3D Scanning and 3D Printing of Radioactive Sources

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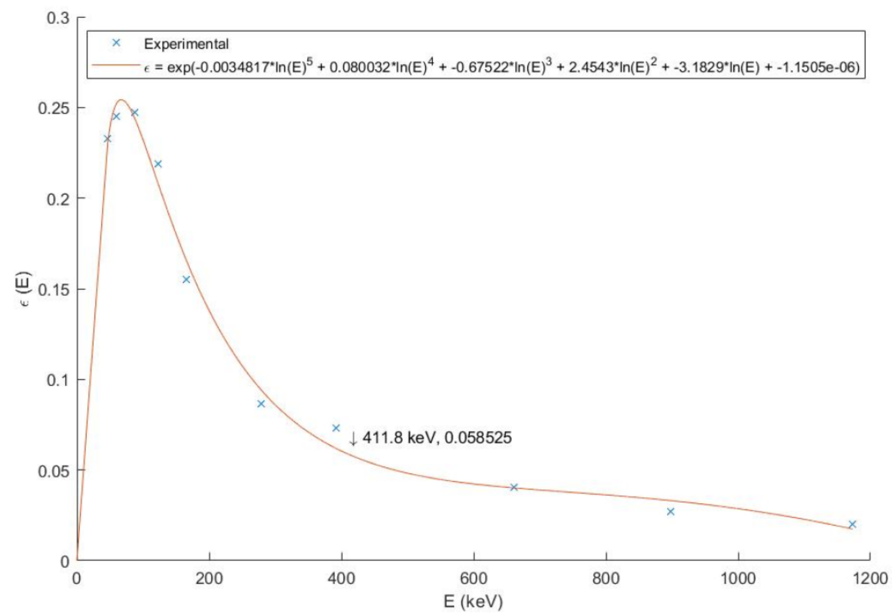
Outline

- **Problem Statement**
- **Historical Paths to Solving this Problem**
- **Experimental Method**
- **Results**
- **Conclusions**

Problem Statement

- Gamma-ray spectroscopy requires three calibrations:
  - Energy to channel
  - Energy to resolution
  - Energy to efficiency
- The comparator method is popular for the energy to efficiency calibration.
- This method allows for unique sample geometries to be generated for comparator method calibrations.



Problem Statement Continued

- Radioactive sample quantification is often desired for uniquely shaped items.

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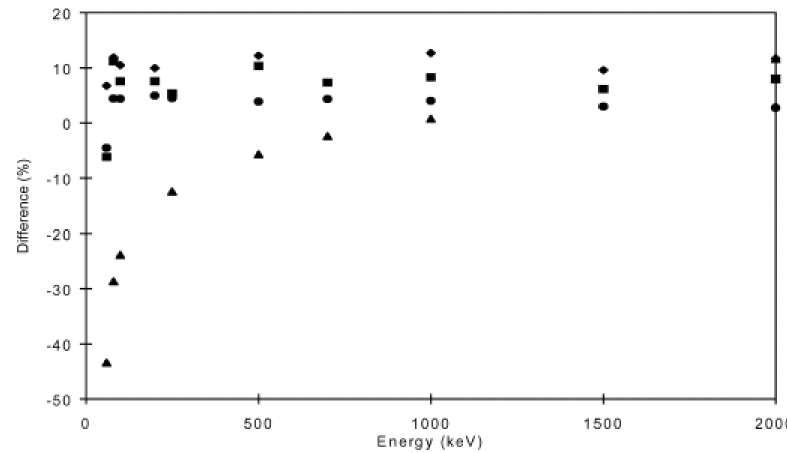
Historical Paths to Solving this Problem

- One path to address this problem is via computational methods.
- Lepy et al. (2001) “Intercomparison of efficiency transfer software for gamma-ray spectrometry” compared many codes to calculate detector efficiency curves.
- The results showed that the computational methods had uncertainty in the range of 5% to 10%

ELSEVIER
Applied Radiation and Isotopes
Volume 55, Issue 4, October 2001, Pages 493-503

Intercomparison of efficiency transfer software for gamma-ray spectrometry

M.C. Lépy[a], T. Altzitzoglou[b], D. Arnold[c], F. Bronson[d], R.Capote Noy[e], M. Décombaz[f], F. De Corte[g], R. Edelmaier[h], E.Herrera Peraza[i], S. Klemola[j], M. Korun[k], M. Kralik[l], H. Neder[m], J. Plagnard[a], S. Pommé[n], J. de Sanoit[a], O. Sima[o], F. Ugletveit[p], L. Van Velzen[q], T. Vidmar[k]



Difference (%) between computed and experimental efficiencies for the reference distance using the supplier's data for different codes (■=code B4, •=code 5-a, ⧫=code C3, ▲=code C1).

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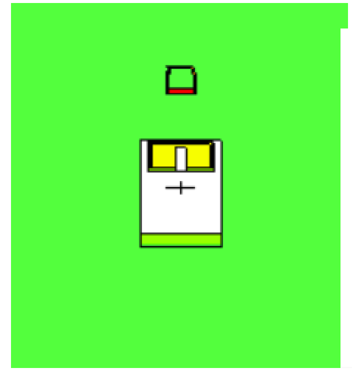
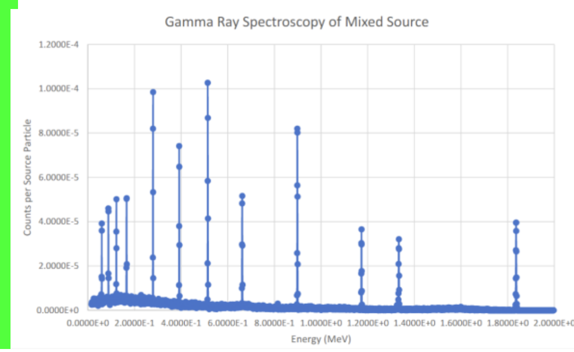
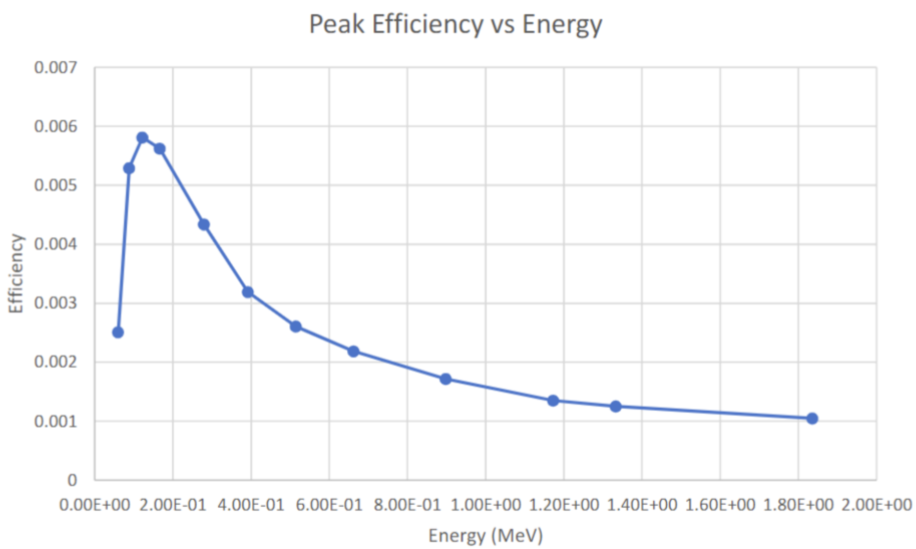
Monte Carlo Methods

- Codes including MCNP and GEANT are commonly utilized to model detector efficiencies.
- Problems exist in precise modeling of the detector including features such as the dead layer.
- Model entry and export control of software can add complications.







Project for NRE 3112 Radiation Detection at Georgia Institute of Technology

Mesh-Grid Method

- Semiempirical mesh-grid method and works for arbitrary source shapes and counting geometries have also been developed.
- Can work with arbitrary source shapes.
- Minimal computational resources.
- Most results are better than 10%.

J Radioanal Nucl Chem (2009) 282:223–226
DOI 10.1007/s10967-009-0246-9

A software package using a mesh-grid method for simulating HPGe detector efficiencies

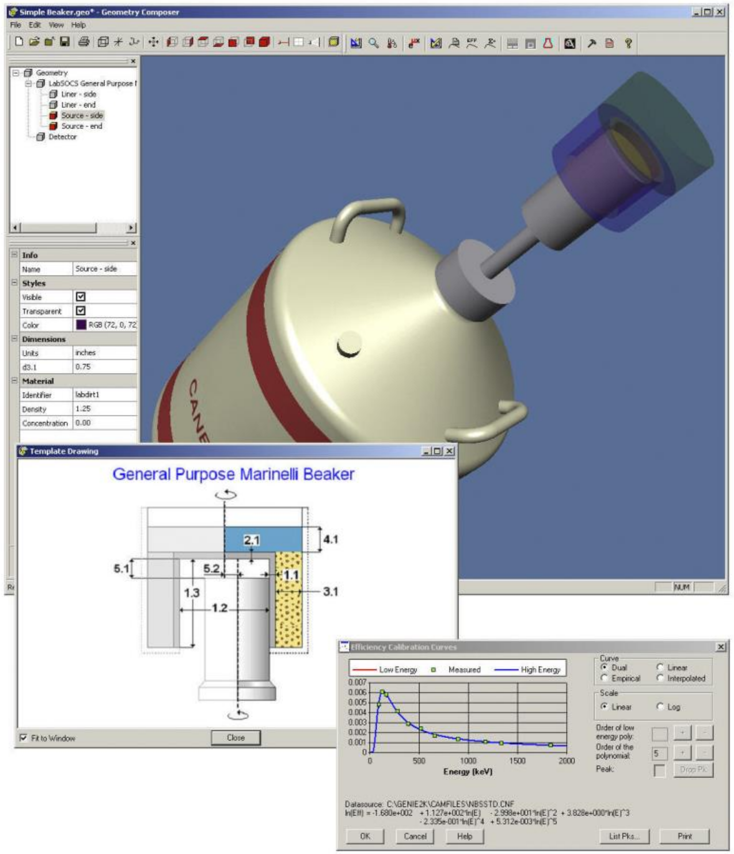
K. R. Jackman · R. E. Gritzo · S. R. Biegalski

Table 3 Experimentally measured efficiencies and KMESS effective solid angle calculated efficiencies for a volume source at a distance of 0.474 cm

Energy (keV)	Experimental efficiency	Effective solid angle efficiency	Difference (%)
59.54	3.472E−03	3.050E−03	12.16
88.04	9.409E−03	9.054E−03	3.78
122.06	1.154E−02	1.146E−02	0.74
165.86	1.083E−02	1.085E−02	−0.17
279.20	7.147E−03	7.237E−03	−1.26
391.69	5.069E−03	5.145E−03	−1.51
661.66	2.982E−03	3.054E−03	−2.42
898.04	2.215E−03	2.288E−03	−3.28
1173.24	1.724E−03	1.796E−03	−4.16
1332.50	1.536E−03	1.607E−03	−4.65
1836.06	1.164E−03	1.235E−03	−6.09

Commercial Software

- Mirion's LabSOCS (Laboratory Sourceless Calibration Software) mathematical efficiency software is an option for solving this problem.
- Each detector is computationally characterized.
- Users may enter in source geometries.



https://www.mirion.com/products/labsocs-calibration-software

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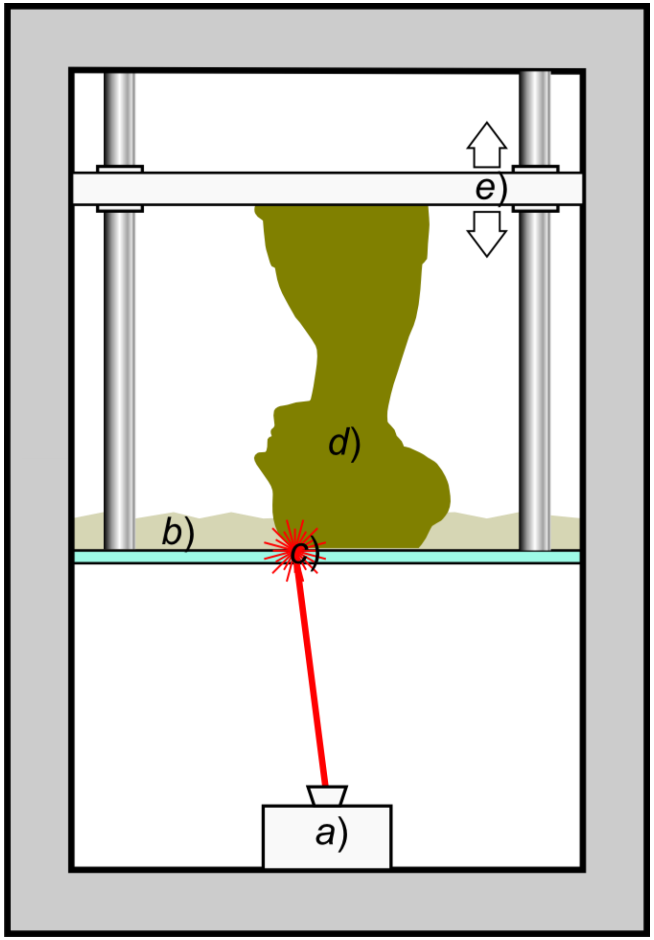
3D Scanning and Printing

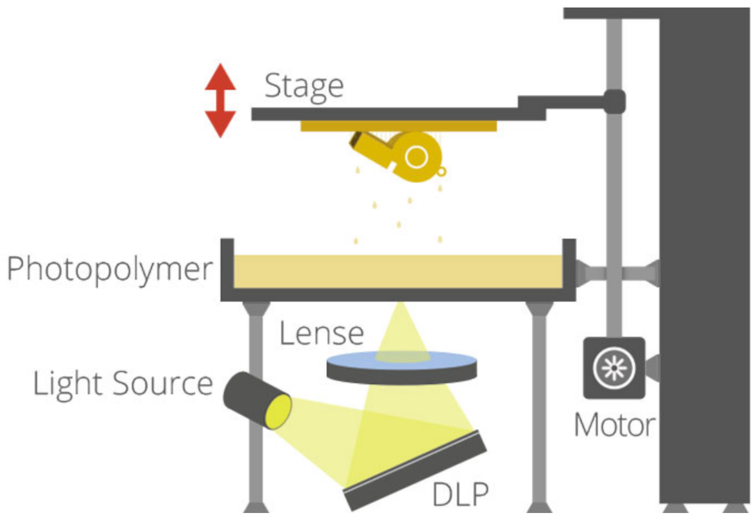
- Current additive manufacturing methods offer an alternative solution to this problem.
- Unique radioactive source geometries may be printed to match unique sample geometries.
- Geometries may be developed via CAD software. They may also be developed via 3D scanners.



https://en.wikipedia.org/wiki/Stereolithography

Stereolithography

- Stereolihography is the additive manufacturing method used for this project.
- Photopolymerisation of a resin is utilized to build objects.
- Post processing of samples are necessary to clean sample and solidify polymer.



https://www.3dprinting.lighting/

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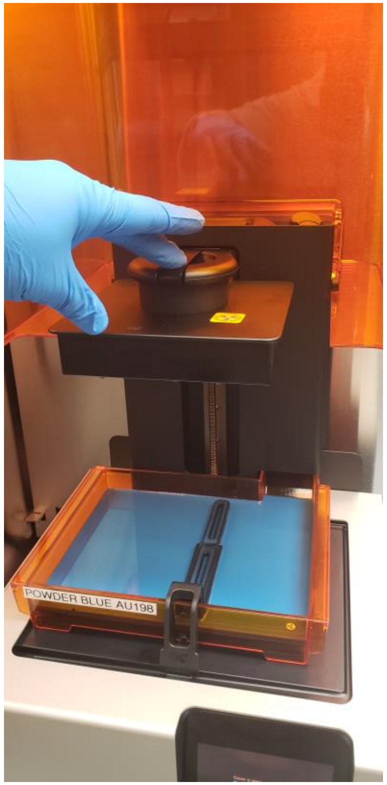
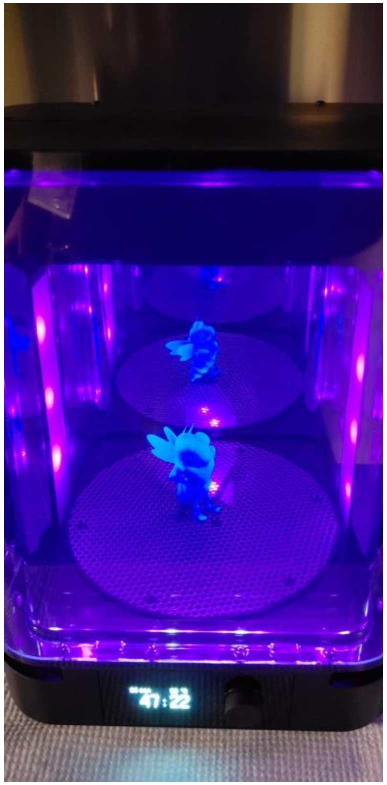
Experimental Method

1. Scanning
2. Isotope production
3. Resin mixing
4. 3D printing



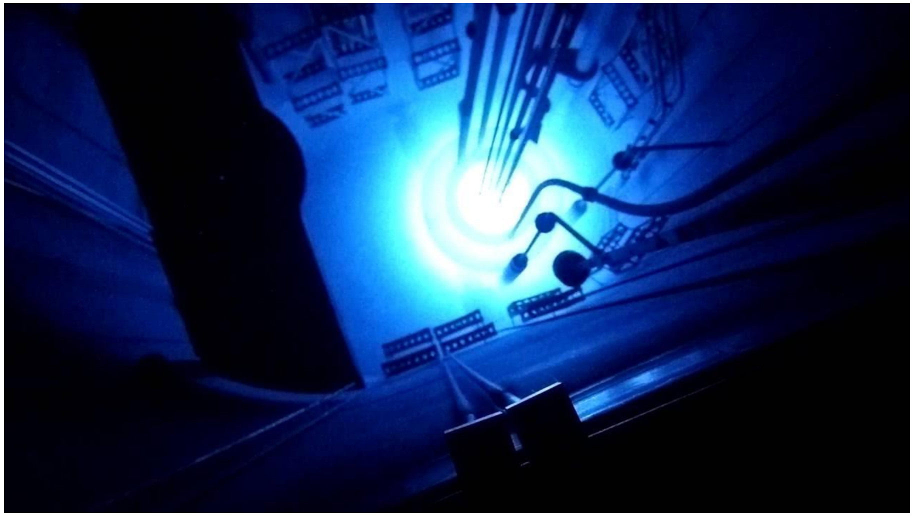


Scanning

- A Matter and Form V2 3D scanner is utilized to create a .stl file.
- The 3D scanner has a HD CMOS sensor with two lasers.
- .stl file converted to gcode for printing.

Isotope Production

- A NIST gold standard solution is irradiated (Au in HCl solution).
- For these experiments, the solution is irradiated in the 3L facility at The University of Texas TRIGA reactor.
- Targeted activity is approximately 1 kBq per sample.



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Resin Mixing

- Formlabs clear resin was utilized.
- ^{198}Au was combined with the resin in a 1 liter beaker.
- A Cole-Palmer EW-50006-03 compact digital mixer was utilized to mix the gold into the resin.
- Resin was mixed for five minutes.

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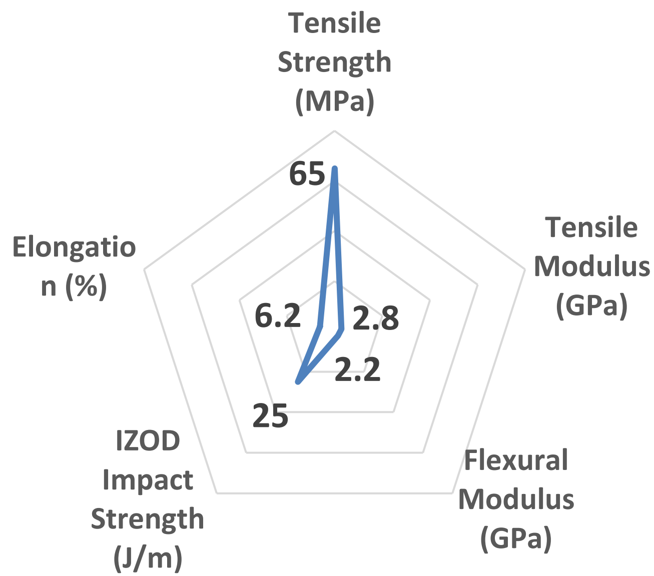
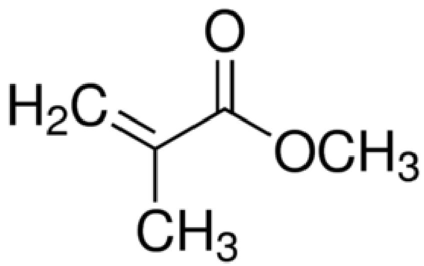
Materials: Standard Resin

Compound	% Weight Contribution	C.A.S No.
Methacrylated oligomers	Proprietary	Proprietary
Methacrylated monomers	Proprietary	Proprietary
Photoinitiator(s)	Proprietary	Proprietary
Pigments	<0.1	Proprietary
Additives	<0.5	Proprietary



Property	Value	Units
Specific Gravity	1.085 ± 0.005	g/cm^3
Viscosity	8.75 ± 0.25	g/cm·sec
Boiling Point	➢ 100	°C
Flash Point	➢ 100	°C
Vapor Pressure	Unk	Pa



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Printing

- Formlabs stereolithography system utilized for printing.
- Form Wash and Form Cure used to clean and cure the samples.

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Gamma-Ray Spectroscopy

- Gamma-ray spectroscopy conducted on Canberra Broad Energy High Purity Germanium (BEGe) detector.
- GENIE-PC utilized for counting and spectrum analysis.
- Samples were counted to achieve 1% counting statistics.
- Dead-times were less than 1%.

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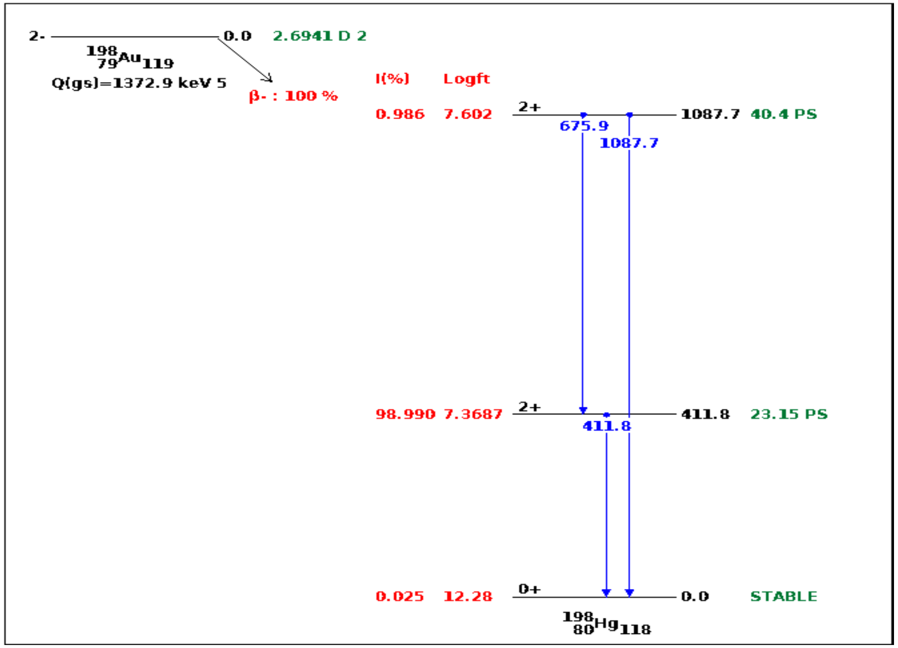
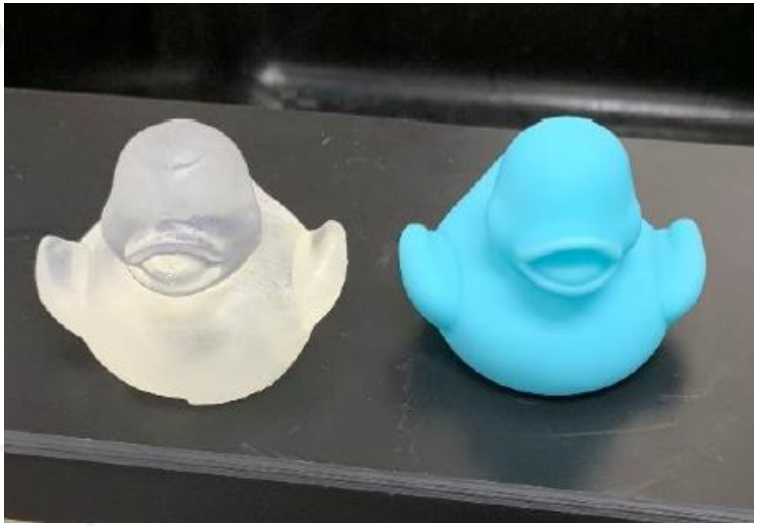
Results

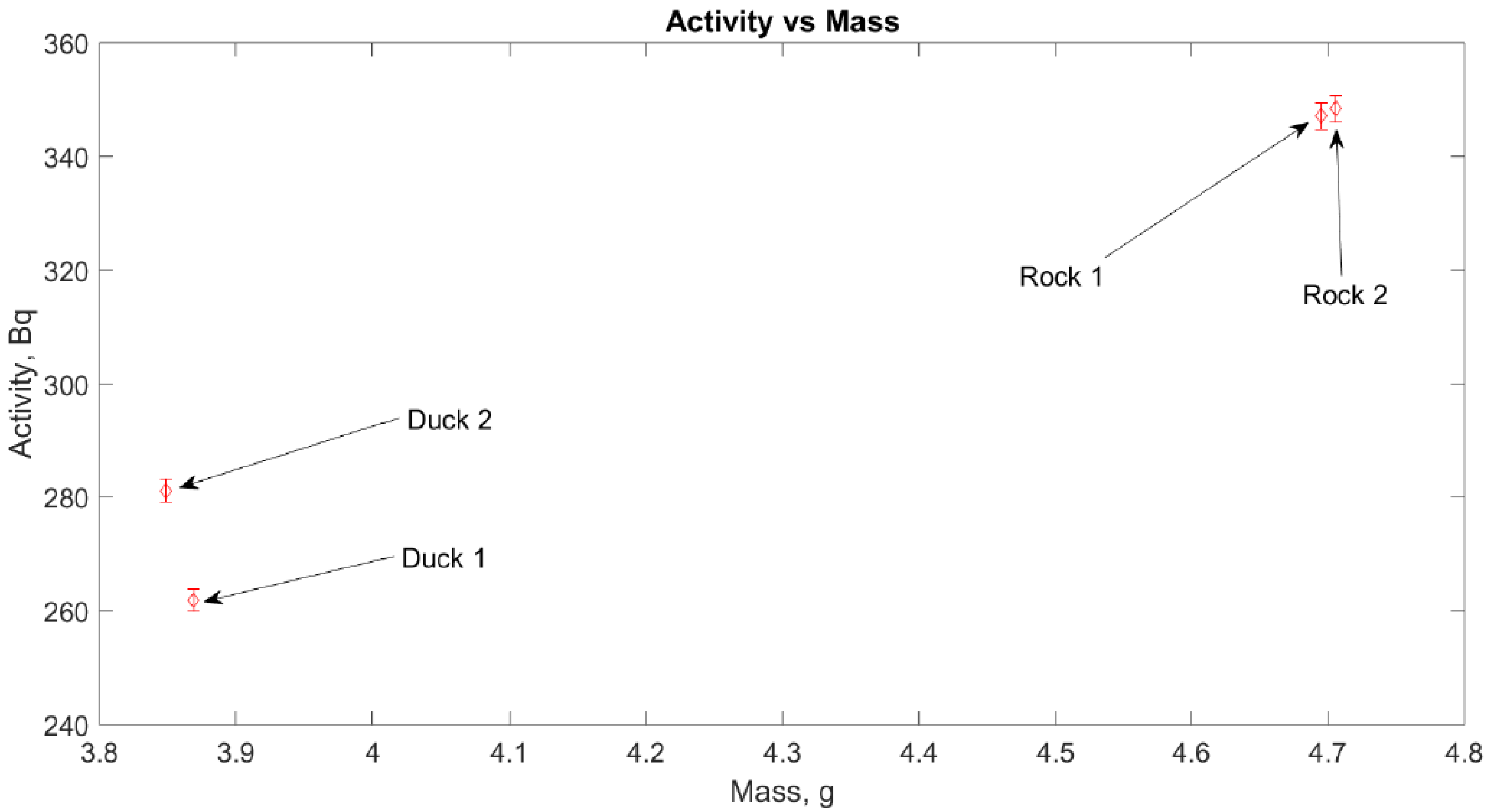
- Multiple sample geometries were explored.
- Goal was to look at replications and reproducibility of both mass and activity.
- Both total activity and specific activity were examined.



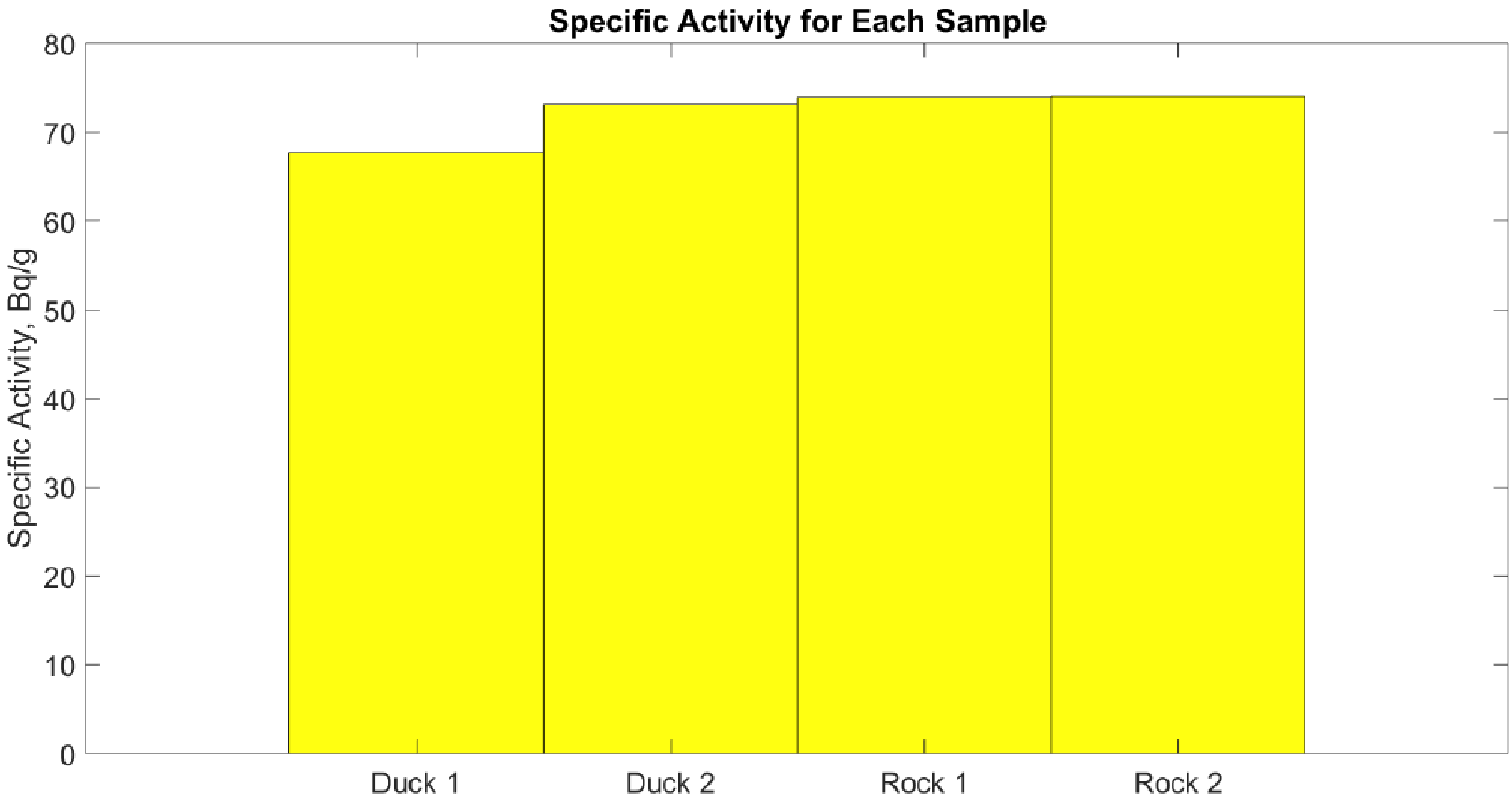
Ducks and Rocks



Ducks and Rocks Results



Specific Activity



Conclusions

- Samples with complicated geometries were scanned and then printed with a resin with ^{198}Au mixed in.
- Radioactive facsimiles were produced and then counted on a HPGe detector.
- Mass differences between replicated samples was 0.2%.
- Specific activity was 72.18 ± 3.033 Bq/g (4% standard deviation).
- Work needs to be conducted to improve homogeneity of resin during printing.
- Given initial results, it is practical to foresee this method reducing uncertainty and approaching 1%.

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