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PORTABLE GAMMA-RAY SPECTROMETERS AND SPECTROMETRY SYSTEMS

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Abstract

The current state-of-the-art in portable gamma-ray spectrometers and portable spectrometry systems is discussed. A comparison of detector performance and features of commercially available systems are summarised. Finally, several applications of portable systems are described.

1. GENERAL

The basic components for any gamma-ray spectrometer system, portable or other wise, include a spectrometer, a spectroscopy amplifier, bias supply, data processing equipment, system power supply, and ancillary equipment: cables, tripods, shielding, etc. The issue of portability is primarily one of size and weight. For gamma-ray spectrometers and spectrometers systems, it is also desirable to have low power detectors that operate at ambient temperatures. Ultimately the issue of portability must be balanced by the requirements for system performance. Most gamma-ray detectors can be made small and compact, but the efficiency, dynamic range and energy resolution can vary significantly. The focus of this report will be to discuss readily available portable spectrometers and spectrometry systems in the context of their portability and performance.

2. GAMMA-RAY SPECTROMETERS

Presently, two types of gamma-ray detectors are readily available and commonly used in gamma-ray spectroscopy: semiconductor and scintillator. These two detector types offer a variety of possible detector choices. However, only three detectors are currently being used with portable gamma-ray spectrometry systems: high purity germanium (HPGe), thallium-activated sodium iodide (NaI(Tl)), and cadmium zinc telluride ($Cd_{0.9}Zn_{0.1}Te$ or CZT)

2.1 PORTABLE HPGE DETECTORS

HPGe detectors are solid state devices that were developed in the mid 1970's. There are two basic types of HPGe detectors: normal and reverse electrode. They are more commonly referred to as "p-type" and "n-type" respectively. The designation specifically refers to impurity concentration. The n-type or reversed electrode detector has a thin outer contact layer, which gives them good sensitivity to low energy photons. HPGe detectors are characterised by their efficiency relative to a 7.6 cm x 7.6 cm NaI(Tl) crystal for the 1332 keV photon at a source-to-distance of 25 cm. Currently HPGe detectors range from 10 % to 170% relative efficiency. The small bandgap[1] (0.7 eV) of germanium prohibit room temperature operation of HPGe

[1] An energy region separating the conduction and valence band in insulators and semiconductors.

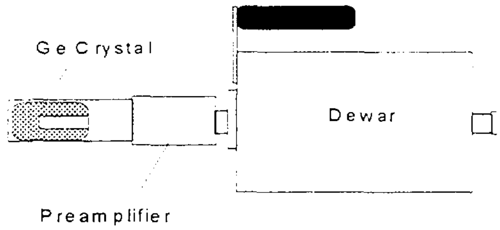

Fig. 1. A schematic drawing of a portable HPGe detector indicating some key components.

detectors. Leakage across the bandgap is sufficiently reduced by cooling the Ge crystal with liquid nitrogen[2] (LN_2). An HPGe detector is made portable by mounting the crystal and preamp. assembly to a small dewar, typically 1.2, 3 or 5 l. capacity. Fig. 1 is drawing of a portable HPGe detector.Despite the small dewars, portable HPGe detector can be heavy and rather large. A moderately sized detector can be over 40 cm long and weigh as much as 10 kgs when filled with LN_2. For continuous or prolonged operations portable HPGe detectors need a daily[3] supply of LN_2. Moreover, a room temperature detector requires a 'cool-down' period once the dewar has been filled. For a moderately sized crystal (100–200 cm^3), the cool-down period can range from 4-6 hrs. For larger detectors, the cool-down period can last 8 hrs. This can be a inconvenience for some emergency response applications. HPGe detectors require a bias voltage of 3000 to 5000 V. A complete spectrometry system using an HPGe detector consists of a preamplifier (usually incorporated as part of the detector), a shaping or spectroscopy amplifier, a multichannel analyser (MCA), and a laptop computer. A block diagram of a typical HPGe spectrometer system is shown in Fig. 2. Despite their size and need for LN_2, portable HPGe detectors are preferred for many *in situ* applications because of their broad energy range, large active volume, and superior energy resolution.

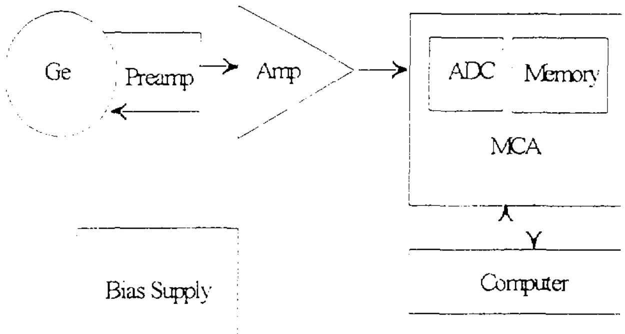

Fig. 2. A schematic diagram of a HPGe spectrometry system.

2.2 NaI SPECTROMETERS

Advantages of a NaI scintillator include high luminescence, room temperature operation and the ability to be machined in a variety of size and shapes. Typically the sizes range from 3 cm x 3 cm to 7.6 cm x 7.6 cm. Crystal sizes greater than 7.6 cm x 7.6 cm are readily available but are not recommended for portable systems. The crystals (and PMTs) are somewhat fragile and can be damaged by mechanical or thermal shock. Moreover, their

[2] Other cooling options are available, but would not be considered portable.
[3] Detectors mounted to 3 and 5 l. dewars that can last several days between refills.

luminescence varies with changes in ambient temperature. Compared to HPGe detectors, NaI(Tl) have poor energy resolution. The energy resolution for a NaI(Tl) is typically expressed as a percent of the gamma-ray energy, for HPGe detectors the energy resolution is about 2 keV across the entire spectrum[4]. At 662 keV a NaI(Tl) detector will have an energy resolution of about 8% to 10%. Most portable NaI spectrometers employ an 'inline' design whereby the crystal and PMT are hermetically sealed in light-tight metallic cylinders. They usually require a bias voltage of about 600-800 V. A block diagram of a typical NaI spectrometer system is shown in Fig. 3.

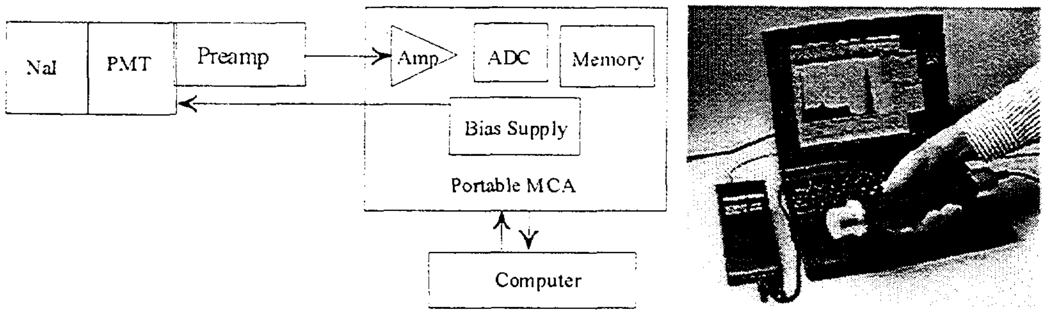

Fig. 3. A schematic drawing of portable NaI(Tl) spectrometry system (left). A picture of a portable spectrometry system (right). (Courtesy of Amptek, Inc., Bedford, MA)

2.3 CZT SPECTROMETERS

With a bandgap of 1.5 eV, the semiconductor CZT can operate a room temperature. This means good resolution without LN_2. Unfortunately, problems with crystal inhomogeneity, excessive charge trapping, and mechanical cracking have hampered fabrication of crystals with large active volumes. Currently the largest active volume available is about 1 cm^3; typical volumes for commercially available spectrometers are closer to 0.05 cc. CZT detectors are recommended for moderate to low energy applications. Fig. 4 shows a diagram of a CZT detector. Table 1 summarises the properties of HPGe, NaI(Tl), and CZT spectrometers.

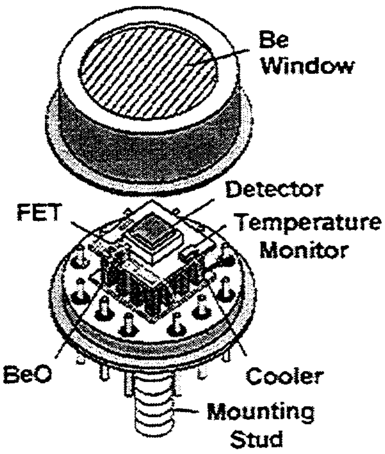

Fig. 4. A schematic drawing of a CZT detector (Courtesy of Amptek, Inc., Bedford, MA).

[4] Resolution for HPGe detectors is expressed in terms of full with at half-maximum (FWHM). The resolution for a 40% relative efficiency detector at 122 keV can be less than 1 keV, at 1.33 MeV the resolution can be less than 2 keV.

TABLE 1. Comparison of portable spectrometers

Detectors	High Purity Germanium (HPGe)	Sodium Iodide NaI (Tl)	CdZnTe (CZT)
Type	Solid state	Scintillator	Solid state
Resolution	2-3 keV	8% @ 662 keV	1.5 keV @ 122 keV
Energy Range (typ.)	40* keV – 10 MeV	5** keV – 3 MeV	< 1 MeV
Size & Shape: Crystal	Coaxial and planar (30 – 400 cc)	Cylindrical (typ.) 3 cm x 3 cm, 5 cm x5 cm, 7.6 cm x 7.6 cm	Rectangular (~0.05 cc)
Size & Shape: Detector	Cylindrical shape 40-50 cm long 5-15 kg	Cylindrical shape 20-40 cm long 1-5 kg	Rectangular ~ 10 cm long ~ 1- 2 kg
Operating temp.	77 K	300 K	300 K
Cost (USD) (est.)	(10-100k)	10 k	5 k

**this refers to p-type detectors, n-type has good efficiency down to about 5 keV*
***for thin NaI crystals*

Clarke and Williams [3] reported a more recent entry to field of portable spectrometers. They examine the performance of a CsI(Tl) scintillator (1.8 cm x 1.8 cm x 4 cm) with integral p-i-n diode (1.8 cm x 4cm). Advantages of this detector include room temperature operation and no bias supply. However, no commercial version of this portable detector is readily available.

For a more complete discussion of the principles of gamma-ray detection and gamma-ray detectors we refer the reader to Debertin and Helmer [1] and Knoll [2].

3. PORTABLE SPECTROMETER SYSTEMS

3.1 INTEGRATED SYSTEMS

An integrated system is a complete, fully functional spectrometry system. While they are intended for general purpose surveys, some systems have been optimised for very specific applications such as the measurement of the isotopic composition of Pu or the enrichment of U. Most systems utilise NaI scintillator with a multichannel analyser with a built-in display. Some are hand-held and all weigh just a few kilograms. A brief summary of available integrated systems can be found in Table 2.

3.2 MODULAR SYSTEMS

Modular Systems provide the flexibility to construct a portable, laboratory grade spectrometry system for field applications. The portability of the HPGe systems results from small LN_2 dewars and compact, battery powered (MCAs). A configuration can be as simple as a HPGe detector, a set of cables and a portable MCA. A more typical configuration will consist of a detector, cables, and portable MCA and a laptop computer. Fig. 5 is a block diagram of a typical modular system. Note that the bias supply and amplifier are physically housed with MCA. A modular HPGe system can be quite heavy and rather cumbersome. For example a complete HPGe spectrometry system with a 40% relative efficiency detector

TABLE 2. A comparison of integrated spectrometry systems

Integrated Systems	Detector	ADC	Spectrum capacity	Size & Weight	Operating Time	Other
Scout512 (Quantrad)	NaI(Tl) (1"x1", 2"x2",3"x3")		251 spectra w/time and date	11.5x5x19 cm 0.82 w/o detector	12 V Lead acid	
PN-114 (Princeton Electron Systems)	NaI(Ti) (1"x1"-3"x3") or CdZnTe (CZT)	80 Mhz Wilkinson 1k resolution	configurable 2048 bytes	28x28x8.9 cm 6 kg	2.5 hrs 5 A-h lead acid	
EasySpec (Canberra)	NaI(Tl) (1"x1", 2"x2",3"x3")	66 Mhz Wilkinson 1k resolution	90 spectra w/time and date	19x10x5 cm 1.3 kg	7 hrs NiMH	
GDM 40 PRS (GammaData)	NaI(Ti) 3"x3"	80 Mhz Wilkinson 2 k resolution	1600 spectra (256 ch.@ 2 bytes)	46x34x15 cm 12 kg	8 hrs	Has GPS capability
Gamma-X (Amptek)	NaI(Tl) (30x30 mm up to 152 x76 cm)	MCA 8000A (Successive Approximation FCT <5 µs 16k resolution		17x7x2 cm	16-24 hrs 2 AA cells	Needs computer
"ROVER" (Amptek)	CZT	MCA 8000A				Needs computer
GR-130 (Exploranium)	NaI(Ti) 74 cc, 0-3000 keV or 0-1500 keV	256 channels resolution	Up to 30000 readings or 200 full 256-channel spectra	10x23x9 cm 2.2 kg	+30 hrs 2 D cells	Hand-held survey instrument

mounted to a 1.2 l dewar with a ruggedized MCA and a laptop computer weighs about 20 kg. A brief summary commercially available battery powered MCAs can be found in Table 3.

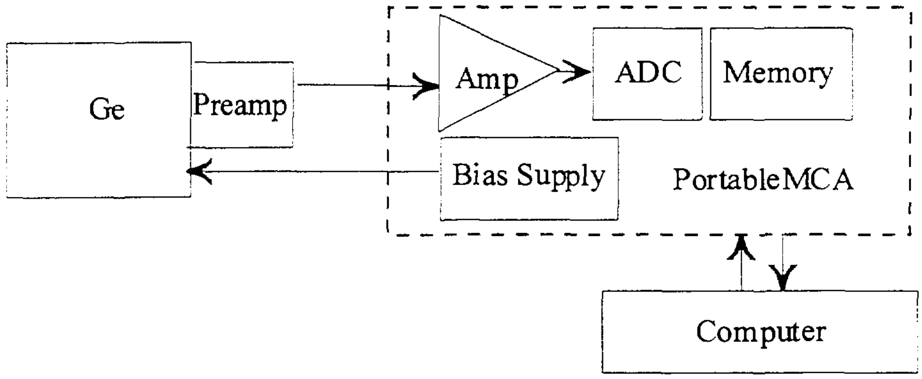

Fig. 5. A schematic drawing of a HPGe portable spectrometry

4. CURRENT APPLICATIONS OF PORTABLE SYSTEMS

Portable gamma-ray systems are primarily used for *in situ* measurements. Typical applications include cargo inspection, non-destructive testing, environmental, industrial, security, and surveillance applications.

4.1 ENVIRONMENTAL MEASUREMENTS AND DECOMMISSIONING OPERATION

In situ measurements are central to most environmental surveillance and site decommissioning operations. They usually involve measurements at a site for extended periods, often from a vehicle or other temporary shelters. They also involve low level measurements for environmental surveillance, or relatively hot samples in the case of decommissioning operations.

4.2 IN-SITU SPECTROMETRY OF SOIL USING PORTABLE GAMMA-RAY SPECTROMETRY SYSTEMS.

The Environmental Measurements Laboratory (EML) has been using portable and transportable spectrometry systems for nearly 30 years. The laboratory developed the technique of *in situ* gamma-ray spectrometry for a real-time assessment of gamma emitting radionuclides in surface soil. Currently, the method typically involves the use of a "downward-looking" uncollimated HPGe detector positioned 1 m above the ground. The activity per unit mass for a given radionuclide can be derived from the peak count rate using parameters that describe the soil characteristics and the depth profile of the radionuclide distribution. The *in situ* technique is well suited for quickly determining levels of contamination over large areas. A single uncollimated *in situ* gamma-ray measurement provides a position-weighted average over the detector's field of view, which is typically several hundred square meters. A comprehensive discussion of the technique may be found in Beck et al. [4] and ICRU Report 53 [5].

For general environmental applications the specific activity for the source is usually low and the gamma-rays of interest can range from 63 keV to 2.6 MeV[5]. The spectrum is

[5] The 63 keV photon is from Th^{234}, a progeny of U^{238}. The 2.6 Mev photon is Tl^{208}, a progeny of Th^{232}.

TABLE 3. A comparison of portable MCAs

Portable MCAs						
	Bias Supply	Amplifier	ADC	Size & Weight	Operating Time	Other
MCA 8000A (Amptek)	N/A	N/A	Successive Approximation FCT <5 μs 16k resolution	17x7x2 cm 0.3 kg	16-24 hrs	Needs computer, Does not provide bias voltage or a spectroscopy amp
M^{3}CA (Aquila Tech. Group)	300-3500 V 200-1200 V 125 μA	Course Gain: 1,2,4,8,16,32, 64 2 selectable TC	100 MHz Wilkinson 4k resolution	10x22x9 cm		
InSpector (Canberra)	0-5000 V, 100 μA 0-1300 V 500 μA	Gain: x2 to x1500 STC 1 / 4μs	100 MHz Wilkinson 8k resolution	29x27x5 3.2 kg	6 hrs	
NaI InSpector (also CdTe)	0-1300 V 500 μA	Gain: x2 to x1500 STC 0.5 / 1 μs	100 MHz Wilkinson	29x27x5 3.2 kg	6 hrs	Optimized for NaI or CdTe scintillators
Vista (5002, 5004, 5008, 5016) (Aptec)	0-5000 V 0-200μA	No information available	Fixed Conversion 800 ns to 5 μs depending on model 2k-16 k res.	35 x 25 x 6 cm 5 kg	2 –4 hrs	4 model No. to choose from depending on performance requirements
OYDESSEY 6 (Aptec)	0-5000 V @100μA 0-2000 V @250 μA	Built-in high performance spectroscopy amplifier for HPGe or NaI(Tl) detectors	Flash, 16k	Brief case size		Includes computer W/ full I/O Housed in an ABS plastic alloy carrying case
NOMAD™Plus (EG&G)	0-5000 V @100μA 0-2000 V @250 μA	Gain x4 to x 1000 STC 1 / 6μs	Successive Approximation 16K resolution FCT <5 μs	46x33x15 cm 8 kg	6-8 hrs	Housed in a Zero-Haliburton aluminum case with removable lid
Dart (EG&G)	0-5000 V, 100 μA 0-1250 V 750 μA	Gain: x3 to x1000 STC 1 / 6 μs	Successive Approximation 8K resolution FCT <12 μs	9x14x30 cm 2.3 kg	6 – 7 hrs	Does not require a computer for data collection

usually complex, the gamma emitting progeny of radium and thorium combine for 33 individual lines having at least 1% intensity. It is recommended that for the analysis of environmental spectra a HPGe detector be used with an ADC capable of least 4K resolution, with 8K preferred. While HPGe detectors are preferred for environmental applications, they are not strictly necessary, especially if one is interested in Cs^{137} or Co^{60}. *In situ* measurements of the Mishelyak River were performed using an integrated system featuring a NaI detector (Wollenberg et al. [6], Drozhko et al. [7]). The count rate associated with most environmental applications is modest (< 0.5 kcps) and can be handled many, if not all, portable MCAs. A typical set-up that EML uses for environmental work consists of a 40% relative efficiency p-type HPGe detector mounted to a 1.2 L dewar, and a battery powered MCA with an ADC with 16k resolution. Data storage and data acquisition is accomplished with laptop computer running MCA emulation software. The limiting factor of this set-up is battery power. The computers will last for 2 hours, while MCA is a little better lasting about 7 hrs.

4.3 NUCLEAR SAFEGUARDS

Nuclear safeguards applications prevent unauthorized proliferation of nuclear material. Regulatory Agencies routinely make *in situ* measurements during inspection trips at various nuclear sites. Data collection times are often short, and sometimes must be conducted in hostile environments. A CZT detector can be useful for cargo inspections looking for enriched uranium and plutonium. Both U and Pu have low energy photons, the excellent resolution and compact size of a CZT make it a sensible choice for such applications.

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