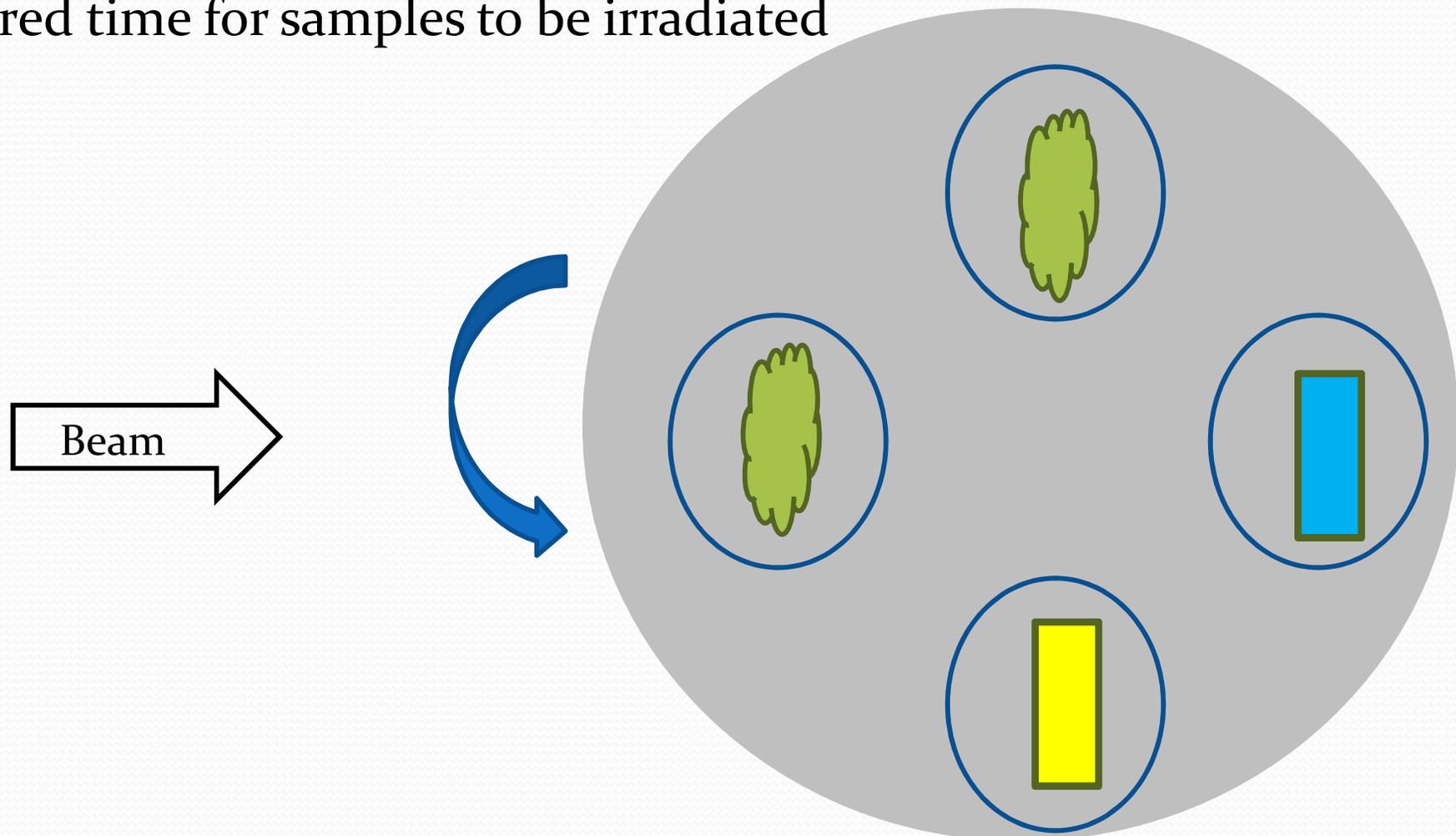
Irradiation Setup – Stack

- Samples can undergo irradiation in a “stack” configuration. All samples are wrapped in copper foil to monitor the amount of gamma rays being received by each sample, so corrections can be made. Calibration material is placed at the front and used for calculations. Reference material is placed in the rear and is treated as a sample for quality control. Aluminum foil can be used to hold the samples in place.



Irradiation Setup – Rotating Table

- Samples can undergo irradiation in a “rotating table” configuration. Samples are rotated in and out of the beam, the rotations are timed to match the pulses of beam from the accelerator. This allows a more homogeneous amount of gamma rays to be absorbed by samples, but can increase the required time for samples to be irradiated



Counting

- After samples have been irradiated, they need to be counted with a high purity germanium detector. This allows a count of different energy gamma rays to be recorded. The energies can be used to identify elements in the sample, and the counts can be used to calculate concentrations

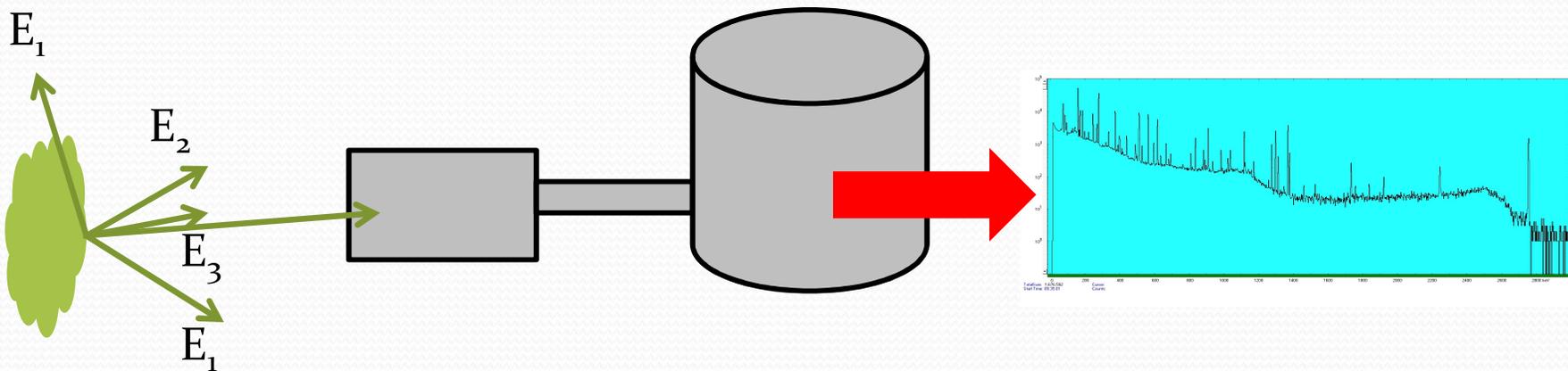


Figure: Samples are placed in front of a high purity germanium detector and give off gamma rays of differing energies (E). The detected gamma rays then form a spectrum with various peaks corresponding to different elements

Counting - Analysis

- The peaks in the spectrum can be fit with a Gaussian shape. This gives the energy to identify the element and number of gamma rays detected to calculate concentrations

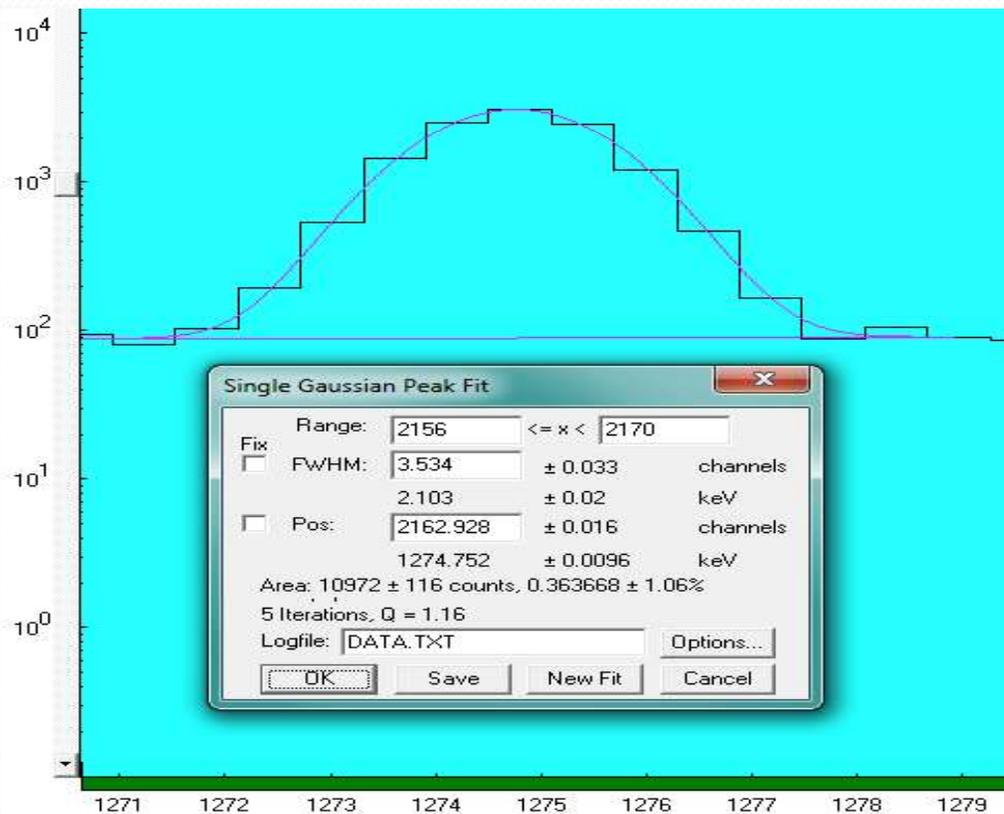


Figure: Spectra zoomed in on a single peak, with a fit giving the energy and number of gamma rays detected

Calculations

- Once gamma rays have been associated with a certain element, the concentration of that element can be calculated if the same energy of gamma rays were seen in the calibration material.

Calculations

- Subscripts s, CM, denote sample and calibration material respectively.
- P is counts in the spectrum peak (number of gamma rays detected)
- m is mass of the sample, t is time, with the subscripts d denoting time between the irradiation and the start of counting and c denoting the amount of time a sample was counted
- ϕ represents correction factors for differing amounts of gamma rays received during irradiation
- c is the concentration of the element that corresponds to the gamma ray energy detected

$$c_s = \frac{P_s m_{CM} c_{CM} e^{-\lambda t_{CM,d}} (1 - e^{-\lambda t_{CM,c}}) \phi_{CM}}{m_s P_{CM} e^{-\lambda t_{s,d}} (1 - e^{-\lambda t_{s,c}}) \phi_s}$$

Applications to Paleontology

- Non-destructive, broad spectrum trace element analysis technique with low sensitivities and large sample and bulk analysis capabilities is useful in several areas including provenance studies, paleoenvironment reconstruction, paleodiet studies, and paleonutritional studies, etc.
- Useful for any study that looks at trace elements.
- Useful for source matching of unknown samples or illegally obtained samples

Conclusions

- Photon activation analysis provides a trace element analysis tool that is sufficient for several areas of paleontology
- Most importantly it can be used non-destructively, helping to preserve the rare and non-renewable samples that are found in paleontology

References

Images from:

Borgwardt TC (2014) A test of a non-destructive nuclear forensics technique using photon activation analysis of fossils and source matrices. South Dakota School of Mines and Technology