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Author(s): Duncan McArthur
*Richard Gunn
*Thomas Dockray
*Craig Luff

* BNFL Instruments

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UNRESTRICTED RELEASE MEASUREMENTS WITH AMBIENT AIR IONIZATION MONITORS

Duncan MacArthur, Los Alamos National Laboratory
Richard Gunn, Thomas Dockray, Craig Luff, BNFL Instruments (UK)

ABSTRACT

Radiation monitoring systems based on the long-range alpha detection (LRAD) technique, such as the BNFL Instruments IonSens™, provide a single contamination measurement for an entire object rather than the more familiar individual readings for smaller surface areas. The LRAD technique relies on the ionization of ambient air molecules by alpha particles, and the subsequent detection of these ions, rather than direct detection of the alpha particles themselves. A single monitor can detect all of the ions produced over a large object (pipe, I-beam, reinforcing bar, etc.) and report a total contamination level for the entire surface of that object. However, both the unrestricted release limits specified in USDOE Order 5400.5 (and similar documents in other countries), and the definitions of radioactive waste categories, are stated in terms of contamination per area (e.g. 20 dpm/100 cm²). Thus, conversion is required between the total effective contamination as measured by the LRAD-based detector and the allowable release limits. In addition, since the release limits were not written assuming an averaging detector system, the method chosen to average the assumed contamination over the object can have a significant impact on the effective sensitivity of the detector.

INTRODUCTION

Radiation monitoring systems based on the long-range alpha detection (LRAD) technique, such as the BNFL Instruments IonSens™, (1) provide a single contamination measurement for the entire surface of an object rather than the more familiar individual readings for smaller surface areas. As the release limits specified in USDOE Order 5400.5 (and similar documents in other countries) are stated in terms of contamination per area, conversion is required between the total effective contamination as measured by the LRAD-based detector and the allowable release limits.

In addition, the averaging assumptions significantly impact the one's ability to release an object. A much higher total contamination level (as measured with an averaging detector) is acceptable if the object can be assumed to be uniformly contaminated. If all of the contamination must be assumed to be in a single 100-cm² area, the gain due to the averaging technology is minimized. Note, however, that the other characteristics of LRAD monitors, such as the ability to monitor the inner surfaces of pipes as in the BNFL Instruments IonSens™, may argue for the use of this type of detector even if no averaging is preformed.

If minimizing the total release of radioactive material is a good measure of the effectiveness of a release monitor, then averaging systems such as those using LRAD-based detectors are more effective for unrestricted release monitoring than traditional monitoring systems that measure contamination over a small area. However, current release limit regulations are written in terms of contamination per area averaged over a relatively small area. Thus, even if total contamination is arguably a better 'yardstick' for unrestricted release, these measurements must be converted to 'per area' values to allow release under current regulations.

TECHNIQUE

As illustrated in Fig. 1, the LRAD technique relies on the ionization of ambient air molecules by alpha particles. (3, 4) These ions are transported to an ion collector where the small current produced by this ion flow is measured with a sensitive electrometer. This current is proportional to the number of ions and hence to the strength of the contamination **averaged over the entire surface** from which air is collected.

Fig. 1. The LRAD alpha particle detection technique. Alpha particles from a contaminated surface ionize ambient air molecules. These ions are transported to an ion collection grid where the number of ions can be measured as a small current. This current is proportional to the amount of contamination on **the entire surface** being monitored.

Thus, LRAD-based monitors do not depend on direct detection of the alpha particles themselves. The LRAD-based monitoring systems are limited by the distance than the ions can travel through the air (several meters) rather than the range of the alpha particle (several centimeters). A single monitor can detect all of the ions produced over a large object (pipe, I-beam, reinforcing bar, etc.) and report a total contamination level for that object. (5)

AVERAGING MEASUREMENTS

The output of the LRAD ion detector (I) in response to a number of alpha decays within the detector (N_A) is given by

$$I = GF\epsilon_i\epsilon_A N_A, \quad (\text{Eq. 1})$$

where G is the electronic gain of the detector and F is the fraction of the ions generated within the active volume that are transported to the ion detector. In this case, ϵ_i is the efficiency of conversion of alpha particles in free air into ions and ϵ_A is the fraction of alpha energy that is deposited into the air of the detector (as opposed to nearby solid material).

The electronic gain, G, is known and controllable, and the ion conversion efficiency, ϵ_i , can be calculated directly from the properties of the detection gas and the incident alpha particle. (An alpha particle loses about 35 eV per ion pair generated in air, so a typical 5-MeV particle will generate about 140,000 ion pairs.) The factors F and ϵ_A depend on the details of the object/detector system; understanding these geometry factors is essential for relating the contamination measured by the LRAD-based detector to the surface release limits.

Several limiting cases may help to illustrate the interactions between these parameters:

5. If the radiation is generated within a plated calibration source, then almost 1/2 of the alpha particles are emitted into the air above the source; i.e. $\epsilon_A \approx 1/2$.
6. If the ion detector is very close to a small alpha source, then almost all of the ions can be collected; i.e. $F \approx 1$.
7. If the alpha contamination is located in a thick deposit or not located with 2- to 3-cm of air in all directions, then ϵ_A is not as easy to calculate. In most cases (excluding airborne contamination) the efficiency can be bounded, $0 < \epsilon_A < 1/2$. However, in general, this bounding is of little practical use.
8. If the alpha contamination is located in a complex geometry or the ion detector is located far from the contamination, then F are not as easy to calculate.

To summarize, ϵ_A is a measure to the number of ions generated in the surrounding air by each alpha decay. The parameter F is related to the effectiveness of the transport system in transporting these ions between the contaminated area and the ion detector. F is determined by the detection system and is not variable once the detector has been

defined. However, ϵ_A is determined by the type of measurement and measurement assumptions being made. It is instructive to consider two cases, the spot measurement where contamination is assumed to be contained within a single 100-cm² area, and the surface measurement, where the contamination is assumed to be uniformly spread over a larger surface area.

SPOT MEASUREMENTS

If all of the contamination on an object is (or must be assumed to be) in a single spot, then the outputs from an averaging detector and a traditional detector should be identical. In this case, a "spot" is defined as an area smaller than the regulatory specification (100 cm², 300 cm², etc.) If the amount of radioactivity that is measured by the averaging detector is X dpm, then the measured value for comparison with release limits would be X dpm/100cm² and the LoD of the measurement system would be given by

$$\text{LoD}_{\text{measurement}} (\text{dpm}/100 \text{ cm}^2) = \text{LoD}_{\text{detector}} (\text{dpm}) \quad (\text{Eq. 2})$$

Taking a more concrete example, the Limit of Detection (LoD) specification for the BNFL Instruments IonSensTM is 15 Bq (900 dpm) for 6 σ confidence in 300 s. Converting this to the more commonly used 95% confidence level, the LoD becomes

$$\text{LoD}(95\%) = \text{LoD}(6\sigma) \times \frac{2\sqrt{2}}{6} \quad (\text{Eq. 3})$$

Thus, the LoD(95%) is approximately 7.5 Bq (450 dpm) in 300 s. The detector response is totally dominated by statistical noise near this LoD, so the relationship between LoD and measurement time (MT) is given by

$$\text{LoD} \propto \frac{1}{\sqrt{MT}}, \quad (\text{Eq. 4})$$

or, in this case

$$\text{LoD} = \frac{450}{\sqrt{MT/300}} \text{ dpm} . \quad (\text{Eq. 5})$$

For reference, Eq. 5 is displayed graphically in Fig. 2. This figure displays the sensitivity of the IonSensTM monitor as a function of measurement time.

Fig. 2. Limit of Detection (LoD) of the stock IonSens monitor for localized contamination as a function of measurement time. This assumes that the LoD of the IonSens in 300 s is specified as 450 dpm.

SURFACE MEASUREMENTS

If the contamination is spread evenly over the entire surface of an object, then the effective sensitivity is much better for a given LoD. If the total amount of radioactivity that is measured by the averaging detector in this case is again X dpm, and the surface area of the object being measured is Y cm², then the measured value for comparison with release limits would now be $X (100/Y)$ dpm/100cm² and the LoD for the measurement becomes

$$\text{LoD}_{\text{measurement}} (\text{dpm}/100 \text{ cm}^2) = (100/Y) \text{LoD}_{\text{detector}} (\text{dpm}) \quad (\text{Eq. 6})$$

Thus the effective LoD of the measurement has been reduced by a factor of $Y/100$.

Again, a concrete example may clarify matters. If the surface area of a section of pipe is 3,000cm² and the release limit is 20 dpm/100 cm² **averaged** over the entire pipe, then the total limit as measured in a averaging detector is 600 dpm. Thus, the IonSens should be able to make this measurement in somewhat less than 300 s.

The inner area (Y) of a pipe that is L-cm long and D-cm in diameter is given by

$$Y = \pi LD. \quad (\text{Eq. 7})$$

Thus, for a pipe with a uniformly contaminated interior, the measured LoD is given by

$$\text{LoD}_{\text{measurement}} (\text{dpm}/100 \text{ cm}^2) = (100/\pi LD) \text{LoD}_{\text{detector}} (\text{dpm}). \quad (\text{Eq. 8})$$

The standard IonSens system can incorporate 1, 2, or 3 chamber modules; each 2-m in length. The IonSens is also specified to measure pipes from 5-cm to 15-cm in diameter. Figure 3 is a graph of the averaged detection limit (Eqn. 8) for three lengths of pipes in the specified diameter range.

Fig. 3. Effective LoD as a function of pipe diameter for "typical" pipe lengths of 180 cm (6 ft), 360 cm (12 ft), and 540 cm (18-ft) in an IonSens pipe monitor. This graph assumes that contamination is uniformly spread over the interior of the pipe and that the specified LoD for the IonSens is 450 dpm. The measurement time is 300-s.

The effective LoD as shown in Fig. 3 is very low for a measurement time of 300-s. If the contamination is averaged over a large pipe surface, a shorter measurement time may be appropriate. Figure 4 illustrated the effective LoD under the same conditions as Fig. 3, but using a measurement time of 100-s. This figure results from applying both Eq. 4 and Eq. 8 to the basic LoD of 450 dpm in 300 s.

Fig. 4. Effective LoD as a function of pipe diameter for “typical” pipe lengths of 180 cm (6 ft), 360 cm (12 ft), and 540 cm (18-ft) in an IonSens pipe monitor. This graph assumes that contamination is uniformly spread over the interior of the pipe and that the specified LoD for the IonSens is 450 dpm. The measurement time is 100-s.

RETURN ON INVESTMENT

A system such as the IonSens™ returns the initial cost of the system in two ways – **labor savings** for production surveys of items and **avoidance of disposal costs** for items with inaccessible contamination, which otherwise would require disposal as LLW.

Preliminary data on the performance of the IonSens™ is presented below. (6)

The rate at which pipe can be surveyed by the IonSens™ monitoring system is determined by the level of sensitivity required. The typical measurement time required to achieve a 95% confidence level is one minute. The "support" time (loading, unloading and data recording) required for each measurement is approximately three minutes. Comparing this rate of production with that of traditional hand surveys, the IonSens™ can produce monitored pipe at a rate that is a factor of ten higher than manual methods.

Table I illustrates a direct comparison of survey rates for the IonSens™ versus the rate achieved using the manual probe method. For the manual method, the probe is only effective over a width of approximately 2.5-cm due to the curvature of the pipe. Also, traditional survey methods could only be used on the exterior and ends of the pipes. The IonSens™ not only surveys both inside and outside surfaces in a single measurement, but also performs the survey on surfaces that are inaccessible to the manual probe.

Table I. Production Survey Rates for Manual Methods versus IonSens™. For these measurements, the pipes were 5-cm in diameter pipe and 180-cm long; thus, the total surface area of each pipe (both sides) was about 5600-cm². The labor rate is assumed to be \$40 per hour.

IonSens™		Hand-Held Probe	
Measurement Time -Electrical (s)	60	Scan Speed (cm/s)	1.0
Measurement Time – Total (s)	240	Scan Width (cm)	2.54
Monitoring Rate (cm ² /hr)	84,000	Monitoring Rate (cm ² /hr)	9,100
Labor Cost (\$/m ²)	\$4.80	Labor Cost (\$/m ²)	44.00

The full cost of an IonSens™ pipe monitoring system (including delivery, procedures and commissioning tests) is less than \$175,000. The labor cost data shown in Table I indicates that the system payback period is approximately 500 hours of operation, for pipe in 180-cm (6-ft) lengths.

The cost of disposal can be reduced by survey and release of the pipes that would otherwise require disposal as LLW, due to the inaccessible surfaces inside the pipe. Based on a disposal cost of \$40 per cubic foot, the payback period for disposal cost avoidance would be a reduction of 4375 cubic feet. A single IonSens™ monitor can survey this volume of pipe in approximately 1700 hours.

CONCLUSIONS

Average measurement systems, such as the IonSens pipe monitor, can be used extremely effectively in situations where the contamination can be assumed to be uniformly distributed over an entire object. In particular, the 20 dpm/100 cm² release limit for removable plutonium can be effectively monitored on reasonable sized pipes.

This measurement system can still be used effectively if the contamination must be assumed to be in one spot. However, in this case, plutonium contamination would have to be fixed so that the 500 dpm/100cm² limit would apply. This could be achieved by cleaning the pipe to remove loose contamination prior to monitoring. Either fixed or removable uranium could be effectively measured with the IonSens.

Systems such as the IonSensTM can be used as an effective part of an operating cost reduction program for health physics departments and waste minimization programs. The initial investment in an IonSensTM pipe monitoring system is repaid in less than one year of operations on pipe and similar objects.

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