Performance of a Large Area Mercuric Iodide Lung Counter

M. W. Mallett, M. E. Ennis
Los Alamos National Laboratory
Health Physics Measurements, HSR-4
MS G761, Los Alamos, NM 87545 USA
mallett@lanl.gov

A. E. Proctor, L. van den Berg, J. W. Hintenach
Constellation Technology Corporation
7887 Bryan Dairy Road, Suite 100
Largo, FL 33777 USA
lvdberg@contech.com

Abstract—A new detector system based on mercuric iodide technology was designed and constructed specifically for in vivo measurement applications. The system contains four mercuric iodide room-temperature semiconductor detectors, each with an area of 25 mm × 25 mm, for photon detection and spectrometry. The combination of multiple matched detectors in a single housing achieves the large area needed for in vivo measurements, while overcoming the inherent limitations in the growth of large, high quality crystals of high-Z semiconductor materials. The use of large semiconductor detectors operating at room temperature eliminates the need for liquid nitrogen cooling required for germanium detectors which presents a potential danger in the confined space characteristic of in vivo measurements. The high quality room temperature detectors preserve the spectroscopic quality requirements for transuranic detection. The performance of the mercuric iodide in vivo detector meets the performance requirements specified in ANSI N13.30, and compares satisfactorily with the performance of germanium detector systems typically used for in vivo lung measurements.

Keywords—mercuric iodide; array; radiobioassay; in vivo; lung.

I. INTRODUCTION

Historically, the measurement of low-energy photons required deciding between two competing spectroscopy qualities—improved detection efficiency provided by scintillators (NaI), or improved energy resolution afforded by semiconductors (HPGe). In an attempt to achieve both qualities for in vivo measurements, systems featuring multiple germanium detectors have been employed to increase efficiency via increased surface area. The Los Alamos National Laboratory's (LANL) In Vivo Measurement Laboratory (IVML) utilizes such a system incorporating six HPGe detectors. The primary operational drawback to this scenario is the requirement of a large amount of liquid nitrogen cooling in a confined space (inside the in vivo shielding). The large liquid nitrogen dewars needed to cryogenically cool the germanium crystals also yielded a system too cumbersome to routinely position each detector independently for a given subject.

Investigations of other semiconductor materials with higher effective atomic number (Z) have been made in an effort to improve detection efficiency while maintaining superb energy resolution [1-2]. Mercuric iodide (HgI_2), $Z = 80$ -53, is one

such material. One benefit of this technology is that due to the large bandgap width (2.1 eV), a detector based on HgI_2 can be operated at room temperature. Thus, the need for liquid nitrogen reservoirs is eliminated. However, the principal obstacle to an in vivo system based upon HgI_2 has been the inability to manufacture crystals of sufficient size to yield a practical detector. For example, HgI_2 crystals are now commercially available up to 25 mm × 25 mm and 1-2 mm in thickness. This compares unfavorably to commonly used HPGe detectors having active areas of 2000-4000 mm².

One solution would be to electrically couple multiple HgI_2 crystals in a single detector housing. Four 25 mm × 25 mm crystals could be arrayed to form a single large area detector identical in size to a single 2500 mm² HPGe detector. The circuitry should accommodate a common bias, separate detector preamps, and separate signal outputs for each of the detectors in the array.

II. DETECTOR DESIGN

Constellation Technology (CT) and LANL designed, constructed, and performed the initial characterization of a large area mercuric iodide detector suitable for in vivo measurement application. The circuit board design is shown in Fig. 1. The mercuric iodide lung counter is shown in Fig. 2.

Figure 1. Circuit board and component location design, rear side.

A.E. Proctor's current address is Nucsafte, Inc., 765 Emory Valley Road, Oak Ridge, TN 37830.

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Figure 2. Mercuric iodide array lung counter.

The lung counter features four 25 mm × 25 mm HgI₂ crystals. The total active area is 2500 mm². Each crystal is approximately 1.5 mm-thick. One high voltage (HV) input and four separate signal output connections are present on the detector housing. Gain matching and spectral summing is achieved via external shaping amplifiers and MCA software.

The NIM bias supply is nominally set at +1500 V. A HV divider is used so that a single supply can bias each of the four detectors. The divider outputs are fed to separate RC-filters for each detector. Individual detector bias levels were selected to yield the best resolution. Detector performance was optimized for transuranic photon emissions, ~10-200 keV.

An in-line backup battery supply containing dry cell batteries maintains bias during power failure. The +135 V bias permits rapid recovery, allowing the full operating voltage to be reapplied instantaneously. Internal diodes prevent current flow through the batteries when the detector is biased using the NIM supply.

A separate preamp is provided for each detector. The eV Products¹ Model eV-5093 preamp is an ultra-low noise, charge-sensitive unit specifically intended for use with HgI₂ detectors. The onboard 12 VDC filter supplies power to the preamps. The capacitance of the detectors in the lung counter has been measured as 30-35 pF. This corresponds to an approximate 2.5 keV FWHM noise level from the preamp.

The end window of the lung counter housing is 0.76-mm thick carbon fiber-epoxy. It has been coated with paint to minimize light entry inside the unit. Also, the inner window surface is coated with a thin (100's of angstroms) metal EMI shield. The thin window exhibits effectively 100% photon transmission above 40 keV.

III. CHARACTERIZATION METHODS

Characterization of the HgI₂ lung counter was performed at LANL following the tenets of ANSI N13.30, *Performance Criteria for Radiobioassay* [3]. This standard prescribes the method for performing in vivo calibrations as well as acceptable detection limits to warrant accreditation. Lung measurement calibrations were performed using the standard torso phantom as shown in Fig. 3.

¹eV Products, 373 Saxonburg Blvd., Saxonburg, PA 16056.

Figure 3. Torso phantom calibration. Lung sets have uniformly distributed radioactivity (top). The lung counter is suspended from a dental arm using flexible arm clamps (bottom).

The torso phantom is constructed of tissue equivalent materials including a rib cage in the anterior base chest plate. Lung sets are available for different radionuclides (e.g. Am-241, Pu-238/-239, Eu-152, fission products, etc.) distributed uniformly throughout the lung/air-equivalent material. The base chest plate has a mean chest wall thickness of 1.63 cm.

The performance criteria of ANSI N13.30 defines the minimum detectable amount (MDA) in simplified form as

$$MDA = \frac{(4.65s_b + 3)}{KT}, \quad (1)$$

where s_b is the standard deviation of a total blank count (e.g. a non-contaminated person) and K is the calibration factor at the peak energy (counts/photon). At LANL, the standard subject counting time, T , is 2000 s. Inherent in the definition is a 5% probability of Type I and Type II errors ($\alpha = \beta = 0.05$).

IV. RESULTS AND CONCLUSIONS

Characterization testing of the HgI₂ lung counter was performed using an Ametek ORTEC² Model 572A shaping amplifier with a selected 10 μs shaping time. Data collection was made using a MicroACE™ MCA card with a selected ADC conversion gain of 2048 channels. An Am-241 spectrum collected for one of the four array detectors is shown in Fig. 4. The 26, 33 and 59.5 keV photon lines are clearly distinguishable. However, the 14, 17, and 20 keV lines cannot be differentiated.

²Ametek ORTEC, 801 South Illinois Avenue, Oak Ridge, TN 37830.

Figure 4. Lung counter spectrum for Am-241.

The measured energy resolution of the HgI₂ lung counter was 6.2 keV (5.0%) at 122 keV. Additional results are given in Table I for the array. Also reported is the measured resolution of the Princeton Gamma-Tech³ Model NIGP 2020 HPGe planar detector currently used in the IVML six-detector system.

Calibration of the HgI₂ lung counter was made using the torso phantom. Measurements were made using several lung sets, including Am-241, enriched uranium (U-235), and Ba-133. All measurements were performed using the base chest plate with the lung counter anterior to the right lung. From this data, the calibration factor, K , was determined over the useful energy range of the detector (5-200 keV).

TABLE I. HgI₂ LUNG COUNTER ENERGY RESOLUTION

Energy (keV)	FWHM (keV)	
	HgI ₂ Lung Counter	IVML HPGe Detector
14.4	2.3	0.66
59.5	4.0	0.70
122	6.2	0.85

MDA results for the HgI₂ lung counter are given in Table II. All results are based on a 2000 s count time, T . Also reported are MDA results for the current IVML six-HPGe detector system. Note that the results cited for the HgI₂ system are for a *single* lung counter (four detectors with 2500 mm² total active area) whereas the IVML results are for a system featuring *six* HPGe detectors (12,000 mm² total active area).

The results of Table II show that the HgI₂ lung counter satisfies the performance requirements of ANSI N13.30. The lung counter is approximately 25% more efficient than a single HPGe detector. This is equivalent to the increase in active area of the HgI₂ array (2500 mm² vs. 2000 mm²). Approximately 4.7 HgI₂ lung counters would have the same detection efficiency as the IVML six-HPGe detector system.

The HgI₂ lung counter also represents a mobile system by virtue of the in-line backup battery. Negligible discharge of the crystal bias was observed following more than six months with no external bias applied. The full operating voltage was reapplied instantaneously. As such, the system is suitable for emergency response applications where portability is required.

TABLE II. HgI₂ LUNG COUNTER MDA

Radionuclide	Minimum Detectable Amount, MDA (Bq)		
	Minimum Test Level	HgI ₂ Lung Counter	IVML HPGe Detector ^a
Am-241	100	38	8
Th-234	500	340	75
U-235	30	28	5

a. Results based on all six HPGe detectors, total active area = 12,000 mm²

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³N-type detector, 50 mm in diameter, 20 mm-thick, 0.51 mm-thick beryllium window, -2500 V bias. Princeton Gamma-Tech, 1026 Route 518, Rocky Hill, NJ 08553.