VeriTainer radiation detector for intermodal shipping containers

R.H. Redus [a,*], M. Alioto [b], D. Sperry [a], T. Pantazis [a]

[a] *Amptek, Inc, 14 DeAngelo Drive, Bedford MA 01730, USA*

[b] *Veritainer, Inc., 650 Fifth Street, Suite 308, San Francisco, CA 94107*

Elsevier use only: Received date here; revised date here; accepted date here

Abstract

The VeriSpreader[TM] radiation detection system will monitor every container passing through a shipping terminal without impeding the flow of commerce by making the radiation measurements during normal container handling. This is accomplished by integrating neutron and spectroscopic gamma ray detectors into a container crane spreader bar, the part of the crane that directly engages the intermodal shipping containers while moving from ship to shore and vice-versa. The use of a spectroscopic gamma detector reduces the rate of nuisance alarms due to naturally occurring radioactive material. The combination of gamma and neutron detection reduces the effectiveness of shielding and countermeasures. The challenges in this spreader bar based approach arise from the harsh environment, particularly the mechanical shock and the vibration of the moving spreader bar, since the measurement is taken while the container is moving. The electrical interfaces in the port environment, from the crane to a central monitoring office, present further challenges. It is the packaging, electronic interfaces, and data processing software that distinguish this system, which is based on conventional radiation sensors. The core of the system is Amptek's Gamma-Rad, which integrates a ruggedized scintillator/PMT, digital pulse shaping electronics, electronics for the neutron detector, power supplies, and an Ethernet interface. The design of the VeriTainer system and results from both the laboratory and a proof-of-concept test at the Port of Oakland, California will be presented.

Keywords: Homeland security, gamma-ray spectroscopy, scintillators.

1. Introduction

Since the 9-11 attacks, the threat of a weapon of mass destruction falling into the hands of terrorists has become a major concern throughout the world. In response, many nations are taking steps to prevent such weapons from being smuggled into their countries. The United States has begun to deploy technology to prevent clandestine importation via intermodal shipping containers of materials that could be used in a radiological dispersal device or a nuclear weapon. Examples of such technology include radiation portal monitors (RPMs) and Hand-Held Radioisotope Identification Devices (HHRIIDs). While helpful, HHRIIDs and RPMs add one or more extra steps in the handling of each scanned container, which is labor intensive and impedes the flow commerce, discouraging the inspection of many containers. In addition, many containers arrive at and depart from terminals by rail and never pass through a portal. Although policymakers are discussing the goal of monitoring every container, the current reality is that only 2% of the 6 million containers are actually screened annually. This inspection shortfall represents an urgent national need [1], [2].

The system reported here, called the *VeriSpreader*[TM], can scan one-hundred percent of containers in the normal flow of shipping port commerce[3][1]. It integrates sensitive neutron and spectroscopic gamma ray detectors into a container crane spreader, the piece of the container crane that directly engages an intermodal shipping container as it is moved onto and off of a container ship at a container terminal. Every container loaded or discharged by the crane must be handled by a spreader; VeriSpreader[TM] takes advantage of this handling time to monitor for radiation, without impeding the flow of commerce, using spectral measurements to reduce false

[*] Corresponding author. Tel.: 781-275-2242; fax: 781-275-3470; e-mail: RHRedus@amptek.com.

alarms due to naturally occurring radioactive material (NORM) and to increase sensitivity.

There are challenges to this approach. A container crane spreader experiences severe mechanical shock, due to frequent and harsh impact when the spreader engages and disengages the container. It must make the measurement while the container is moving, so it is under constant vibration during the measurement. The spreader is exposed to high humidity levels, to salt air, and to large temperature swings. It must operate in an electromagnetically noisy environment, from communications radios, radars, and high current actuators. Data must be transmitted along the 60 meter boom to the operator and then to a central monitoring site, often kilometers away. All these practical challenges are in addition to those of more conventional monitors: detecting the radiation with sufficient sensitivity and then processing the spectra to remove background and ultimately to assess the threat of an object being measured.

2. VeriTainer Concept

The VeriSpreader™ solution is based on an array of conventional radiation detectors. The packaging, electronic interfaces, and data processing software distinguish this system from others and make it practical for field use. These aspects will be the focus of this paper.

A block diagram of the VeriSpreader™ system is shown in Figure 1. The key components include:

1. Array of eight radiation detector units (RDUs)
2. Cameras with OCR software
3. Ethernet/fiber optic communication link
4. Data processing software

Each RDU contains a ^{3}He neutron detector and Amptek's GammaRad module. The GammaRad, in turn, includes a 76 mm x 152 mm (3" x 6") NaI(Tl) scintillator coupled to a photomultiplier tube (PMT) for gamma ray spectroscopy. The GammaRad includes digital signal processing and power supply electronics for the gamma ray spectrometer, a counter for the neutron detector, and an Ethernet interface. Each RDU is shock mounted in an environmentally sealed aluminum housing. The cameras and OCR software are used to determine container number and status of the twistlock (which holds the container on the spreader bar). Data from each RDU are transmitted by Ethernet to a shock mounted Ethernet switch and via fiber optics in specially designed spreader cable to a computer in the crane electrical room. From there, data can easily be transmitted anywhere using standard networking technology. The computers execute data processing software which includes algorithms to correct the gain for temperature variations, background subtraction, and the analysis of the processed spectra to assess the threat.

The VeriSpreader™ has been developed by VeriTainer, Inc. in collaboration with Amptek, Inc. A proof-of-concept prototype has been built and was demonstrated at the Port of Oakland, CA, from Aug through Oct 2005. This system, described here, used four RDUs, with 76 mm x 76 mm NaI(Tl) crystals, and preliminary processing software. A second generation system is being deployed with eight RDUs, each containing 76 mm x 152 mm NaI(Tl) crystals. Figure 2 shows the proof-of-concept system in use at the Port of Oakland, in Oakland CA.

Figure 2. Photograph of VeriSpreader™ in use at the Port of Oakland.

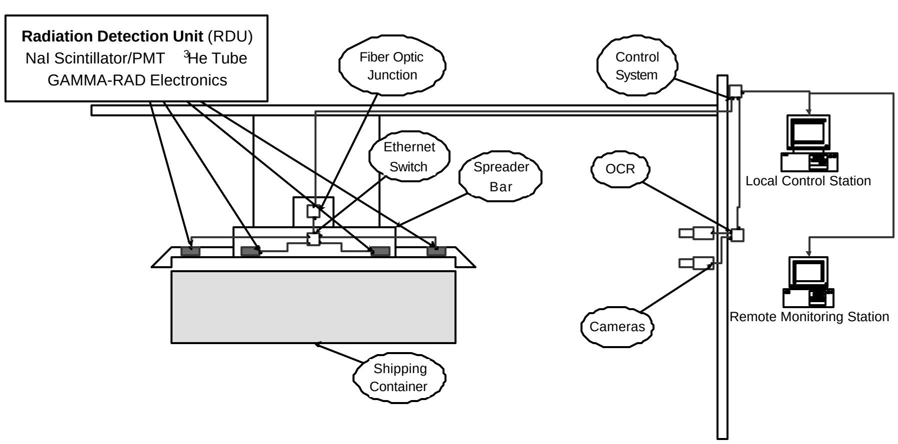

Figure 1. Block diagram of VeriSpreader™ system, discussed in the text.

3. GammaRad Spectrometer

Gamma ray spectroscopy is a well established technique for identifying radioisotopes, which can not only detect the presence of radioactive material but can separate naturally occurring radioactive material (NORM) from special nuclear material and other potentially threats [4], [5]. The heart of the gamma-ray spectrometer in the GammaRad is a 76 mm x 152 mm NaI(Tl) scintillator coupled to a ruggedized PMT. The scintillator, PMT assembly, and HV supply are provided by Scionix (Ltd) and have been qualified for use in harsh mechanical, thermal, and electromagnetic environments. The radiation detection performance of the GammaRad, such as resolution, sensitivity, photopeak efficiency, are typical for a 76 mm x 152 mm NaI(Tl) scintillator with PMT. Examples are shown in Figure 3. The Gamma-Rad can be tailored with various other scintillators, including a 10 x 10 x 40 cm^3 NaI(Tl) or a 2.5 cm $LaCl_3$.

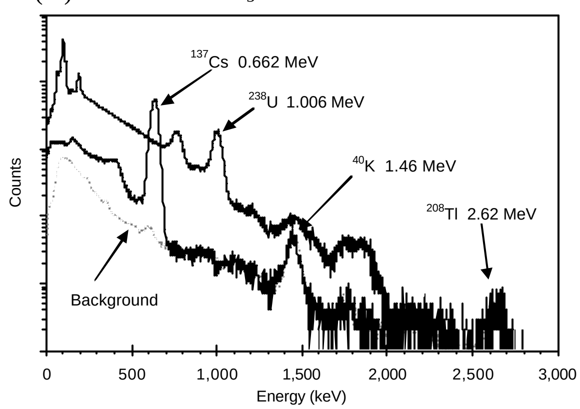

Figure 3. Typical laboratory spectra, showing natural background (thin, gray plot), a ^{137}Cs spectrum, and a spectrum from natural uranium oxide.

The onboard data processing electronics are based on Amptek's DP4 digital pulse processor, which combines a charge amplifier, digital pulse shaping amplifier, a multichannel analyzer, and versatile interface hardware and software. The DP4's digital approach offers several important advantages over more conventional analog systems, particularly in remote applications.

In the GammaRad, the DP4 implements trapezoidal pulse shaping with a peaking time of 2.4 µsec and a flat top of 1 µsec. This is equivalent to a 1 µsec semi-Gaussian shaper. The gain is typically set for 3 MeV full scale, with the threshold typically set to 15 keV. The MCA has 8k channels but is usually set to 1k channels. In this application count rates are usually very low, but the GammaRad operates well at count rates up to 1.5×10^5 sec^{-1}.

It is well known that the gain of a scintillator and PMT are a strong function of temperature and can also vary with PMT aging and other phenomena, necessitating some form of gain stabilization. This is implemented in software, with the gain scaling applied on the previously acquired spectra. The ^{40}K background peak is used as the reference.

The GammaRad has several different serial interfaces available, including RS232, USB, and Ethernet. Both RS232 and USB have very limited distances so are not suitable for the hundreds of meters over which data must be transmitted in a port. Ethernet provides a very robust and long range interface, which is ideal for this application. The Ethernet port can be connected to standard Internet access, to permit monitoring from anywhere on the Internet.

4. Other VeriTainer System Elements

Neutron Detector: Neutrons are a well known signature of special nuclear material. In the VeriSpreader™, neutrons are detected using moderated ^3He tubes with 1 m active length, 50 mm diameter, and 4 atm pressure, supplied by St. Gobain Crystals & Detectors. A high voltage supply, specially designed pulse processing electronics, and housing are attached directly to the output of the ^3He tubes. The entire assembly is shock mounted in an environmentally sealed housing. TTL pulses from each ^3He tube are routed into the electronics of a GammaRad, where they are counted and transmitted along with the gamma ray data.

RDU Packaging: The GammaRad module, although ruggedized, requires additional packaging to withstand the environment of the crane spreader bar. It is therefore packaged inside a sealed, shock mounted package, which is located in the spreader bar. The shock mounting attenuates shocks of grasping a container to an average of <5 g and attenuates vibration during crane operation enough to obtain good quality spectra. The sealed environment also keeps humidity and salty air away from the high voltage electronics. The box includes feedthroughs for the power and Ethernet connection.

Optical sensor: In addition to the radiation sensors, a pair of video cameras is mounted on the crane, with optical character recognition (OCR) software. These cameras monitor the spreader's twistlock status to determine when the spreader has a container in its grasp. Each container number is read electronically by the crane-mounted OCR system. Twistlock status and time-stamped container numbers are fed into the VeriSpreader™ data acquisition software, enabling the radiation data to be associated with a container number in real time.

Data Processing Software: The data processing software is a vital part of a successful gamma-ray spectroscopy system. The software must acquire raw spectra, correct for gain shifts, remove background, and analyze the spectrum to determine if radioactive materials are present. If so, threat material must be distinguished from NORM, and then the threat level communicated to the operators.

For the proof-of-concept study, the data were post processed after the measurements were completed. The goal of the proof-of-concept study was to demonstrate that suitable quality data could be obtained in the container crane environment. The data obtained during this preliminary study are being used to refine data processing algorithms, which will operate in real-time in the future. Selecting and demonstrating the spectroscopic analysis algorithms are key elements in completing this system.

5. Results

To demonstrate the feasibility of this approach, a pilot project was carried out at the Ben E. Nutter Container Terminal at the Port of Oakland. The prototype system was used from 14 Aug through 25 Oct 2005, during which 22 ships (6529 containers) were monitored.

Figure 4 shows some spectra obtained during this study at the Port of Oakland. The background spectrum shown was averaged for almost a day and half. The "typical" spectrum was obtained on a moving crane (this one for 45 seconds). Also shown is a fortuitous result, the spectrum obtained from a shipping container with a declared uranium cargo. Most importantly, spectra obtained on a moving spreader bar in the Port are nearly identical to those measured in the lab. Both background and natural uranium spectra were measured in both settings and are nearly identical. The spectroscopic performance of the GammaRad, on the crane, is typical of a NaI(Tl) scintillator in the lab.

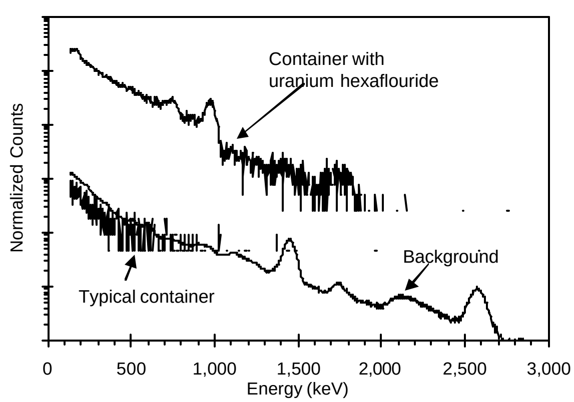

Figure 4. Representative spectra taken during the pilot project at the Port of Oakland. A background measurement is shown, taken during a break in operation, along with the measurement of a typical container. The spectrum emitted by a container of uranium is also shown.

We have begun modeling and simulation work to assess the sensitivity of the VeriSpreader^{TM} to compare it to that of standard portal monitors under standard test conditions [6]. This standard does not directly apply to the VeriSpreader^{TM}, but our goal is to have a minimum detectable activity (MDA) comparable to common portal monitors. We anticipate that eight 76 mm x 152 mm NaI(Tl) scintillators will provide a minimum detectable activity comparable to that of a double-sided portal monitor using eight, 10 x 10 x 40 cm^3 NaI(Tl) scintillators. This has been shown through simple calculations and preliminary lab results and will be refined through further simulations and measurements.

6. Conclusions

The key conclusion demonstrated at the Port of Oakland, is that the VeriSpreader^{TM} is capable of high quality spectroscopic measurements in the demanding environment of a container spreader bar. Spectra measured on a moving spreader in the Port of Oakland were similar to those measured in a lab environment. The practical issues of packaging, data transmission, and reliable operation were demonstrated. Data were taken in the Port and monitored, in near real-time, across the country using the Internet. Lab measurements and simulations show that the sensitivity is comparable to many portal monitors now in use. These results demonstrate the validity of the concept: 100% screening of intermodal shipping containers for radioactive material, during normal handling and operations.

The next step in the deployment of the VeriSpreader^{TM} include: (1) refining the algorithms used for data processing and determining if a container is hazardous; (2) optimizing the sensor geometry to enhance sensitivity, and (3) implementing prototype systems in ports to more fully validate the system. The next generation systems are now being assembled with testing anticipated in the coming months.

Acknowledgements

The authors wish to thank Paul Schotanus of Scionix, Ltd. for his assistance in the development of this system.

References

[1] *GreenLane Maritime Cargo Security Act*, sponsored by Senators Murray and Collins, Bill S.2008

[2] Jonathan Weisman, *House passes $7.4 billion port security bill*, **Washington Post**, 5 May 06

[3] J. Alioto, M. Alioto, *Container crane radiation detection systems and methods*, U.S. Patent 6,768,421

[4] G. Knoll, *Radiation detection and measurement*, Wiley & Sons, 1989

[5] G. Gilmore, J.D. Hemingway, *Practical gamma-ray spectroscopy*, Wiley & Sons, 1995

[6] *Performance criteria for spectroscopy-based portal monitors used for homeland security*, ANSI N42.38-WD-F1 (Draft), P. Chiaro (chair of working group)