Stand and deliver

A FUNDAMENTAL tenet of ionizing radiation detection has been that this detection may only occur if a radioactive particle physically interacts with the detector. Clearly this has a great many implications for military and other field personnel. Perhaps the most severe of these is that, for a great many radioisotopes of concern, personnel must themselves enter the radiation field in order to ascertain its severity. This necessity not only results in untoward doses to these personnel, but will inevitably lead to the personnel becoming contaminated and hence risking spread of contamination to "clean" areas.

Equipment recently developed at Defence R&D Canada – Ottawa (DRDC Ottawa) belies this precept. Our so-called "standoff" radiation detection system allows detection of various types of radioactive particles at distances up to kilometres greater than their concomitant ranges in air. The system has been proven in national and international field trials and has many perceived militarily-significant applications.

This system was developed under the Government of Canada's Chemical, Biological and Radiological/Nuclear Research Technology Initiative (CRTI) Project CRTI-01-0203RD "Standoff Detection of Radiation", with DRDC Ottawa and Bubble Technology Industries (BTI), Chalk River, Ontario as partners.

All radioactive particles are attenuated – to some extent – by interactions with air molecules. Table 1 below lists the ranges (for alpha and beta) or mean-free paths (for gamma and neutron) of the four militarily-significant forms of radiation.

Thus, especially in the case of alpha or beta radiation, personnel attempting to measure the extent of radiological contamination (as after, for instance, a radiological dispersal device [RDD] event) will be forced to enter the field; in turn they themselves are highly likely to spread contamination.

Putting this into perspective, Table 2 below lists some of the isotopes that are considered threats for RDD or nuclear devices (ND). Note especially those that are primarily alpha and/or beta (and hence short-range) particle emitters. With the abject failure of conventional radiation detection techniques to solve this problem, novel and innovative solutions were required. Thus, DRDC Ottawa looked to another physical property of ionising radiation to develop alternate detection techniques. It has been known for more than 100 years that radioactive sources will ionise the air surrounding them, and in doing so will create excited molecules. These molecules decay via the emission of photons spanning the IR, visible and UV spectra. Measurement of this photo-emission signal will, in theory, confirm the presence of a radioactive source. The intensity of such emissions is extremely weak, and heretofore all attempts to use this technique for radiation detection have proven fruitless.

However, using specially-developed techniques, DRDC Ottawa has built a system based upon the air-ionisation/molecular decay process that can overcome this signal-to-noise quandary. Clearly, detection of these photons will allow standoff detection at great distances, owing to their low attenuation coefficients in air. The DRDC Ottawa standoff radiation detection system carries the moniker Simultaneous Multi-spectral Imager (SMSI). The system employs a telescope to collect light which is then split, so as to image a scene in six different wavelength bands – four containing radio luminescence lines, and two background regions. An important consideration of the system is the use of simultaneous imaging (as opposed to sequential imaging in many other optical imagers), greatly enhancing the duty-factor

Following acquisition, signals from the seven cameras (including a spotting camera) are captured by a pair of frame-grabbers, and their signals in turn are sent to a video processor card that performs a number of simple operations on the images before passing them on to the computer's main processor. The computer also consists of an I/O board and an RS-232 board for communicating with and controlling the cameras.

The detector has a footprint of approximately 1.5 square metres, and it stands approximately 1.5metres high. The optical components are housed in a light-tight enclosure in the upper third of the device. The silver box at the centre is the control computer. The tilt and swivel of the telescope are both manually controlled. The detector weighs a total of 122kg, of which the top stage is 88kg. The software GUI runs on the acquisition computer and allows the user to set instrument and acquisition settings (eg focal distance and exposure time), control the instrument and acquisition system (eg start and stop acquisition, save data), and to see the acquired and data processed images in real-time as they are collected. Data is saved in MATLAB-compatible binary files, which facilitate post-processing in MATLAB. MATLAB was used to perform all of the post-processing for the laboratory prototype, and the image processing routines in the present detector were written in MATLAB and compiled to dynamically linked libraries (DLLs) that are called by the data acquisition system.

SMSI Stand-off Radiation Detection Results

A number of trials have been prosecuted at DRDC Ottawa in order to ascertain the efficacy of SMSI, and to model its performance. Sources used for these trials include:

Four 241Am (alpha source) foils, each approximately 1inch by 6inches. Each foil has an approximate activity of 6 mCi.

Beta sources 90Sr (0.5 Ci) and 147Pm (2 Ci), each a circular source of approximately 1cm in diameter.

An industrial X-ray machine, operated at 80 kVp. This was viewed head-on (ie with beam aimed at the detector) and in profile (ie with the beam aimed straight up). Based on dose rates at small distances (less than 1m) from the X-ray machine, this machine is like a gamma source with an activity of a few thousand Curies.

The environmental conditions are important (note city lights and full moon). Originally it was supposed that SMSI would only work under "pitch black" conditions. The extremely low signal-to-noise ratio for this work was of concern – even under ambient (man-made and lunar) night light conditions. However, SMSI produced quality results.

At 30m from the source SMSI was able to give outstanding performance for both alpha and beta detection – something for which there is no parallel in open literature. When the sources were turned by 90 degrees to the detector, however, the greater range of beta particles to alpha particles was immediately apparent. This was a critical step tpwards the confirmation of SMSI's capability and a great deal of further information was derived from this.

Figure 6: A selection of results from field trials at DRDC Ottawa. On the left are alpha and beta sources from 30 m, 135m, and 500m. On the right are measurements of an X-ray machine from 61 m and 135m. At 30 m and 135m, only one Am-241 foil was used (6 mCi). At 500m, four Am-241 foils were placed side by side (total of 24mCi). Figure 6 offers a collage of experimental results.

On the left side are results showing the effects of increasing source-to-detector distance for alpha- and beta-emitting sources. Note that even though the ^{241}Am - sources are lower in total activity by factors of roughly 20 and 100 (when compared to ^{90}Sr and ^{147}Pm respectively) they are easier to detect. In fact, at 500m the beta sources proved impossible to detect. This is unquestionably due to the higher Linear Energy Transfer (LET) of alpha particles (over beta particles), resulting in a more highly dense air ionisation "cloud" around the source. In fact the very physical process that renders higher-LET harder to detect at distances using conventional techniques aids and amplifies detection with SMSI. On the right-hand side of Figure 6 are the SMSI-observed patterns from the x-ray machine at 61m and 135m. Note that, as above, when the radiation is directed perpendicular to the source-detector axis, the ionisation distribution pattern in air is clearly visible.

The standoff detector was taken to Pacific-Northwest National Laboratories in Richland, Washington for field trials that took place during the last week of June 2005. A selection of results is shown in Figure 7. The sources that were used at these field trials were:

An array of ^{241}Am sources. The array

Table 1

Particle	Range/Mean Free Path in Air
alpha	Centimetres
beta	Metres
n	hundreds of metres
gamma	Kilometres

Table 2

Isotope (Principal Emission)	Terrorist Threat	Range or Mean-free Path
^{60}Co; ^{137}Cs; ^{192}Ir	RDD	Up to km
^{90}Sr	RDD	Few m
^{3}H	RDD (inside building)	cm
^{235}U; ^{239}Pu	Improvised Nuclear Device (IND) or Acquired Nuclear Device (AND)	cm
^{241}Am	RDD	cm
^{252}Cf (n)	RDD	200 m

Figure 6

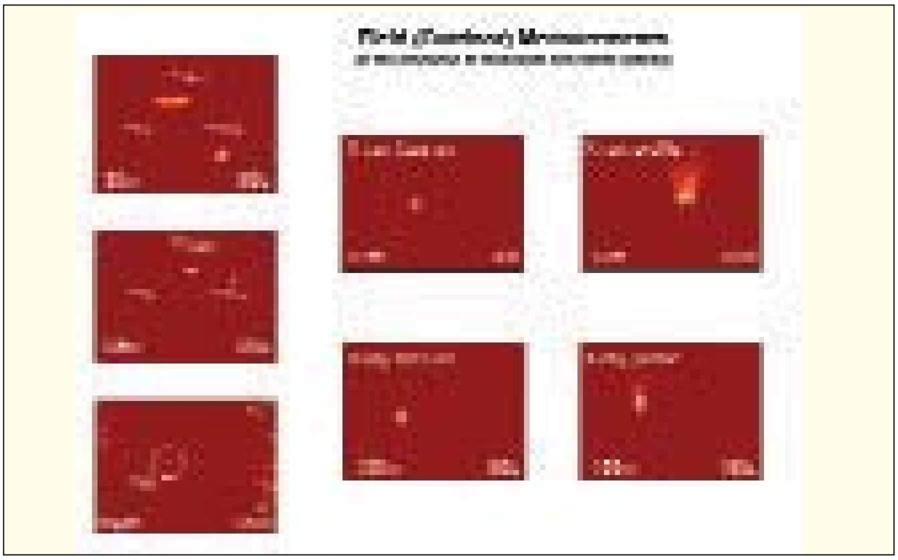
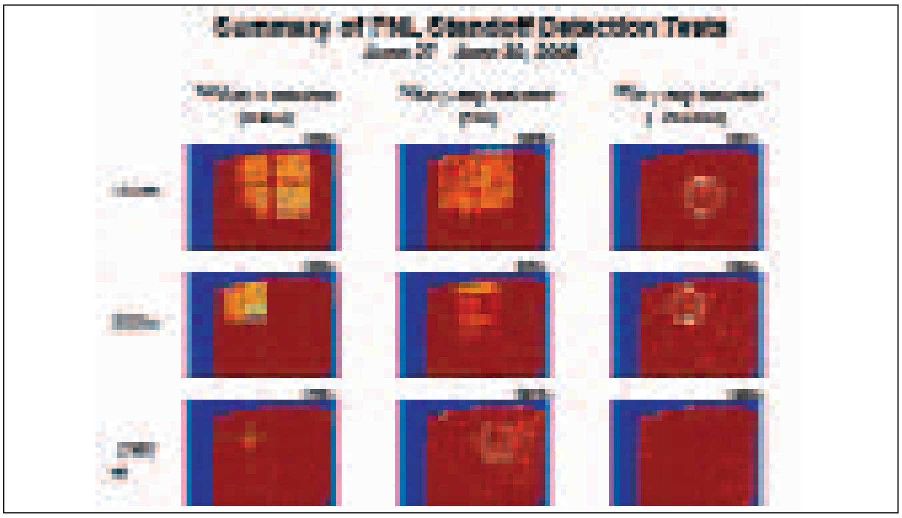


Figure 7



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consists of four sub-arrays, each of which consists of 100 sources (10 rows of 10 each), each with a diameter of approximately 2 inches and containing 1 mCi. The whole array measured about 1.5 m wide and high, with a total activity of 400 mCi.

A similar array of ^{90}Sr sources. The only difference between the arrays is that each of the individual ^{90}Sr sources is 2.5 mCi (as opposed to 1 mCi), making the total activity 1 Ci.

An industrial radiography source of ^{192}Ir, with an activity of 20-50 Ci. The source was not collimated.

Figure 7: Selected measurements from the field trials at Pacific-Northwest National Laboratories. The alpha source is clearly visible from 1,250 metres. Several interesting facets are apparent. Firstly, as noted previously, the higher the LET, the higher r is the s the efficiency of SMSI detection. In this case, the alpha-source activity is roughly half of the beta-source activity and a tenth of the gamma-source activity. Yet the alpha-source is clearly visible at 1.25km, while the beta-source is barely detectable and the gamma-source is not seen. Note also that in the alpha image at 160m, there is an apparent "blank spot" in the lower left. This was in fact caused by a radiation trefoil placard obscuring this area of the source.

Real-world performance

Based upon a combination of measurements and calculations, the nomogram in Figure 8 gives the SMSI performance.

Figure 8: SMSI Sensitivity. Lines and shaded regions provide expected levels of sensitivity, based on calculations (note that these are based on four 300-second measurements). Data points represent experimental measurements, and validate the calculations.

If anything, the observations show the calculations to be overly conservative. As emphasised above, higher-LET radiation is easier to detect using SMSI.

Possible Future Upgrades

SMSI has proven itself to be capable of detecting radioactive sources under a variety of lighting conditions, including dawn, dusk, full moonlight, and high-intensity ambient night lighting (such as streetlights). However, the system will not work in broad daylight owing to the extremely low signal-to-noise. Future upgrades should include an expansion of this operable "time window". Other upgrades may centre on expansion of the system's field-of-view, addition of a sighting scope, further refinement and optimization of the spectral regions of interest, ruggedisation and ergonomics.

Other Potential Standoff Methods

The air-fluorescence technique

(embodied in SMSI) presented here has clearly demonstrated radiation detection capabilities not previously realisable. However, there may well be other unexplored techniques that can augment (or possibly even surpass) SMSI's capabilities. These techniques may include – but are not limited to – other air fluorescent phenomena

A suggested, but by no means exhaustive, list of potentially useful techniques includes:

Radiolytic production. Radiolysis is the cleavage of one or several bonds following exposure to radiation. Short-lived, unique radicals may thus be produced. These may decay (either naturally or following some form of excitation) and their emission spectra may in turn give a unique signature.

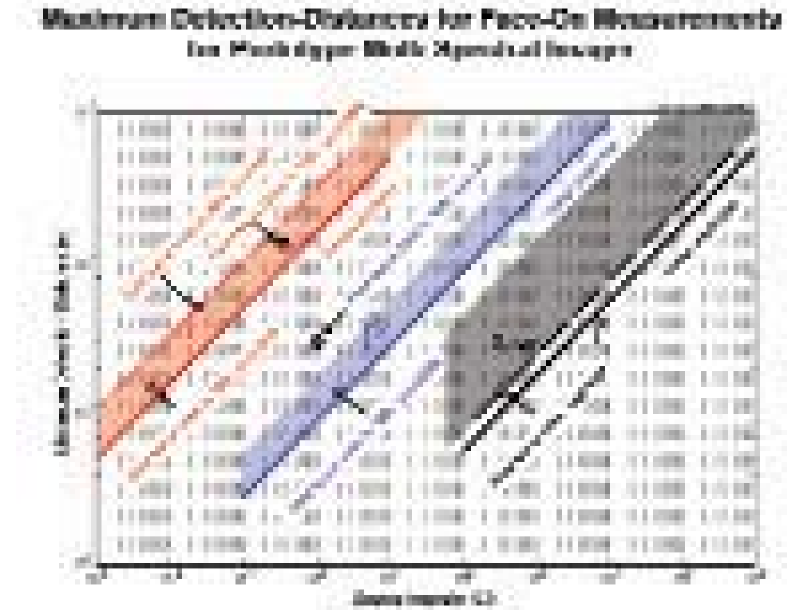
Calixarenes. These "basket" molecules exhibit strong scavenging characteristics for specific targeted elements. Thus, they may be useful in the detection of trace quantities of radioactive material, perhaps in interdiction applications.

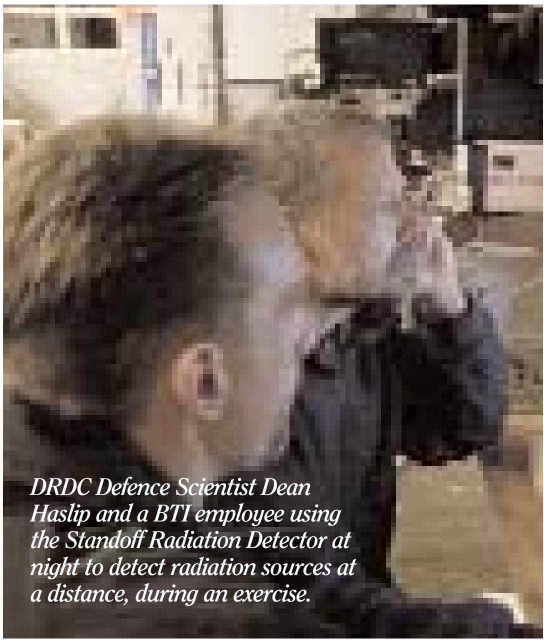
Magnetic perturbation methodologies. There are recurring reports of this phenomenon.

Fourier Transform Infrared (FTIR) is actually a technique to detect and identify molecules. It may have application if (as is often the case) the molecular form of the source is known.

Optically-stimulated luminescence of shielding or other ubiquitous materials. Radiation may excite metastable states in surrounding materials. Thus the current or

Figure 8



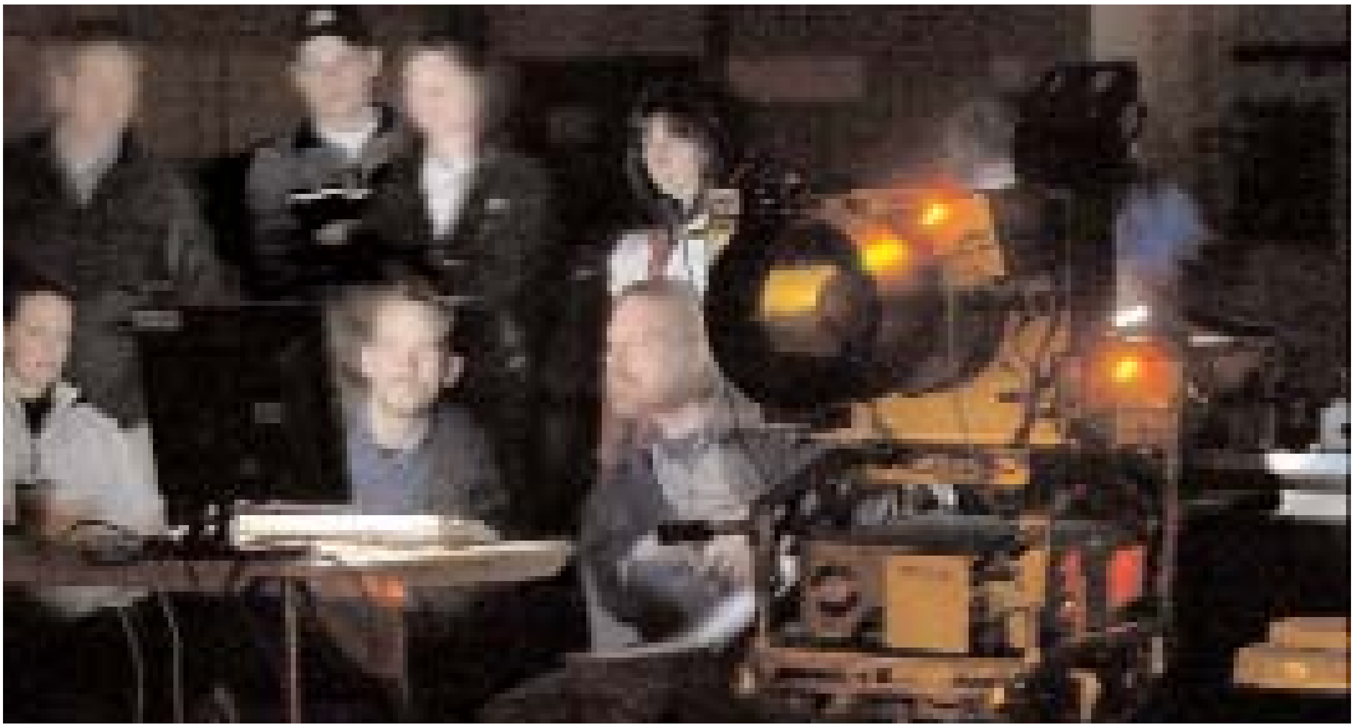


DRDC Defence Scientist Dean Haslip and a BTI employee using the Standoff Radiation Detector at night to detect radiation sources at a distance, during an exercise.

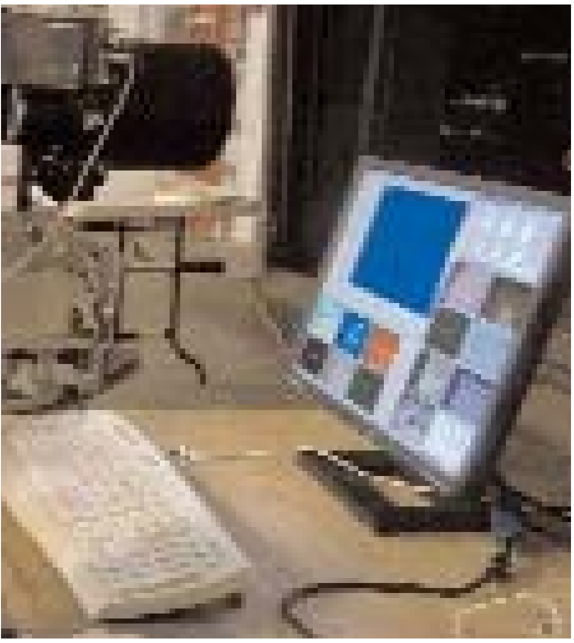
previous location of a radioactive source (or more accurately the source's ionisation profile in that material) may be known. The technique is now being applied by DRDC to forensics and arms-control verification applications.

A Nato Industrial Advisory Group (NIAG) technical study has been requested to examine some of these.

DRDC has developed a novel ionising radiation detection technique, which allows detection of sources at previously unimagined distances. For example, 400mCi _-sources have been positively detected at over one kilometre, compared to only a few centimetres with any other reported method. The current system may be described as lab-prototype, and may be readily modified (or upgraded) for specific tasks. Other "non-conventional" methods of radiation detection are currently under investigation within DRDC.



DRDC Defence Scientist Dean Haslip and a BTI employee (seated, right) using the Standoff Radiation Detector at night to detect radiation sources at a distance during an exercise. Other exercise participants observe results on the monitor.



DRDC Defence Scientist Dean Haslip and a BTI employee using the Standoff Radiation Detector at night to detect radiation sources at a distance, during an exercise.