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J. Richardson, B. Yuldashev, S. Labov, R. Knapp

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Improved Technology to Prevent Nuclear Proliferation and Counter Nuclear Terrorism

Jeffery Richardson[1], Bekhzad Yuldashev[2], Simon Labov[1], and Richard Knapp[1]
[1]Lawrence Livermore National Laboratory, P.O.Box 808, Livermore, CA 94551-0808
[2]Institute of Nuclear Physics, 702132 Ulugbek, Tashkent, Uzbekistan

ABSTRACT

As the world moves into the 21st century, the possibility of greater reliance on nuclear energy will impose additional technical requirements to prevent proliferation. In addition to proliferation resistant reactors, a careful examination of the various possible fuel cycles from cradle to grave will provide additional technical and nonproliferation challenges in the areas of conversion, enrichment, transportation, recycling and waste disposal. Radiation detection technology and information management have a prominent role in any future global regime for nonproliferation. As nuclear energy and hence nuclear materials become an increasingly global phenomenon, using local technologies and capabilities facilitate incorporation of enhanced monitoring and detection on the regional level.

Radiation detection technologies are an important tool in the prevention of proliferation and countering radiological / nuclear terrorism. A variety of new developments have enabled enhanced performance in terms of energy resolution, spatial resolution, passive detection, predictive modeling and simulation, active interrogation, and ease of operation and deployment in the field.

For example, various gamma ray imaging approaches are being explored to combine spatial resolution with background suppression in order to enhance sensitivity many-fold at reasonable standoff distances and acquisition times. New materials and approaches are being developed in order to provide adequate energy resolution in field use without the necessity for liquid nitrogen. Different detection algorithms enable fissile materials to be distinguished from other radioisotopes.

INTRODUCTION

The objective of nuclear proliferation prevention is to eliminate uncontrolled access to materials, information, and expertise by potential proliferators. Perhaps the most technically challenging aspect of this objective is intercepting the illicit transport of radiological and/or nuclear material from source locations to the end-user. This technical challenge is two-fold: detecting material of interest and monitoring transit routes. Radiological and/or nuclear material of interest can have intrinsically subtle signatures, be shielded to mask the signature, or have signatures similar to non-threatening material. Transit routes can vary from single, highly monitored exits at controlled storage facilities to uncontrolled borders in rugged mountains or along remote coastlines.

There is a global expectation that we are on the threshold of a significant expansion in the civilian nuclear power industry. There are many proliferation challenges associated with this expansion and ample uncertainty in how the global supplier and user network will operate. But it is a certainty that an increase in the civilian use of nuclear power will be accompanied by an increase in the amount of nuclear material in global transit. Improved detection and monitoring technology will be central to proliferation-resistant nuclear energy development. This paper will explore some emerging concepts for this.

In this paper we will also briefly overview a selection recent technical advances in detection and monitoring made in part through the collaboration among the Institute of Nuclear Physics of Uzbekistan and Lawrence Livermore National Laboratory. Improving technology performance is through increasing resolution, sensitivity, stand-off distance, and ruggedness while decreasing acquisition time and cost. These can be achieved with improved gamma ray imaging, use of new detector materials, improved detector algorithms, and developing new monitoring concepts.

THE CHALLENGE OF THE GLOBAL EXPANSION OF NUCLEAR ENERGY

The increasing global demand for energy and rapidly rising costs for fossil fuels indicates that there will soon be large increases in the use of nuclear energy. One consequence of this expansion is that the amount of nuclear material in transit from suppliers to users to reprocessors / disposers will dramatically increase. In addition, as markets expand and change, the routes of transport of nuclear fuel will also change. These changes in quantity and direction will challenge efforts to secure shipments of nuclear material that can be attractive to terrorist forces.

GLOBAL NUCLEAR ENERGY PARTNERSHIP

Global nuclear energy commerce requires global cooperation in nonproliferation and this is the a key part of the Global Nuclear Energy Partnership (GNEP) mission. A nuclear fuel cycle (Figure 1) that enhances energy security, while promoting non-proliferation is the GNEP objective. It would achieve this goal by having nations with secure, advanced nuclear capabilities provide fuel services — fresh fuel and recovery of used fuel — to other nations who agree to employ nuclear energy for power generation purposes only.

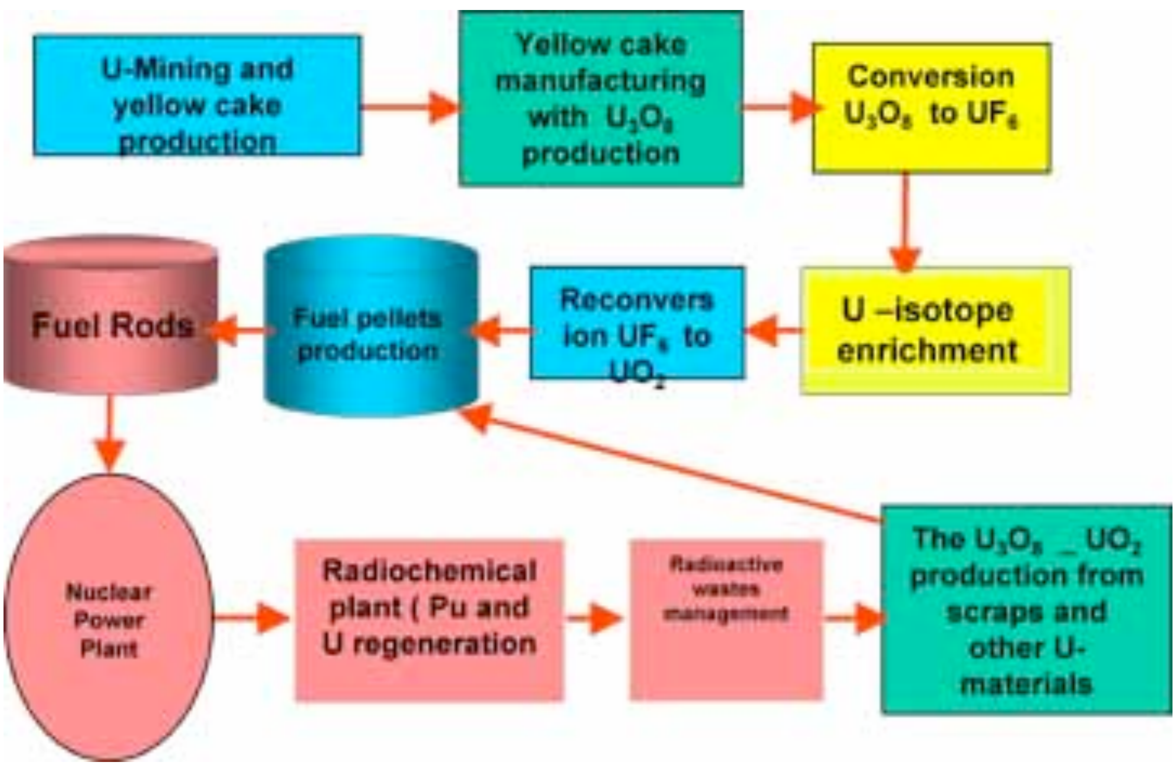

Figure 1: An illustration of the commercial nuclear fuel cycle. The GNEP model is to have nations with enrichment and reprocessing capabilities provide a guaranteed nuclear fuel supply to countries that agree to employ it for power generation only.

The closed fuel cycle model envisioned by this partnership requires development and deployment of technologies that enable recycling and consumption of long-lived radioactive waste. GNEP would demonstrate the critical technologies needed to change the way spent nuclear fuel is managed – to build recycling technologies that enhance energy security in a safe and environmentally responsible manner, while simultaneously promoting non-proliferation.

An important supplementary link in the GNEP nonproliferation objective is to track and intercept illicit transport of nuclear materials in the expanding global marketplace. Effective proliferation prevention requires improved technology for more effective detection of nuclear and radioactive material and more effective monitoring of transportation networks. This later requirement is inherently a multilateral cooperation effort.

CENTRAL ASIA IS A NEXUS FOR NUCLEAR FUEL TRANSPORT

Central Asia is poised, by its geography, natural resources, and technical capabilities, to play a key role in the expansion of the nuclear power industry and efforts to prevent nuclear proliferation. Central Asia is located between the key supplier state of Russia and the expanding user market of East Asia and South Asia (Figure 2). In addition, Kazakhstan and Uzbekistan ranked 3rd and 7th globally in uranium production in 2004 (Table 1). Finally, there is a high level of nuclear-related technical expertise in the region as both a legacy from the Soviet nuclear weapons program and on-going commercial and scientific interests. For example, Kazatomprom currently (Figure 2):

- mines uranium ore
- processes the ore into U_3O_8
- exports U_3O_8 to Russia, the Republic of Korea, Japan, and China
- imports low enriched UF_6 from Russia
- fabricates fuel pellets and exports those to the Ukraine

This commercial traffic is currently significant and will expand in the future.

Table 1: 2004 Uranium Production*

World Rank	Country	Metric Tonnes
1	Canada	10,385
2	Australia	7,917
3	Kazakhstan	3,300
4	Niger	3,154
5	Russia	2,800
6	Namibia	2,038
7	Uzbekistan	2,000
8	U.S.	797
9	China	769
10	South Africa	769

* data from Kazatomprom personal communication

Figure 2: As shown by the arrows, Kazatomprom currently supplies U_3O_8 to Russia, the Republic of Korea, Japan, and China and, after receiving low enriched UF_6 from Russia, exports fuel pellets to the Ukraine.

REGIONAL COOPERATION IN CENTRAL ASIA TO PREVENT NUCLEAR PROLIFERATION

In response to the threat of smuggling of nuclear and radioactive materials, Uzbekistan has been a regional leader in deploying systems to monitor the flow of air, rail, vehicle, and pedestrian traffic to detect illicit material. From 2000 until 2004, the Uzbekistan Customs Services, Uzbekistan Border Guards, and Uzbekistan Institute of Nuclear Physics has worked with Lawrence Livermore National Laboratory on a U.S. Department of Defense funded project to install radiation portal monitors as a demonstration project at high priority ports-of-entry. Since 2004, Uzbekistan Customs Services, Uzbekistan Border Guards, DoD, and Washington Group International have expanded this to cover all major ports-of entry (Figure 3). This interconnected system provides unprecedented monitoring coverage and serves as a global model.

Concurrent with the development of the national radiation portal monitoring system in Uzbekistan are similar but smaller scale efforts in Kazakhstan, Kyrgyzstan, Tajikistan, and Turkmenistan. While each has added value and together they may make a formidable network, multilateral cooperation in developing and operating the networks brings significant benefits. The *Central Asia Technical Workshop to Prevent the Illicit Trafficking of Nuclear and Radioactive Materials* workshop was sponsored by DOE and held in Istanbul, Turkey in 2005 to identify these benefits and promote technical cooperation. Customs and technical experts from the five Central Asian states and Unites States Government attended.

Figure 3: The international ports-of-entry in Uzbekistan.

A consensus was reached concerning the importance of collaboration on these smuggling issues. Furthermore, a five-point program to practically achieve this collaboration was recommended:

- Develop an information website that contains a state-by-state inventory of relevant legislation and regulations; a survey of radiation detection system technical specifications, requirements, and other information of mutual interest, and information on training course contents and schedules
- Develop and implement joint training programs
- Jointly develop and maintain an illicit nuclear and radioactive materials trafficking catalogue
- Use a risk-based approach in the area of radiation monitoring to identify problematic locations and avoid redundancy of efforts
- Create and support a technically equipped mobile response teams to interdict the illicit trafficking of nuclear and radioactive materials

IMPROVED TECHNOLOGY

Within the framework of greatly expanded commercial traffic of radioactive and nuclear materials, is a major requirement to improve the detection technology. More subtle signatures in a wider variety of conditions will be encountered. We present some brief advances below.

GAMMA-RAY IMAGING SPECTROMETER

Advances in gamma-ray imaging detectors have increased sensitivity and spatial resolution to detect weak radioactive sources that would otherwise be masked by background gamma-ray emissions. Gamma-ray imagers are particularly useful when searching for lost, stolen, or hidden nuclear material in a large area. The gamma-ray imaging spectrometer (GRIS) can take gamma-ray “pictures” of the high-energy radiation emitted by nuclear materials [1, 2]. This instrument is useful for a variety of applications, including treaty inspections, mapping radioactive contamination, and determining what is inside a suspect object (Figure 4).

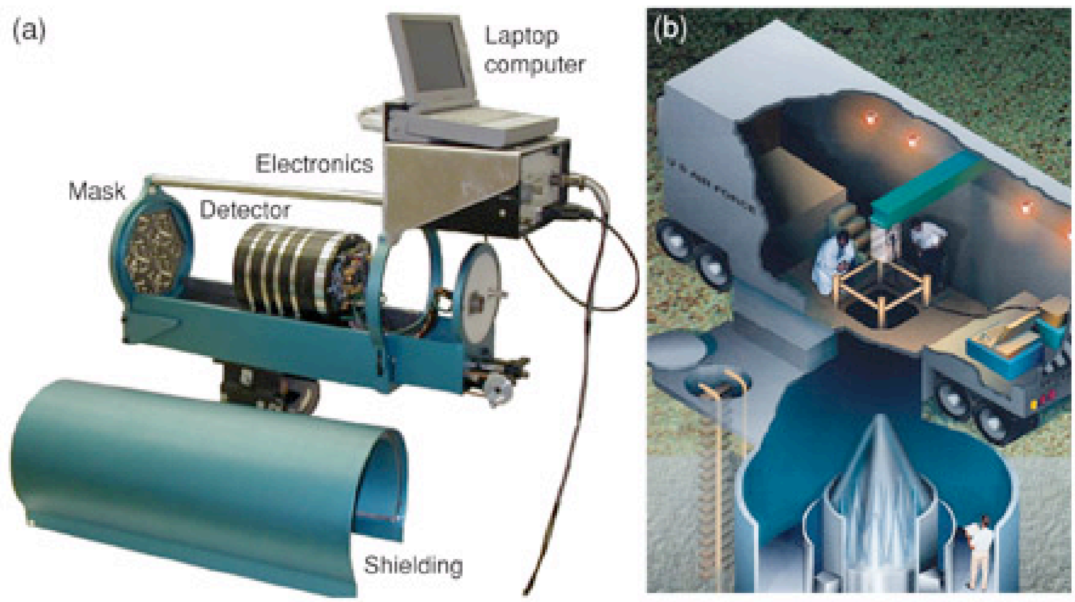

Figure 4: (a) The gamma-ray imaging spectrometer (GRIS) takes pictures of the high-energy gamma radiation given off by nuclear materials. The images are encoded on the detector by using a coded aperture mask that allows the user to recover the image through a computer program. (b) One potential application of GRIS is for nonintrusive treaty inspections. The drawing shows how the instrument might be used to inspect a multiple-warhead missile.

The GRIS system is about half the size of a personal computer and was first developed for use in treaty inspections to monitor the location of nuclear missile warheads in a non-intrusive manner. In addition to its use in counterterrorism applications, GRIS is also expected to be useful in space to search for distant black holes and in hospitals to better detect, diagnose, and treat cancer.

COMPTON CAMERA

The Compton camera is yet another type of gamma-ray imager under development (Figure 5). In addition to taking gamma-ray pictures, this imager should be able to identify very weak and typically invisible gamma-ray sources. The Compton camera operates without a mask or collimator, which can block many of the gamma rays emitted from a source. Instead, gamma rays coming from all directions at once are tracked as they scatter inside the detector. The camera's omnidirectional sensitivity is significantly higher than that of other imaging systems. Mathematical algorithms are used to retrace the paths of the gamma rays within the detector, and the results reveal the direction of the source. The main goal for the camera is to detect clandestine nuclear materials.

ADAPTABLE RADIATION AREA MONITOR

The adaptable radiation area monitor (ARAM) is designed specifically for fast, accurate detection without interrupting the flow of traffic and commerce [3]. The ARAM system can serve as a stand-alone radiation monitor, or it can be networked into a system of monitors to cover a large area. In addition, the system can be used as a fixed detector to monitor slow-moving packages, luggage, or pedestrians and as a portable detector. ARAM is optimized to detect even small quantities of radioactive materials moving at highway speeds (Figure 6). This capability makes ARAM a crucial element in the effort to protect the nation from radiological weapons of mass destruction.

ARAM is an automatic, highly sensitive system that uses a thallium-doped sodium iodide crystal to detect even small amounts of radiation in different scenarios. The crystal may be shielded on as many as four sides to "point" the detector in a particular direction, or it may not be shielded at all. The crystal detects full spectral data by dividing the spectrum into 1,024 energy bins, or channels. It counts single photons, unlike most other detectors, which collect gross counts or divide the spectrum into only 10 channels.

ARAM's method, known as list mode, produces large quantities of raw, time-stamped data that can be analyzed in any number of ways. List mode increases overall sensitivity and the signal-to-noise ratio for spectral data analysis, thereby increasing the probability of a proper identification. This feature is particularly important for detecting radioactive materials hidden inside moving vehicles. The software for the ARAM system provides near-real-time results. By acquiring data in list mode, ARAM can produce output with much finer time resolution than similar programs. Fine time resolution offers numerous advantages: Small sources of radiation moving at highway speeds can be detected and identified, and the direction of the radiation source's motion may be determined. Fine time resolution also protects the source spectrum from contamination by background radiation collected immediately before or after an event. Eliminating this spectral contamination results in better data for radionuclide identification. When a spectral anomaly is detected, "trigger" algorithms operate on the acquired data and produce detailed, easily read event reports. These advanced algorithms include enhancements to improve performance in difficult scenarios, such as roadside monitoring, and to substantially reduce false alarms—for example, when the shielding effect from a large truck causes a change in the level of background radiation.

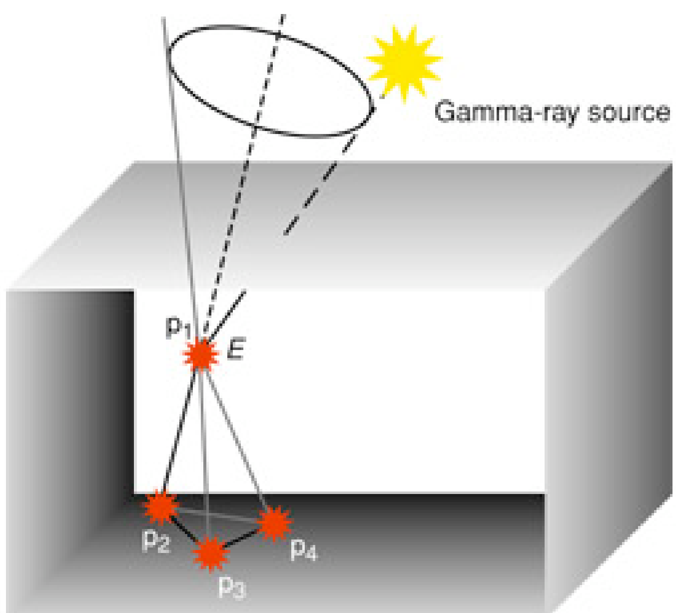

Figure 5: The Compton camera's omnidirectional capability significantly increases gamma-ray sensitivity. A gamma ray enters the detector and interacts through Compton scattering until it is fully stopped by the photoelectric effect. Mathematical algorithms combining all of the gamma rays' energies (E) at each position (p) are used to identify the path of the gamma-ray source.

Monitoring for radiological material involves three steps: detection, localization, and identification. Each step could require a different piece of equipment, depending on a system's design. For example, in some systems, a large portal monitor might perform the initial detection phase of all vehicles. Suspect shipments would then be inspected using smaller handheld detectors to localize and identify the material. The ARAM design combines detection and identification into a single step.

Figure 6: The adaptable radiation area monitor (ARAM) can detect small amounts of radioactive material hidden in a vehicle moving at highway speeds.

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