

Feasibility Evaluation of a CZT-Based In-Situ Screening System for Metallic Activated Waste from a Medical Cyclotron

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1. Introduction

Medical cyclotrons become activated during operation, and the metallic components of the machine body account for a large fraction of the waste generated at decommissioning [1]. IAEA NW-T-2.9 recommends in-situ measurement with portable instruments such as survey meters and CZT detectors at an early stage of Class 2 accelerator decommissioning [2], and ISO 8939:2025 requires the activation assessment of a medical cyclotron to combine computational simulation with sampling analysis, the results being used for zoning and for the determination of disposal levels [3].

Kwon et al. screened the gantry of nine medical linear accelerators with a portable HPGe detector without disassembly or sampling, commonly detecting Mn-54, Co-57, Co-60 and Zn-65 above 10 MV [4]. Vichi et al. assessed the concrete walls of a cyclotron bunker with a CZT detector inside a 5 cm thick lead shield, deriving the field of view, the efficiency calibration and nuclide-wise MDA values [5]. The metallic activated waste of the cyclotron body itself, however, has not been addressed. This work presents a preliminary design of such a screening system, validates its Monte Carlo model, and quantifies the radius and depth over which the system responds.

2. Methods

2.1 Target cyclotron and material characterization

The target machine is a SIEMENS Eclipse™ cyclotron (Fig. 1a; 11 MeV protons, 60/120 μ A for single/dual targets, size 150 $\times$ 150 $\times$ 173 cm). The magnet yoke was selected because it has the largest volume and mass among the activated metallic components. Because much of the material information was missing from the manufacturer's documentation, the yoke composition was measured with a laser-induced breakdown spectroscopy (LIBS) instrument, Sci-Aps Z-300. The nickel coating of several tens of micrometers was ground off at each position (Fig. 1b), and five repeated measurements gave the composition in Table I. Mo, Si, Nb, Ti and Pb appeared at the limit of detection and were excluded as ambient-light noise.

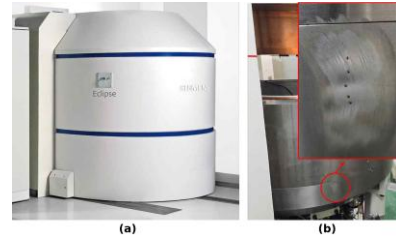


Fig. 1. (a) SIEMENS Eclipse™ cyclotron and (b) LIBS analysis positions on the lower part of the magnet yoke.

Table I: LIBS elemental analysis of the magnet yoke (lower part)

Element	Mass fraction (wt%)	Uncertainty
Fe	98.249	± 0.298
Mn	1.058	± 0.179
Ni	0.287	± 0.121
Al	0.157	± 0.030
Cr	0.133	± 0.011
Cu	0.084	± 0.014
V	0.032	± 0.010

2.2 Screening system configuration

Domestic medical cyclotrons are installed inside hospital buildings, so the vault space available for a screening system is narrow, particularly for self-shielded machines. Following ISO 8939:2025 and the configuration of Vichi et al. [5], the system consists of a Kromek GR1-A+ room-temperature CZT detector (10 $\times$ 10 $\times$ 10 mm crystal, 2.0% resolution at 662 keV) inside a cylindrical pure-lead shield of 8 cm inner diameter, 18 cm outer diameter and 25 cm height.

2.3 Monte Carlo modeling

Since the system measures a spectrum at the surface of a bulk item rather than a powder or chip sample, the measurable radius and depth must be derived from simulated efficiencies. FLUKA 4.5-1 with the FLAIR 3.4-5.2 GUI was used with EM-CASCADE physics. The model was validated by reproducing the CZT efficiency calibration of Vichi et al. (Fig. 2), for which the reported measured and simulated efficiencies agreed within a mean error of 5% [5].

The detection range was evaluated with a 60 $\times$ 60 $\times$ 15 cm low-carbon steel source term containing uniformly distributed Co-60 (Fig. 3), which has the longest half-life (5.27 y) among the nuclides activated in the yoke and is therefore taken as the representative nuclide. The response of a partial source volume divided by that of the

whole source term approaches unity as the source grows, and the detection range was defined where this ratio reaches 0.95.

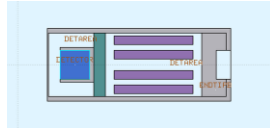


Fig. 2. FLUKA model built to reproduce the reported CZT efficiency calibration.

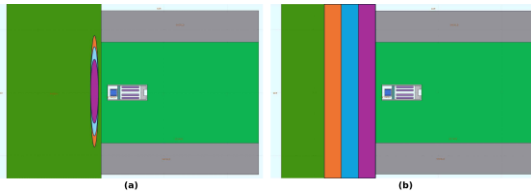


Fig. 3. FLUKA modeling for the detection-range calculation: (a) radial and (b) depth direction.

3. Results and Discussion

3.1 Validation of the model

Table II compares the efficiencies calculated in this work with the published measurements at ten photon energies from 112 to 1,836 keV. The ratios lie between 0.886 and 1.013, i.e. agreement within 5% on average, indicating that the detector and shield modeling is valid for design purposes.

Table II: Calculated detection efficiencies compared with reported measurements

Nuclide	E (keV)	Ref. [5]	This study	Ratio
Co-57	112	1.21E-03	1.213E-03	1.003
Ce-139	166	1.11E-03	1.044E-03	0.941
Cr-51	320	3.94E-04	3.806E-04	0.966
Sn-113	392	2.56E-04	2.591E-04	1.012
Sr-85	514	1.67E-04	1.479E-04	0.886
Cs-137	662	9.89E-05	9.366E-05	0.947
Y-88	898	5.50E-05	5.475E-05	0.995
Co-60	1,173	3.31E-05	3.220E-05	0.973
Co-60	1,332	2.92E-05	2.865E-05	0.971
Y-88	1,836	1.57E-05	1.591E-05	1.013

3.2 Detection range of the system

Interpolation of the calculated ratios gives a detection radius of 10.6 cm and a detection depth of 4.09 cm (Fig. 4). Replacing the lead shield material with BLKHOLE showed that radiation originating outside this range contributes less than 5% of the total signal.

Residual radioactivity in the facility may still interfere from the rear, so additional shielding on that side should be considered. Quantitative nuclide evaluation further requires calibration against certified reference materials, an enlarged simulation database, MDA determination, and detection-range data for the other body materials.

Because the system consists of a compact CZT detector and a small lead shield, it is expected to be applicable under the severe space constraints of domestic cyclotron vaults, and to support the advance partitioning of radioactive and non-radioactive waste areas.

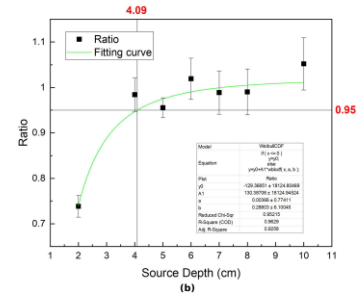
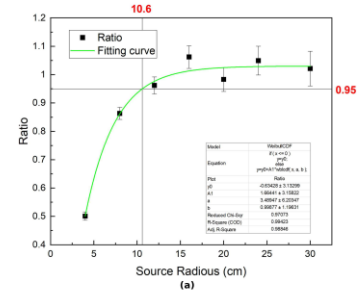


Fig. 4. Detection range of the system: (a) radial and (b) depth direction.

4. Conclusions

A screening system for the metallic activated waste of a medical cyclotron was preliminarily designed and its applicability assessed. The magnet yoke was selected because of its large volume and mass, and Co-60 as the representative nuclide. The FLUKA model reproduced published efficiencies within 5% on average, and the detection range in low-carbon steel was 10.6 cm in radius and 4.09 cm in depth.

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