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Gamma Energy Evaluation for Creation of ^{111m}Cd, ^{113m}In, and ^{115m}In Isotopes

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Summary. — NASA Glenn Research Center is investigating nuclear reactions in deuterated materials exposed to bremsstrahlung photons with kinetic energies from 1-3 MeV. Recent experiments used a continuous beam Dynamitron electron accelerator with a braking target. Electron beam energy loss verification was desired and experiments using cadmium and indium were completed which are known to transition to excited metastable states after exposure to bremsstrahlung photons. The gamma spin-up of ^{111}Cd, ^{113}In, and ^{115}In are with photon beam energies of 1017 keV, 1024 keV, and 941 keV respectively. Recent tests corroborated published gamma energies using a beam energy loss of 62 to 74 keV.

1. – Background

Previous studies [1,2,3] have experimentally investigated the elevated energy levels of cadmium and indium metastable states. The Brookhaven National Laboratory contains extensive databases [4] outlining the known energy states of all elements. The isotopes that were studied under these set of experiments were ^{111}Cd, ^{113}In and ^{115}In and their first excited states are 1016.76 keV (Fig. 1a), 1024.2 keV (Fig. 1b), and 941.4 keV (Fig. 1c) respectively. For clarity, Fig. 1 only shows transition lines of interest in this study.

2. – Experimental Setup

Tests were performed using a Dynamitron electron accelerator having independent control of beam energy (950 keV to 1.32 MeV, ±25 keV to 3-sigma) and beam current (10 μA to 45 mA). The direct current accelerated electron beam enters the beam room via evacuated tube and is scanned over a braking target utilizing the scanning magnet ≈1m above the target. The beam was operated in photon mode for the tests utilizing a 1.2 mm thick tantalum (Ta) braking target. Samples were placed close to the Ta braking target and were exposed while the electron beam scanned at 100 Hz frequency over the length of the target (0.91 m). Fig. 2 shows a diagram of the Dynamitron and the location of the beam sweep and tray where the product (sample) is placed during the exposure.

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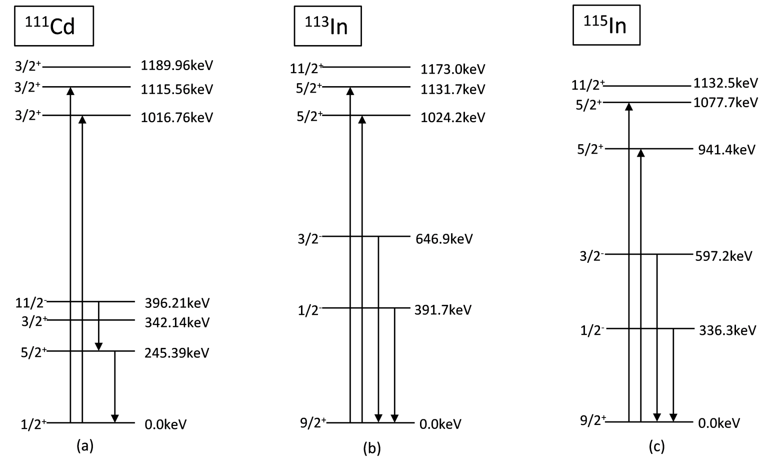
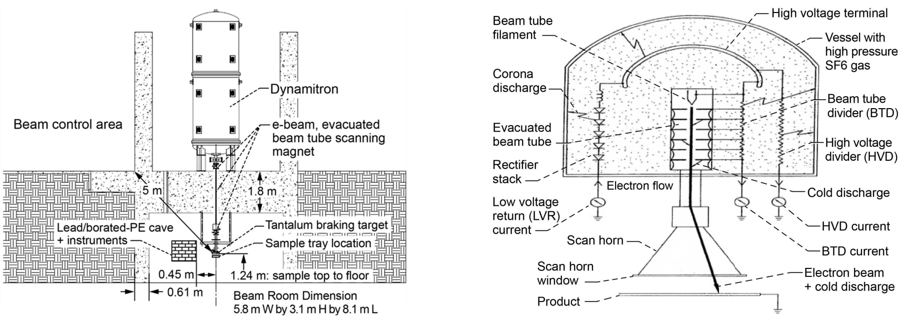


Fig. 1.: Energy level diagram of the excited states of (a) ^{111}Cd at 1016.76 keV, (b) ^{113}In at 1024.2 keV, and (c) ^{115}In at 941.4 keV [4].



(a) Dynamitron overview.

(b) Beam sweep and product tray.

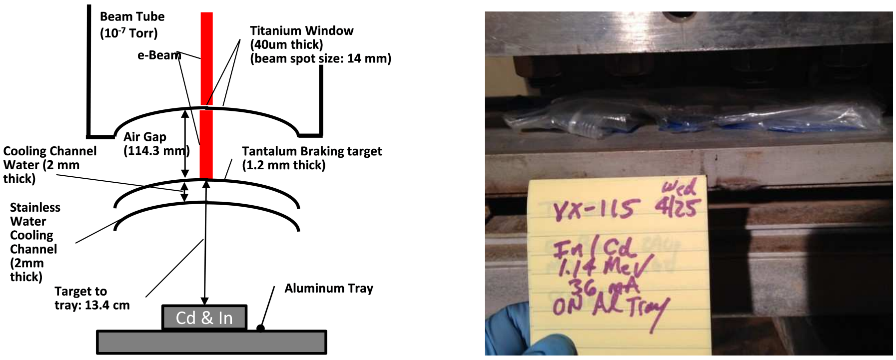
Fig. 2. Schematic of Dynamitron

2·1. *Sample Preparation and Exposure.* – Cadmium (Cd) sheets were cut in approximately 1 cm x 6 cm pieces and arranged in a line with a mass of ≈74 g. Indium (In) ingots of a total mass of ≈30 g were arranged in a line alongside the cadmium. Linear arrangement of the Cd and In allowed for maximum exposure to the sweeping beam.

The Cd and In samples were exposed for 15 to 60 minutes under the bremsstrahlung photon beam. Fig. 3a depicts the side view of the Cd and In samples located 13.4 cm from the Ta braking target which was cooled with ambient temperature water flowing span-wise in a stainless-steel cooling channel. Fig. 3b shows a photograph of one of the Cd and In sample bundles on the product tray just before exposure. After the exposure was completed, the sample bundle was retrieved and counted in a lead shielded, high purity germanium (HPGe) gamma detector cave and counted for 15 to 60 minutes.

3. – Experimental Results

After the gamma scans were collected, resulting peaks were analyzed and determined to be from ^{111m}Cd, ^{113m}In and ^{115m}In. The net area counts and uncertainty of each peak were recorded along with the gamma start time, the beam off time, gamma scan time,



(a) (b)

Fig. 3.: View of Cd and In sample location under the beam. (a) Cross sectional view of electron beam, titanium window, braking target, cooling channel, and sample location and (b) photograph of Cd and In sample on the aluminum product tray.

beam energy, beam current and sample weights. All gamma scans were reviewed using the PeakEasy [5] peak analysis software and gamma peak identifications were completed and statistics of each peak were collected. Confirmation of each radioisotope was made with sequential scans of the same sample and the half-lives of each peak were calculated. Fig. 4 shows the strongest gamma peaks for ^{111m}Cd (245.39 keV), ^{113m}In (391.69 keV), and ^{115m}In (336.24 keV). PeakEasy was able to realize a gaussian peak for each radioisotopes' strongest gamma peak.

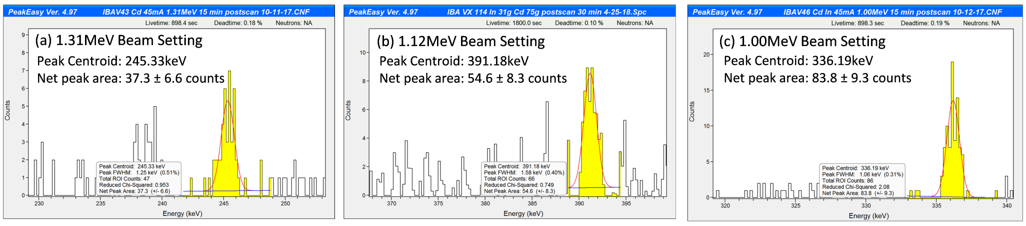


Fig. 4.: Gamma scans of Cd and In samples with background subtracted. (a) ^{111m}Cd: 1.31 MeV beam energy (15min scan), (b)^{113m}In: 1.12 MeV beam energy (30min scan), (c) ^{115m}In: 1.00 MeV beam energy (15 min scan).

3˙1. *Gamma Threshold and Beam Loss Determination.* – The net area count data for each metastable isotope were adjusted to account for different beam currents, exposure times, weight of Cd and In samples, and gamma scan times. The adjusted net area count data were then further adjusted to account for the difference in time between beam off and the start of each gamma scan time with the use of the known half-lives of each respective metastable isotope. The fully adjusted data was then fit linearly as shown in Fig. 5. When not visible, the uncertainty bars are smaller than the data points.

Knowing that the theoretical beam loss is around 70 keV as predicted by the TIGER Monte Carlo code [6], the minimum gamma energy thresholds that cause spin-up of the ^{111}Cd, ^{113}In and ^{115}In isotopes can be determined from the Brookhaven database. The minimum threshold is then subtracted from the x-intercept from the linear fit completed for each metastable isotope. The calculation of the beam loss from both experimental data and the TIGER code is shown in Table I and have a difference of at most 14.2 keV.

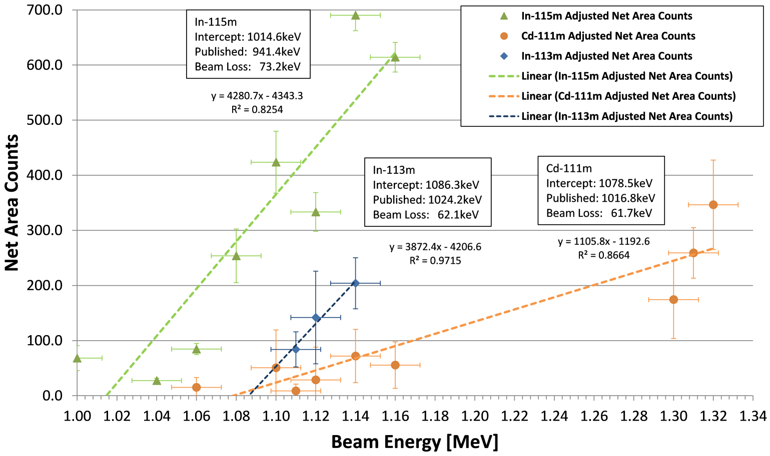


Fig. 5.: Linear fit of adjusted net area counts showing x-intercept and uncertainties (3-Sigma).

4. – Conclusion

The Cd and In experimental data verified the Dynamitron beam loss over the range of 1.015-1.086 MeV and corroborated the Brookhaven National Laboratory metastable thresholds; 1.02 MeV (^{111m}Cd), 941 keV (^{115m}In), and 1.024 MeV (^{113m}In). The experiments determined losses of 62.1 to 73.3 keV vs. the TIGER code losses of 75.8 to 78.2 keV and both show that as beam energy decreases, the beam loss increases. Considering the additional material present in the electron beam cavity during the experiment (titanium window and steel housing), higher energy photons may have been produced. These photons would slightly increase the bremsstrahlung endpoint which may account for the lower experimentally measured energy loss vs. the TIGER code prediction.

Table I. *Comparison of Beam Loss: Experiment vs. Prediction.*

Beam Energy Setting [MeV]	Experimental Evalulation [keV]	TIGER Code Prediction [keV]
1.015	73.3	78.18
1.020		77.92
1.078	61.7	75.90
1.080		75.87
1.086	62.1	75.77

* * *

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