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Title: Monitoring for Alpha Emitters in High-Airflow Environments

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REAL-TIME MONITORING FOR ALPHA EMITTERS IN HIGH-AIRFLOW ENVIRONMENTS

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ABSTRACT

Key problems in detecting alpha contamination for site characterization and decontamination and decommissioning that remain to be solved include measurement of airborne contamination, material holdup within pipes, and leakage of material containers. These problems are very difficult using traditional alpha detectors and systems. The ionization detection method (long-range alpha detection or LRAD) offers a number of specific advantages for these environmental measurements. An LRAD system detects the air molecules ionized by alpha-emitting contamination rather than the alpha particles. Thus, LRAD-based detectors are not limited by the short range of alpha particles and can be used to detect contamination anywhere that air can penetrate. Extending this technology to large enclosures or long pipes requires a system optimized for large airflows. In this paper we will present designs and preliminary results for high-volume flow-through air monitors based on the LRAD technique. In addition, we will discuss the behavior of the monitors and their potential applications.

I. INTRODUCTION

Several of the remaining hurdles faced in site characterization and decontamination and decommissioning involve the detection of small amounts of alpha-emitting contamination. The production of airborne contamination is a key issue for both personnel and environmental safety during remediation or decontamination. The presence of scale or holdup within pipes and process equipment must also be ascertained. In addition, containers of nuclear material and waste must be checked for leakage. Radioactive alpha-emitting gases such as radon can build up in storage facilities and escape into the environment. Traditional alpha detection technology often cannot do an adequate monitoring job in these situations. The ideal monitoring technology should be fast enough to contain costs but sensitive enough to ensure personnel safety and verify that radioactivity releases are within acceptable limits.

Common properties of many actinides create challenges for the design of monitoring instruments. The gamma- or X-rays emitted from many isotopes have small branching ratios and relatively low energies, and the density and atomic number of the material (to be monitored) itself can contribute a relatively large amount of self-absorption. Alpha radiation is usually emitted more often, but it is not as penetrating as the gamma radiation. The short range of the alpha particles (typically several centimeters in air) has traditionally hindered the use of alpha detection for contamination monitoring. For these reasons, the detection of small quantities of actinides on surfaces, objects, personnel, inside of pipes and ducts, and in other small volumes can push the envelope of traditional monitoring technologies.

Nuclear material or waste can also be detected via the ionization produced in air by collisions between emitted particles and air molecules. In a small volume of air, alpha particles are particularly well-suited to such ionization monitoring because of their short range and high rate of ionization. The mean energy expended by an alpha particle in a collision (with an air molecule) resulting in an ion pair is approximately 35 eV. Thus, the typical alpha particle emitted by an actinide nucleus, having ~ 5 MeV energy, will produce about 140,000 ion pairs. The electron liberated in an ionization quickly attaches to a neutral air molecule creating equal numbers of positive and negative ions. The ions are carried in air currents to an electrode, where a sensitive electrometer measures the resulting current from the half of the ions with the appropriate polarity. This technique is termed long-range alpha detection (LRAD).

Detecting 140,000 ions rather than a single alpha particle directly provides several benefits. The relatively slow recombination rate of ions in the diffuse ion cloud allows them to be collected from a substantial distance - at least several meters - compared with the range of a typical alpha particle of a few centimeters in air. A second advantage is that real-time measurements are possible. The presence of nuclear material or contamination usually produces many more ions than effectively result from background events and therefore the signal due to the contamination can be observed above background levels quickly. A final advantage is the good sensitivity that can be obtained even with a real-time measurement. In a traditional detector, either the alpha particle reaches the monitor and is detected or it does not. However, only some fraction of the 140,000 ion pairs must reach the LRAD-based monitor in order to register an alpha event. Thus, some ion losses can be tolerated in the system while retaining greater sensitivity than a direct alpha particle detector.

II. AIRFLOW IONIZATION MONITORS

Two techniques have been employed to transport the ions to collection electrodes. An electrostatic field can be used to collect the ions when monitoring the actinides on relatively flat surfaces such as soil,[1] concrete,[2] walls,[2] and liquids.[3] Very large areas (at least 1 m^2) can be monitored in a single measurement with a electrostatic detector. Alternatively, small surface monitors have also been deployed. Swipes can also be monitored to provide real-time monitoring capability on curved or contoured surfaces.[4]

The airflow ion collection technique[5] is more useful for objects or collections of objects, internal volumes, or air itself. Air flowing over an object collects all of the ions produced from alpha decay on any surface exposed to air and transports them to the measurement electrode. The whole object can be monitored simultaneously. Examples include hands or arms, hand tools, electronics modules, and rubble and scrap. Air flowing through an internal volume will similarly transport ionization from internal surfaces. Examples of this application include pipe and duct work, glove boxes, or cargo holds of vehicles.

Another type of airflow detector is useful for airborne contaminants. Three detection regimes exist for this system.

(1a) If a filter is placed in the air stream in front of the ion collection region, then the monitor is sensitive only to alpha emitters which pass through the filter and decay (emit an alpha particle) before passing through the grid. For an electrostatic filter, the ions normally present in the incoming air stream are removed and do not create a signal in the detector. In this regime, the monitor is sensitive to airborne contamination.

(1b) If the filter also removes airborne particulates, then the only alpha emitter that can enter the decay volume is the noble gas radon. Then the monitor is sensitive to the alpha decay of radon and its daughters. Radon detectors based on LRAD technology have been studied extensively.[6]

(2) If no filter is placed before the ion collection region, then the monitor is sensitive to all sources of ionization within the effective enclosed volume. Possible sources include radon, airborne contamination, contamination on the surfaces within the volume, particulates, and ambient ionization due to natural radiation. For example, for a detector placed directly on a pipe or glovebox, contaminants on the interior surface of the pipe or glovebox will be detected. On the other hand, a detector placed in the exhaust for a room or building will detect airborne- or surface contamination within that room (provided the contamination is within the range of the

detector as determined by ion cloud lifetime in the system).

A variant on the application of ionization monitoring in the third regime is created by the placing of a monitor within a volume to sample the air, as opposed to sampling the exhaust from a system. For example, such a monitor brought into a closed room (or the cargo hold of a vehicle, for example) will serve as a "sniffer" (if not left in the volume for continuous monitoring). This one-time monitoring of ambient ionization levels within a large volume can still indicate the presence of actinides or radon although it does not provide the time history of a continuous monitor.

At present, airflow monitors rely on ion collection grids perpendicular to the air flow. The single grid design incorporates a grid held at a potential of between 45 and 300 Vdc (depending upon the monitor). The signal is also taken from this single grid. In the double grid design, the signal is taken from a grid that is essentially at ground (Fig. 1). A second grid parallel to the first is held at the high voltage. The collection efficiency is somewhat reduced in this type of monitor because the electric field does not extend upstream of the first grid. But this confinement of the electric field also makes the response of the double grid monitor less dependent on the monitoring geometry. Moreover, the bias voltage is not superimposed on the output signal in these detectors.

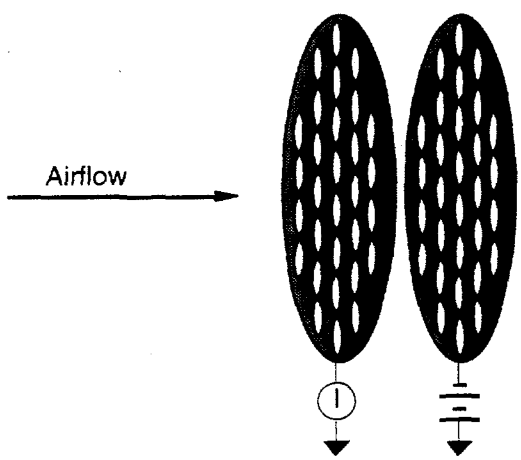

Fig. 1. Illustration of double perpendicular grid ion detector design. The air must pass through the holes in the grid structure.

III. HIGH-AIRFLOW MONITOR

In many of the applications mentioned above, large airflow is important - whether for increasing the speed of a one-time measurement, increasing the distance the ions can travel before recombination, or improving the sensitivity and response time of a continuous monitor. For an air monitor with no filter, at higher airspeeds the monitor is sensitive to a larger volume than at lower air speeds.

At higher air speeds, the perpendicular grid design operates poorly for at least 3 reasons; (1) the grids reduce the conductance (air flow) of the system, (2) the grids create turbulence in the air stream which increases ion losses, and (3) ions moving at high speed may pass right through the holes in the grids without impacting on the metallic surface (and contributing to the detected current. If the collection electrodes are parallel to the airflow, however, a solid plate can be used in place of the grid, and multiple plates can be operated in parallel, rather like venetian blinds (Fig. 2).

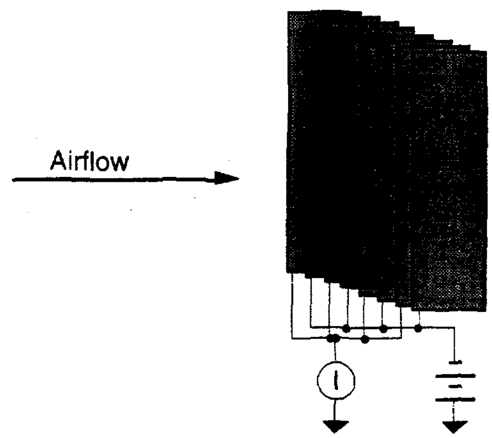

Fig. 2. Parallel plate (high air flow) ion detector. The airflow is much less restricted by this structure than by the grid structure shown in Fig. 1.

Plates parallel to the airflow have been found to permit much higher airspeeds. Figure 3 illustrates the difference in response of monitors with perpendicular grid and parallel plate electrode geometries.

The efficiency of the perpendicular grid detector reaches a maximum at about 100 cm/s and decreases at higher airspeeds. At low airspeed, the distance the ion cloud travels before complete neutralization is not large enough to get all of the ions produced to the collection plates so both grid geometries lose efficiency. In contrast, the ion collection efficiency of the parallel plate detector maintains high efficiency at high airspeeds.

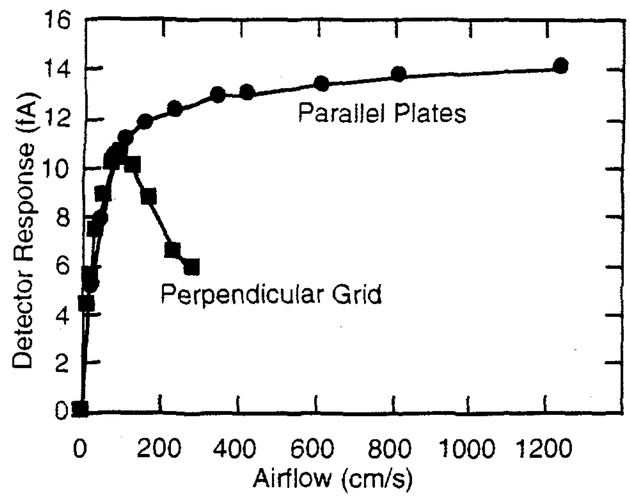

Fig. 3. Response of the perpendicular grid and parallel plate ion detectors as a function of airflow. A small Pu-239 source was located 61 cm. in front of each detector.

The conductance of the air is increased in the parallel plate design. Consider the case of air flow through a pipe. There will be some resistance (or inversely, conductance C) to the flow of air. In the pipe itself, the airspeed s is reduced to the effective airspeed, s_{eff}, via[7]

$$\frac{1}{s_{eff}} = \frac{1}{s} + \frac{1}{C} \quad (1)$$

The conductance of the pipe itself (C_p) is given in l/s by

$$C_p = 135\frac{d^4}{\ell}p \quad (2)$$

where d is the pipe inner diameter (cm), ℓ is the length of the pipe (in cm, assumed greater than $10d$), and p is the average pressure (in mbar) within the pipe. Placing an ionization monitor with conductance C_m within the pipe adds to the resistance of the system,

$$\frac{1}{C} = \frac{1}{C_p} + \frac{1}{C_m} \quad (3)$$

The perpendicular grid is akin to an aperture, with an effective opening given by the total open area due to all of the holes in the grid. The conductance C_m is a complex function of the pressure drops even for laminar, viscous flow[7], however, it is proportional to the area. The parallel plate monitor may instead be considered a very simple baffle. The conductance is much larger than for the perpendicular grid if plate thickness is much less than plate separation.

In a 10 cm diameter single grid airflow monitor, the ratio of open area to closed grid is 0.27. In a prototype 10 cm diameter parallel plate monitor, if the conductance C_m is also proportional to the open cross-sectional area, the ratio of open area is 0.94. Thus at least qualitatively, the latter should permit larger air speeds compared to the former given the same air driver or fan.

The efficiency of the collection plates is given by

$$\varepsilon_p = \frac{cV_pL}{FS^2}n \quad (4)$$

where c is a diffusion parameter of approximately 1 cm/sec / (V/cm), V_p is the voltage on alternate plates, L is the plate length, n is the number of plate pairs, F is the linear air speed, and S is the separation between adjacent plates. (This efficiency ε_p does not include the ion transport efficiency from the actinide through the particular geometry to the detection volume.) In the prototype, V_p = 300 Vdc, L = 10 cm, n = 7, and S = 1.5 cm. Thus ε_p is approximately 100%.

IV. APPLICATIONS

A. Pipe and Duct Monitoring

Pipes and ducts, both in operating facilities and facilities undergoing decontamination and decommissioning, have potential internal contamination or hold-up of process liquids and gases containing actinides. It is difficult to detect and localize such internal contamination with traditional alpha probes or by detecting gamma rays.

An ionization monitor appropriate to this application is an airflow monitor that is attached to the interval volume (i.e., the piping).[8] Air is drawn through the piping system via another opening (possibly with filtering) and exits through the monitor. Ion losses are due largely to interaction with the pipe walls rather than recombination within the pipe. Several sizes of piping, from 1.27 cm to 25 cm in diameter, have been tested using perpendicular grid ion detectors (see the contribution of MacArthur, et. al., to this conference).[9]

Monitors capable of higher airflow will increase the effectiveness of the ionization detection technique in long pipes. The data shown in Fig. 3. was taken with a prototype that was attached to 10 cm diameter pipe.

A closely related application is monitoring the inner surfaces of gloveboxes.[10] With increased airspeed, sensitivity to contamination on the remote surfaces of a glovebox may be increased.

B. Large Volume Monitoring

Surface contamination may occur within very large volumes such as cargo vehicles or enclosed rooms. In such cases it may be impractical to flush the entire volume with air (as done with pipes or gloveboxes). Instead, a monitor can be placed within the closed volume and ambient air drawn through the monitor. The signature of actinide contamination would be increased ambient ion density within the closed volume.

The appropriate airflow monitor for use in large volumes would have no filter. This monitor would detect the increased number of ambient ions as well as actual airborne actinides or radon. High airflows would permit greater sensitivity and/or shorter measurement times. A conceptual application to monitoring the cargo space in a vehicle is shown in Fig. 4. Alternative applications include train cars or aircraft cargo bays and other situations for which a monitor cannot be mounted permanently.[11]

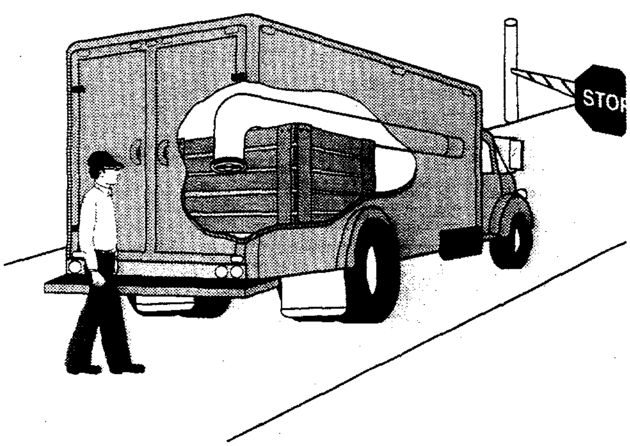

Fig. 4. Conceptual illustration of an LRAD-based vehicle monitor. The air inside the vehicle is recirculated through the ionization detector during a measurement.

C. Air Monitoring

Potential applications for air monitoring include (1) searching for increased ambient ion density due to surface contamination (described above), (2) monitoring air-borne contamination, and (3) tracking radioactive gases. As described earlier, airflow monitors suitable for use in these situations are respectively (1) filterless, (2) with electrostatic filters only, and (3) with both particulate and electrostatic filters. Advantages of airflow ionization monitors in general over other air monitors have been described in more detail elsewhere.[12]

A monitor for airborne contamination can be either portable (i.e. brought temporarily into the area to be sampled) or permanently attached to an exhaust port such as an emissions stack. In the former situation, higher airflow may permit faster measurement as it does for large-volume monitoring. In the latter situation, high airflow monitoring may be a requirement (depending upon the throughput and design of the particular stack).

In a ventilation system or stack with high air speed, the moving air can either be sampled or monitored in full. The drawback of sampling is that some assumptions must be made regarding the mixing efficiency in order to draw a conclusion on the level of actinides in the air as a whole. One drawback of monitoring the whole stack might be the decrease in throughput created by the presence of the monitor. Therefore, in many cases, the optimum solution is continuous monitoring of all air passing through a chokepoint or similar location in a ventilation system. The design of both the ion filter and the subsequent ion collection electrodes must address the need for optimum throughput. The prototype parallel plate monitor may have an optimum arrangement of the ion collection electrodes.

A radioactive gas monitor consists of a good particulate and electrostatic filter, followed by a decay volume, and then the ion collection electrodes. An increase in airflow will permit an increase in the sensitive detection volume and might provide a lowered detection limit. Radon monitoring systems using low or no airflow have been tested extensively.[13]

D. Debris Monitoring

A common problem in decontamination and decommissioning is the assay of debris. Such debris could include concrete rubble from demolished buildings, pieces of structural steel, or garbage. Such debris can be placed on a tray (or a conveyor belt for continuous monitoring) and air can be drawn through the debris and into an ionization monitor. Higher airspeed through the layer of debris can allow greater sensitivity to contamination near the bottom of the layer, perhaps resulting in shorter measurement time and subsequently larger throughput of debris. Of course, the airspeed will be limited depending upon the nature of the debris. Very high speeds could be applied to structural steel, less forceful air to dusty concrete rubble, and weak air flow in the extreme case of foam peanuts.

A monitor was fielded for tests of assay of munitions propellant potentially contaminated by uranium.[14] The propellant had the form of small cylindrical pellets and was poured into a layer. One conclusion of this work is that ions (produced by contamination present in the propellant) can be transported through at least 5 cm of such relatively closely-packed "debris". The increase in sensitivity with increased airspeed in shown in Fig. 5.

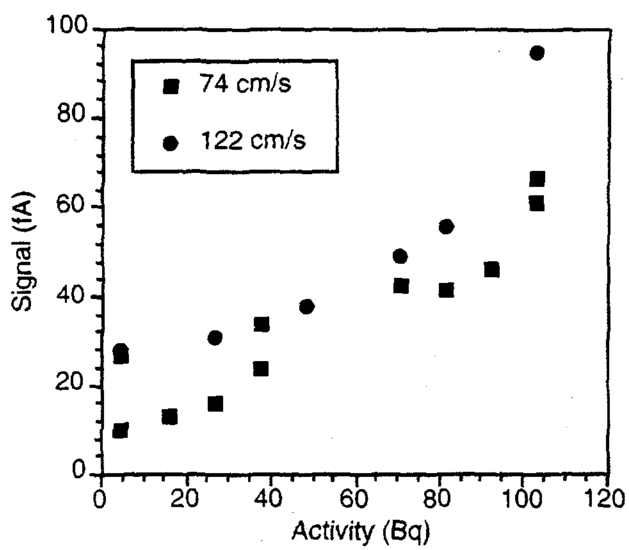

Fig. 5. Efficiency as a function of alpha activity in a measurement through 5 cm of propellant. Note that the efficiency is greater at the higher airspeed.

E. Personnel Monitoring

Effective, sensitive, and fast monitoring of personnel for actinide contamination is important in both facility and decontamination and decommissioning operations. Ionization detectors have been tested with perpendicular grid designs for both hand and arm monitoring.[15] In the relatively small volume needed for such monitoring, the capability for high airflow may not be important. In a related application, the whole body might be monitored simultaneously within an airflow booth. The much larger volume of such a booth will certainly require a larger flow of air in order to ensure adequate sensitivity to contamination anywhere on the person.

V. CONCLUSIONS

Many applications of ionization monitoring (or LRAD, when applied to alpha emitters) require or can be improved by using the high-airflow ion detectors described in this paper. The parallel plate ions detectors outperform the perpendicular grid models whenever long-distance ion transport is a requirement. Parallel plate detectors also improve the detection efficiency in situations where the ions may be captured prior to detection. Finally, the high-airflow detector is essential in situations (such as ventilation systems) where a high airflow is already present.

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