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Implementing auto-loading germanium systems for neutron activation measurements at Sandia's Z-Facility

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Motivation

Neutron yields are an important metric for ICF experiments and can be inferred through neutron activation measurements. These measurements are performed on HPGe detectors that need to be supervised. Recently, two of our detector systems were converted to an auto-loader system. This will reduce the need to manually swap samples and allow for easy overnight counting should an experiment happen late. Before these systems are implemented they must be calibrated to ensure quality data return for use in our yield analysis.

Indium activation is essential to infer DD-neutron yields from ICF experiment at the Z-facility

Deuterium is the primary fuel used in ICF experiments at the Z-facility

$$^2_1D + ^2_1D = ^3_2He(0.82\ MeV) + n^0(2.45\ MeV)$$

One of the primary reactions of interest is the activation of indium-115 by DD neutrons

^{115}In(n,n')^{115m}In, Reaction Threshold Energy = 0.38 MeV, $t_{1/2}$ = 4.49h, resulting in a 336 keV gamma

Yields from ICF experiments can be inferred from measuring the decay of activated indium nuclei using the following formulas

$$Y = \frac{4\pi N_o \langle d^2 \rangle}{mhF} \qquad N_0 = \frac{(C-B)}{(e^{-\lambda t_1} - e^{-\lambda t_2})}$$

Where:

- N_0 = Initial number of activated indium nuclei
- $\langle d^2 \rangle$ = square of the mean distance (cm) sample is from the source
- *m* = mass (g) of indium sample
- *h* = MCNP correction factor
- F = Detector F-Factor
- (C – B) = pulse height area of the 336.23 MeV gamma ray
- λ = inverse mean half-life of ^{115m}In
- t_1 = start time (min) of sample counting measured from the end of irradiation
- t_2 = stop time (min) of sample counting measured from the end of irradiation

F-factor Calculations

The F-factor is a calibration of the entire counting system. This is determined in the laboratory using the following expression:

$$F = \frac{(C-B)\lambda}{\varphi m\,(1 - e^{-\lambda t_0})(e^{-\lambda t_1} - e^{-\lambda t_2})}$$

Where:

- φ = neutron flux (n/min/cm^2) at the sample
- t_0 = is the irradiation time of the indium sample
- t_1 = start time of the count
- t_2 = end time of the count

The quantities that determine the F-factor are determined in a laboratory setting with details below.

Calibration Methodology

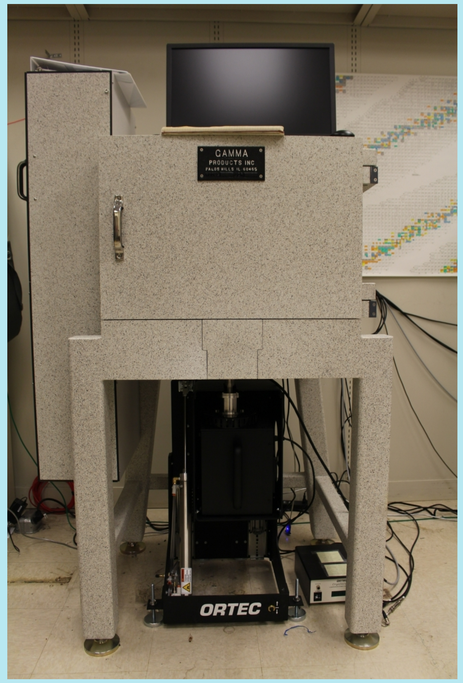
Indium samples are activated by neutrons generated by an erbium di-deuteride target irradiated with a 175 keV deuteron beam at Sandia's Ion Beam Laboratory

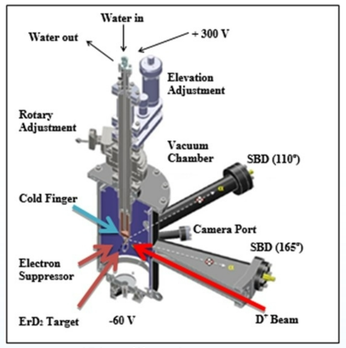
Sample are fielded at 95° with respect to the deuteron beam which produces 2.45 MeV neutrons.

Neutron flux is determined by the associated particle from the fusion reaction (proton or the helium-3).

The indium sample activity is then measured with our HPGe detector systems.

These quantities are then used to determine the F-Factors.





IBL calibration setup

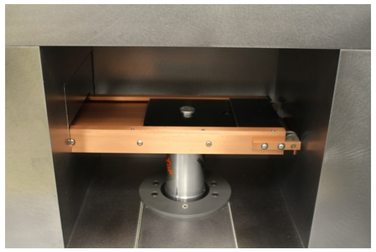
F-Factor Results

Detector	DD: In 336	DT: In 336	DT: In 190	DT: Zr 909
Ge 3	2.591E-05	5.058E-06	3.021E-05	2.892E-05
Ge 6	2.456E-05	4.845E-06	2.813E-05	2.681E-05

These detectors were installed into their new auto-loader systems which have a 9mm standoff between the sample and the detector.

Activated Indium Samples Counted Using New Auto-Loader Detector Systems

- This new system is able to count up to 24 activation samples without supervision.
- The hardware in this system includes:
  - Two ORTEC HPGe Pop Top Detectors
  - Two ORTEC Integrated Cryocooling Systems & ICS Stand 2
  - Two Gamma Products Inc. G300W Automatic Sample Changer
    - Each unit contains two cassettes with twelve trays inside
  - ORTEC GammaVision software connected to Gamma Products G3X software



Auto-Loader System Qualification

The auto-loading counting systems have been independently calibrated. As an additional qualification of the system, several shots were counted on our existing system and the new auto-loading systems to compare their measured N_0. Results from one of those shots are shown.

	Sample 1		Sample 2		Sample 3		Sample 4	
	Detector	N_0	Detector	N_0	Detector	N_0	Detector	N_0
Established	Ge 1	3.14E+06	Ge 1	3.32E+06	Ge 1	1.47E+07	Ge 1	3.00E+06
Auto-loader	Ge 3	3.08E+06	Ge 3	3.06E+06	Ge 3	1.40E+07	Ge 3	3.09E+06
	Ge 6	2.94E+06	Ge 6	3.02E+06	Ge 6	1.36E+07	Ge 6	3.07E+06

	Sample 5		Sample 6		Sample 7		Sample 8	
	Detector	N_0	Detector	N_0	Detector	N_0	Detector	N_0
Established	Ge 1	5.63E+06	Ge 1	5.65E+06	Ge 1	1.86E+06	Ge 1	5.35E+06
Auto-loader	Ge 3	5.52E+06	Ge 3	5.33E+06	Ge 3	1.77E+06	Ge 3	5.28E+06
	Ge 6	5.42E+06	Ge 6	5.02E+06	Ge 6	1.71E+06	Ge 6	5.19E+06

Sample	Percent Difference in N_0 between Ge 1 & Ge 3	Percent Difference in N_0 between Ge 6 & Ge 1
1	+1.91 %	+6.37 %
2	+7.83 %	+9.04 %
3	+4.76 %	+7.48 %
4	-3.00 %	-2.33 %
5	+1.95 %	+3.73 %
6	+5.66 %	+11.15 %
7	+4.84 %	+8.06 %
8	+1.31 %	+2.99 %
Mean	3.91 %	6.39 %

The deviations from the auto-loader numbers and the existing system are with in the absolute error of our calibration system. This means that we can reliably utilize these new systems to autonomously perform activation measurements. A similar validation data set for the 190 keV decay of indium and the 909 keV decay of zirconium due to 14.1 MeV DT neutrons are in progress but not yet completed.

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