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Field Deployable Gamma Radiation Detectors for DHS Use

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ABSTRACT

Recently, the Department of Homeland Security (DHS) has integrated all nuclear detection research, development, testing, evaluation, acquisition, and operational support into a single office: the Domestic Nuclear Detection Office (DNDO). The DNDO has specific requirements set for all commercial off-the-shelf and government off-the-shelf radiation detection equipment and data acquisition systems. This article would investigate several recent developments in field deployable gamma radiation detectors that are attempting to meet the DNDO specifications. Commercially available, transportable, handheld radio isotope identification devices (RIID) are inadequate for DHS' requirements in terms of sensitivity, resolution, response time, and reach-back capability. The leading commercial vendor manufacturing handheld gamma spectrometer in the United States is Thermo Electron Corporation. Thermo Electron's identiFINDER™, which primarily uses sodium iodide crystals (3.18 x 2.54cm cylinders) as gamma detectors, has a Full-Width-at-Half-Maximum energy resolution of 7 percent at 662 keV. Thermo Electron has just recently come up with a reach-back capability patented as RadReachBack™ that enables emergency personnel to obtain real-time technical analysis of radiation samples they find in the field[1]. The current project has the goal to build a prototype handheld gamma spectrometer, equipped with a digital camera and an embedded cell phone to be used as an RIID with higher sensitivity, better resolution, and faster response time (able to detect the presence of gamma-emitting radio isotopes within 5 seconds of approach), which will make it useful as a field deployable tool. The handheld equipment continuously monitors the ambient gamma radiation, and, if it comes across any radiation anomalies with higher than normal gamma gross counts, it sets an alarm condition. When a substantial alarm level is reached, the system automatically triggers the saving of relevant spectral data and software-triggers the digital camera to take a snapshot. The spectral data including in situ analysis and the imagery data will be packaged in a suitable format and sent to a command post using an imbedded cell phone.

Keywords: Radio isotope identification device (RIID), Resolution, Reach-back capability

1. BACKGROUND - CURRENT TRENDS IN MOBILE DETECTION

A number of gamma and neutron detectors of various sizes, sensitivities and resolutions have been designed, prototyped and field tested in recent years at the Remote Sensing Laboratory in Las Vegas, Nevada and Suitland, Maryland. These sensors have been built with a comprehensive approach towards search localization and screening of radioisotopes of interests. Larger sodium iodide crystals (10.16 x 10.16 x 40.64cm) for gamma detection and larger arrays of pressurized helium tubes (91.44 x 5.08cm) containing as many as 48 of the tubes are deployed for aerial mission. Smaller detector sets with one sodium iodide crystal (10.16 x 5.08 x 15.24cm) sodium iodide crystal and 8 helium tubes (15.24 x 2.54cm) are used for man portable handheld systems. The sensors work on one common principle – they continuously monitor the ambient radiation counts (gamma and neutron) and can generate alarm conditions if a higher than normal radiation field is encountered. The software platform Multiple Application Computer System (MACS) forms the background of

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the data acquisition system, which provides the algorithms for alarm conditions for the detection systems. Recently a very successful remote sensing radiation detector system, Multiple Platform Systems (MPS), has been developed and deployed for large area search and radio isotope screening purpose. The Acquisition and Telemetry (ATU) unit for these detectors uses a PC-104 board stack for gamma and neutron counting and synchronizing radiation data with Global Positioning Satellite (GPS) information. MPS units have a data display unit that can plot the path of a vehicle-mounted system in real time and accept and display the spectral data (energy information) from gamma emitting sources. Recent gamma detectors are capable of quickly determining the relative direction of a point source. Such a detector enhances search capability in any mission where directional information would be useful (portable, mobile, aerial). The new feature of this detector is the use of two detector pairs to uniquely define angles and desensitize the system to background radiation. A pictorial depiction of the orientations of the four gamma detectors is shown in Figure 1 for this direction sensitive sensor.

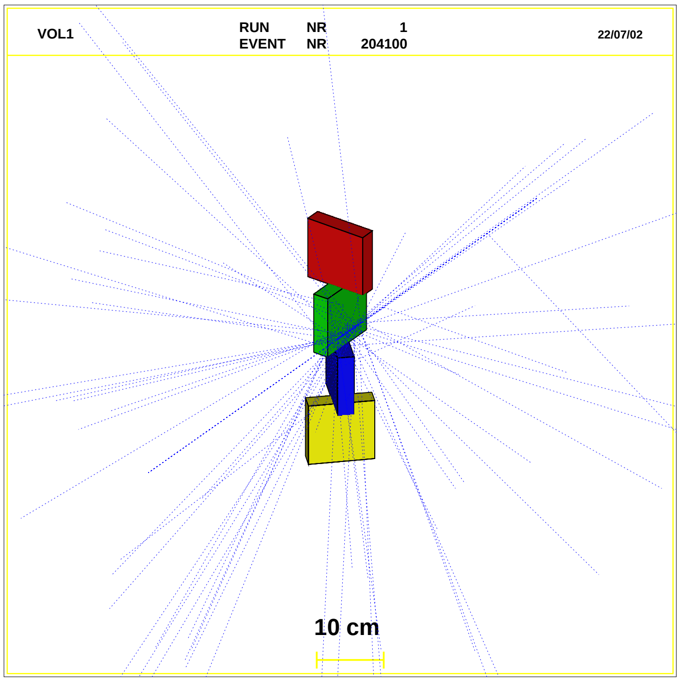

Figure 1. Angular orientation of four sodium iodide crystals (dimensioned 5.08 x 10.16 x 15.24cm) for a direction sensitive gamma sensor package is shown above. The asymmetry is insensitive to source distance and changes in background; it is also insensitive to polar angle (altitude) and energy spectrum of the source.

In fiscal year 2004 the current author studied the properties of cerium-doped lanthanum halide ($LaBr_3$:Ce and $LaCl_3$:Ce) crystals[2]. Although their energy resolution is excellent (~2.7% Full-Width-at-Half-Maximum at 662 keV), the first few batches of crystals suffered from inherent alpha and gamma contaminations. The alpha contamination was due to the presence of actinides during mining. The intrinsic gamma radiation was due to the presence of the isotope ^{138}La (0.090%) in ^{139}La, which is impossible to remove without isotopic separation. Since then, the alpha contamination has been eliminated, reducing the intrinsic background of α-particles ranging in energy between 1.5 and 2.5 MeV from 1-10 Bq/cc to <0.05 Bq/cc and enabling Saint-Gobain Crystals and Detectors, Inc. to commercially manufacture cylindrical crystals sized up to 10.16 x 10.16cm. In the current project, the intrinsic gamma signals were used to control the gains on the amplifier, by subtracting background spectrum, the gamma lines from the contaminant were removed.

2. INTRODUCTION

A small hand-held screening and localizing equipment was developed using 5.08 x 5.08cm lanthanum halide ($LaBr_3$:Ce-5%) crystal and the currently developed MPS electronics. Alarm conditions were generated in localizing mode using the MACS algorithm. Four separate buffers of 1024 channel analog-to-digital converter (ADC) data, each containing 3 seconds of MCA output were continuously saved. At high levels of gamma alarm condition, 12 seconds (6 seconds before and 6 seconds after the alarm has taken place) of spectral data would be automatically analyzed by a standard isotope screening routine. A digital camera, software-triggered by the alarm condition would take a snapshot of the item of interest. The on-board software would produce an eXtensible Markup Language (XML) report sheet on a high gamma alarm that consisted of the 12 seconds of spectral data, digital picture of the suspect object, and the GPS location of the incident. A brief report describing the suspected radio isotopes along with the confidence level would be reported. The XML data file then would be sent out to a known location (be it a command post (CP), or the U.S. Department of Energy's (DOE) Triage facility, or the home team at the DOE Emergency Operation Center (EOC). The crystal, with its photomultiplier tube (PMT), associated high-voltage, pulse-shaping digital signal processing electronics, and an embedded GPS and cell phone card in PC-104 bus (similar to that used in MPS) would be packaged together to build a compact hand-held room temperature gamma spectrometer. Other features of MPS (viz. waterfall data, geographical information system enabled path plot, and instantaneous spectral data) would be available on an attached small notebook. The user would need to have little or no knowledge of gamma spectroscopy.

3. MONTE CARLO N-PARTICLE (MCNP) SIMULATION STUDIES

MCNP[3] has been used to study the sensitivity and energy resolution of sodium iodide (NaI:Tl), lanthanum chloride ($LaCl_3$:Ce), and lanthanum bromide ($LaBr_3$:Ce) crystals of cylindrical shape (7.62 x 7.62cm). The MCNP studies of lanthanum halides show that these crystals are capable of separating the two closely spaced gamma lines emanating from ^{239}Pu at 375 and 414 keV, respectively, while the NaI:Tl crystal cannot (Figure 2.). The recently developed MCNP Visual Editor Graphical User Interface (MCNPVISED 4C2[4]) was used to characterize the basic scintillation properties and detection parameters of the lanthanum halides. MCNPVISED 4C2 enables a visual creation of an MCNP input file that can be read by the Los Alamos National Laboratory MCNP4C2 (CCC-701) Monte Carlo transport code.

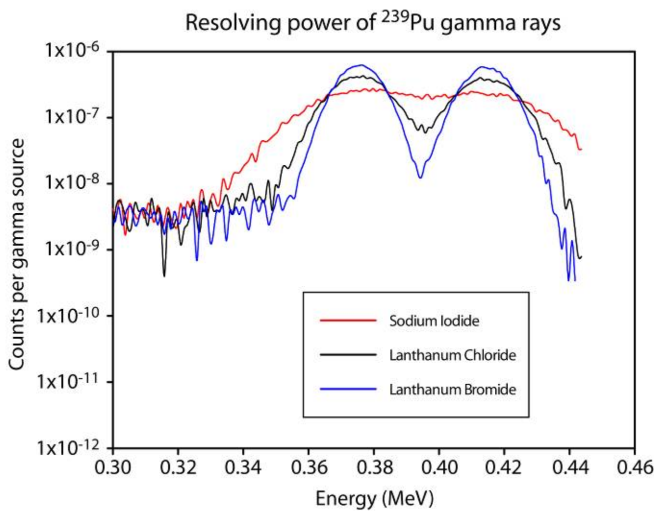

Figure 2. Simulated pulse height spectra from 7.62 x 7.62cm crystals of NaI:Tl (red), $LaCl_3$:Ce (black) and $LaBr_3$:Ce (blue) scintillator with a 1Ci ^{239}Pu gamma source. Gamma counts per second per unit energy are shown as a function of gamma ray energy.

Classical F8 tallies for MCNP (pulse height statistics) were maintained for each of the simulations with specific gamma emitting sources like ^{239}Pu. A comparison of simulated pulse height spectra from different 7.62 x 7.62cm crystals using a ^{239}Pu gamma source shows the higher resolution of the $LaBr_3$:Ce crystal (Figure 2). By computing F4 tallies for the same number of incident photons ranging in energy between (30 keV and 3,000 keV), we calculate relative sensitivities of different scintillation materials as shown in Figure 3.

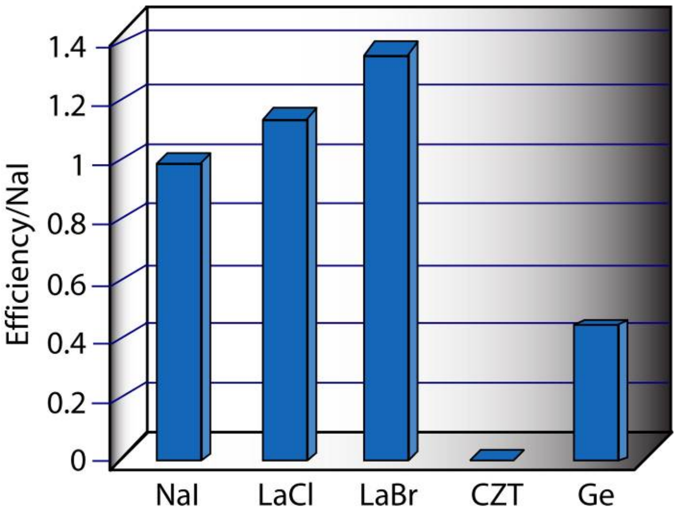

Figure 3. Simulated relative sensitivity of common scintillation materials (30 keV-3,000 keV). Expected sensitivity of $LaBr_3$:Ce is approximately 35% greater than that of NaI: Tl crystals of the same size.

4. HARDWARE SPECIFICATION

The spectrometer is made out of a 5.08 x 5.08cm $LaBr_3$:Ce crystal (Figure 4) attached to a PMT and charge integrating preamplifier that generates voltage pulses proportional to the photon energy (~50 mV), which then gets amplified by shaping amplifier to 5–10 volts and fed to a comparator/discriminator and finally to a multichannel analyzer (MCA). The hardware elements are listed below:

Figure 4. BrilLance™ 380 $LaBr_3$:Ce crystal with its on-line PMT. The crystal is a 5.08 x 5.08cm cylinder requiring +496 VDC to operate.

1. PC-104 based MPS system for a single gamma log
2. Search algorithm as per Infield (continuous data train, alarm based on counts above background)
3. Continuous waterfall display of the gamma energy spectrum
4. Use of similar ADC as used in MPS (single channel, 4 First-In-First-Out buffers, filled sequentially 1, 2, 3, 4, with 4 containing the latest buffer (buffers get refilled with new data).

5. Auto gain stabilization following γ-lines of ^{40}K, or ^{138}La isotope if available
6. Low resolution digital camera Phoenix USB 2.0 from MuTech Corporation
7. Cellular modem COM17045ER. This module provides a direct and reliable Global System for Mobile communication (GSM) connection to stationary or General Packet Radio Service (GPRS) mobile fields around the world. GSM/GPRS connectivity is achieved using the Siemens MC45 engine. This unit works in the 900 or 1,800 MHz and 1,900 MHz band and supports standard network and service provider personalization.

GSM cellular modem: The Real Time Device COM17045 wireless GPRS GSM modem unit (Figure 5) provides a direct and reliable GPRS connection to GPRS GSM 900/1,800/1,900 MHz mobile fields around the world. GPRS GSM connectivity is achieved using the Siemens MC45. This unit works in the 900/1,800/1,900 MHz band supporting GSM 02.22 network service provider personalization. It lets users connect any standard dual-band GSM antenna directly to the OSX connector of the COM17045. The antenna should be connected to the MC45 using a flexible 50Ω cable.

GPS receiver: Integrated on the COM17045 is a fastfix 12-channel low power iTrax02 GPS receiver from Fastrax. This new receiver works reliably in a variety of installations. The receiver works with either 3.3V or 5.0V active or passive antennas. The power consumption of the GPS receiver is 125mW fully operational. A fast 1 to 4Hz updating rate is achieved using the binary iTalk protocol. Two output formats are available: the NMEA-0183 ASCII protocol or the iTalk proprietary binary protocol. Switching between these protocols is controlled with one bit in the internal board registers.

Figure 5. COM17045ER PC104 cellular modem peripheral module

Digital camera: The Phoenix USB 2.0 (Figure 6) used with the spectrometer is a 1,280 x 1,024 (1.3 Mega pixel) camera with 1.25cm optical format. It can scan progressively at a rate of 15 fps at 1,280 x 1,024 pixel density. It uses USB interface cable and has a data transfer rate of 480. It is also capable of collecting 10 bit raw digital video data. The camera has a built-in frame buffer that avoids data loss due to USB congestion. The most interesting feature of this camera that it accepts both hardware and software external trigger. It is a plug-and-play system and can adapt to multiple cameras.

Figure 6. Phoenix USB 2.0 digital camera from MuTech Corporation. This camera was used to obtain digital pictures of the suspect objects when a radiological alarm would generate a software trigger for the camera.

MCA: The low-power analog-to-digital converter (LPADC) is a low current MCA board in a PC-104 form factor (Figure 7). The board contains a dual-port static configured as a ping-pong histogram memory. Thus, there is no loss of converted data while reading the data from the unit. The LPADC also contains live-time and dead-time counters. It's power consumption is about 500mW at background (500 cps). The LPADC can have 256 to 4,096 selectable channels, lower level discriminator (LLD), and an upper level discriminator. The ADC unit controls 0 to 5V Semi-Gaussian shaped input pulse by successive-approximation with a conversion speed of 10 μsec.

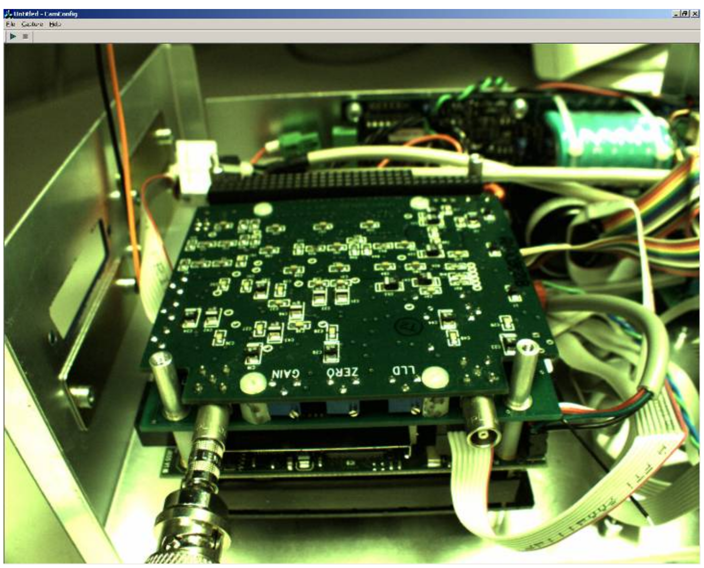

Figure 7. The LPADC board showing the LLD, zero adjustment and the gain pod. This picture was taken by the digital camera shown in Figure 6. The camera resolution is low (has a memory of 1.3 Mega-pixel) but is appropriate for traffic monitoring. The ADC consumes very little power (500 mW) and can run for long periods of time on lithium-ion batteries.

5. EXPERIMENTAL RESULTS

A laboratory setup was built with the 5.08 x 5.08cm lanthanum bromide cylinder with on-line PMT and the high voltage power supply and PC electronic boards packed in a PC-104 card cage that includes LPADC. One crucial aspect of the experiment was to establish a good baseline for gamma energy resolution of the spectrometer (Figure 8). A resolution of 2.7 percent FWHM is obtained with a 5.08 x 5.08cm cylinder. Figure 9 shows the waterfall gamma energy spectral data;

the vertical axis is the time axis, and the horizontal plot is color coded with intensity varying with counts per energy bin. The software allows users to look at the spectral data collected over a period of time period or over a number of events.

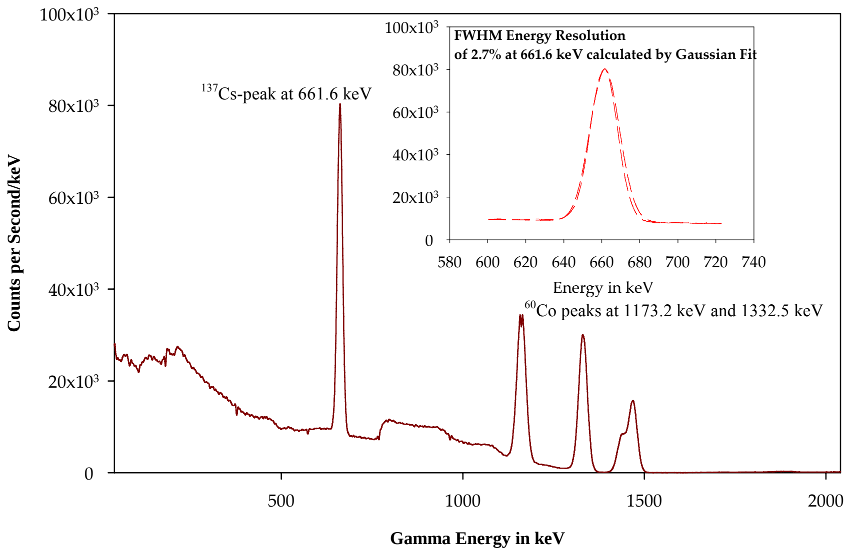

Figure 8. Gamma energy spectrum from ^{137}Cs and ^{60}Co sources taken with 5.08 x 5.08cm lanthanum bromide cylinder is shown above. A simple Gaussian fit of the peak at 661.62 keV shows an FWHM resolution of 2.7 percent.

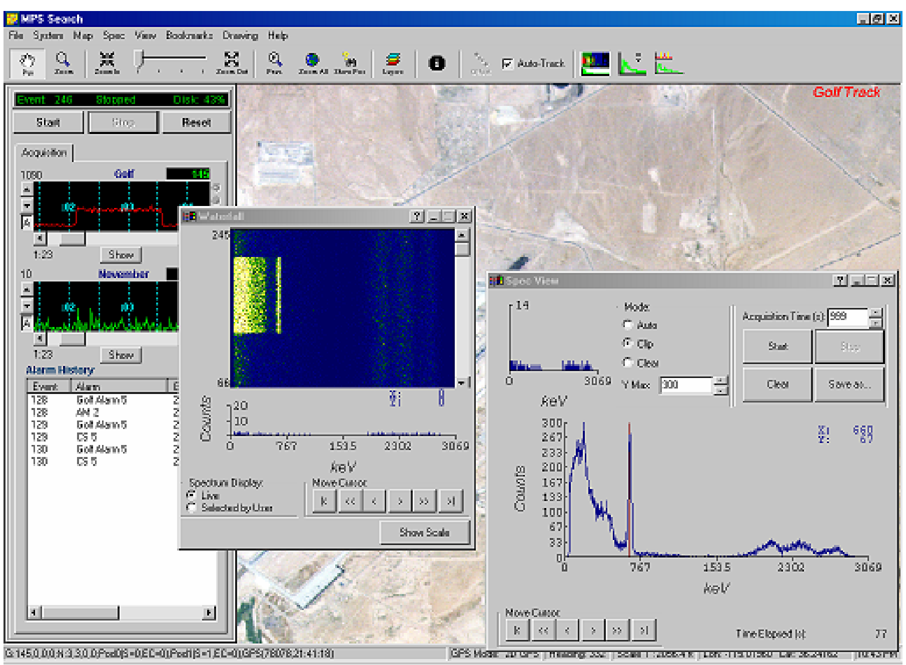

Figure 9. Waterfall data and a user selected spectral data are shown on top of the geo-referenced map. Below are shown data collected live and the corresponding spectral data for a very short interval due to high resolution; even with low counts, the cesium peak stands out at 661.62 keV and will be identified as such.

6. CONCLUSION

A high-resolution gamma spectrometer has been built and tested. It bridges the gap in resolution between that of a sodium iodide spectrometer and that obtained from cadmium zinc telluride. The following improvements have been proposed for the hand-held system that will qualitatively change the way data are processed, and how the light signals from the scintillators are handled by the digital signal processing electronics. Quadratic Compression Conversion (QCC) is based on an algorithm related to the square root of the isotope's energy line(s). This optimizes the spectrum so that peaks are well separated at high, low, and all energies in between. QCC is of particular importance in applications where a wide energy range must be monitored for unknown sources of radiation. The QCC process makes detection of peaks at all energies equally straight forward. Peaks at low energies are well resolved, while at high energies peaks are compressed so that the peak-to-background ratio is dramatically improved for a given number of counts. This directly translates into shorter counting times with better identification and analysis. QCC provides improvements in compensating for the drift of amplification gain due to temperature variation in radiation detectors. Since the compression is a function of energy, the drift will be nearly compensated over a range of temperature.

Miniature packaging can be obtained by the use of silicon drift detectors (SDD). These ultraviolet-enhanced diodes provide excellent wavelength matching to the 380-nm emission of $LaBr_3$. A recent paper[5] presented at the 2005 IEEE Nuclear Science Symposium shows that the SDD has a higher quantum efficiency than the PMT. Moreover, the SDD is not as sensitive to drifts due to temperature and bias voltage changes.

7. REFERENCES

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