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AUTHOR(S): Duncan W. MacArthur, Krag S. Allander, John A. Bounds, Donald A. Close, and James L. McAtee

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LONG-RANGE ALPHA DETECTION APPLIED TO SOIL CONTAMINATION AND WASTE MONITORING

Duncan W. MacArthur, Krag S. Allander, John A. Bounds,
Donald A. Close, and James L. McAtee,
Los Alamos National Laboratory, Los Alamos, NM 87545

ABSTRACT

Alpha contamination monitoring has been traditionally limited by the short range of alpha particles in air and through detector windows. The long-range alpha detector (LRAD) described in this paper circumvents that limitation by detecting alpha-produced ions, rather than alpha particles directly. Since the LRAD is sensitive to all ions, it can monitor all contamination present on a large surface at one time. Because air is the "detector gas," the LRAD can detect contamination on any surface to which air can penetrate. We present data showing the sensitivity of LRAD detectors, as well as documenting their ability to detect alpha sources in previously unmonitorable locations, and verifying the ion lifetime. Specific designs and results for soil contamination and waste monitors are also included.

INTRODUCTION

Alpha contamination monitoring has been traditionally limited by the short range of alpha particles in air and through detector windows. All traditional alpha detectors use direct detection of alpha particles as illustrated in Fig. 1. The limitations of this technique have generally forced alpha monitors to be constructed with very thin windows and to be used in contact with the potentially contaminated object. At least four major problems with conventional alpha monitors can be traced to this range limitation.

Place Fig. 1 here

(1) Current alpha detectors cannot reliably achieve the sensitivity levels demanded by DOE and EPA regulations.
(2) Traditional alpha detectors, since they must be in close proximity to the contamination, are not sensitive to contamination in inaccessible areas, such as cracks in rocks or in loosely packed waste.
(3) These alpha detectors can only detect contamination located directly under the probe; large surfaces that are uniformly contaminated cannot be satisfactorily monitored.
(4) Scanning of large surfaces must be accomplished by hand, which varies greatly with the experience and mood of the scanner.

The long-range alpha detector (LRAD) detects alpha-produced ions rather than alpha particles directly. As an alpha particle looses energy in the air, it creates numerous electron/ion pairs. These charges can be transported for many meters in an air current. An ion detector located in the air current can detect the ions and, hence, the presence of alpha contamination.

The LRAD detector addresses all four of the concerns detailed above. Since the LRAD is sensitive to all ions, it can monitor the contamination on a large surface at one time. Because air is the "detector gas," the LRAD can detect contamination on any surface to which air can penetrate. In this paper, we present data establishing the sensitivity of LRAD detectors to 100- to 300-disintegrations-per-minute (dpm) sources, the LRAD's ability to detect alpha sources in previously unmonitorable locations, and verifying the ion lifetime. In addition, we present designs and preliminary results for soil sample contamination monitors, soil surface contamination monitors, and radioactive waste contamination monitors.

LRAD OPERATION

The long-range alpha detector (LRAD) illustrated in Fig. 2 is sensitive to the ionized air molecules produced by an alpha particle's passage, rather than to the alpha particle itself. The primary mechanism for alpha particle energy loss in the ambient air (and other gases) is ion pair production. In air, an alpha particle loses about 35 eV per ion pair produced; thus, a 5-MeV alpha particle will produce about 150,000 ion pairs as it loses energy in air. These charges can be transported by an air current into an ion detector located up to several meters away from the initial decay.

The energy loss for other common gases ranges from 26 to 43 eV per ion pair (1). Thus, the potential sensitivity gain offered by gases other than air is outweighed by the convenience of operation with ambient air, which does not require special gas handling with attendant environmental concerns.

Place Fig. 2 here

SMALL LRAD

The prototype monitor system based on a small LRAD detector is shown in Fig. 3. From left to right, this figure shows the input electrostatic filter, the sample chamber, a 17-cm connecting tube, and the ion detector and fan assembly. This monitor system has been exhaustively tested for many different applications including those discussed in this paper.

Place Fig. 3 here

Although the design and construction of the small LRAD detector and monitor are discussed in detail in Refs. 2-5; we include a brief discussion here for completeness. The ionized air molecules are drawn into the region between two grids by an air current. A 300-V battery creates an electric field between the grids that attracts one type of ion to the HV grid while pushing the other type onto the sense grid. Both polarities have been used with approximately equal sensitivity. The charge collected on the sense grid passes through a sensitive electrometer; thus, the number of ions and, hence, the number of alpha particles can be read directly. Other detector geometries are discussed in Ref. 6. The LRAD is sensitive only to the total ionization, no spectral or spatial information is produced.

Each of a series of nine small ^{239}Pu alpha sources (ranging from 100 to 1100 dpm) was inserted into the sample chamber for about 10 min. A 10-min period of background data was acquired between each source measurement. Figure 4 shows the response of the prototype LRAD detector to this series of sources. Figure 5 is a graph showing the strengths of all nine sources. In each case, the detected response rises to its maximum value in 1 min or less. The intrinsic transient response is much faster than this; the 1-min averaging time smooths out the final responses.

Place Fig. 4 here

Place Fig. 5 here

All of the source responses (including that produced by the 100-dpm source) are easily distinguished from the background. Figure 4 illustrates the raw data that were acquired by opening the sample chamber, placing the source inside, and closing the chamber. This sequence was repeated for every transition shown in Fig. 4, and created only one small transient at 170 min.

In this prototype, the LRAD (1) can reliably detect a 100-dpm source, (2) responds to all sources in less than a minute, and (3) is relatively immune to physical noise. All of these characteristics are essential in designing an alpha monitor for use in plant monitoring conditions.

We averaged the data points contained in each source response of Fig. 4. These averages and their standard deviations are plotted against the measured value of the alpha sources in Fig. 6. Both x and y error bars represent 1 std dev. This version of the LRAD has a very linear response to small alpha sources that extends to the background, indicating that arbitrarily small sources could be detected by increasing the averaging time..

Place Fig. 6 here

Although standard LRAD monitors use ambient air as a detection medium, to test the effect of changing humidity or airborne dust concentration, other gas mixtures are used in the LRAD. For the first series of tests, we used three different gas mixtures (ambient air; dry, filtered air; and dry, filtered nitrogen) and operated the LRAD with both positive and negative HV applied. The results of these tests are summarized in Fig. 5, which includes the detector response to a 1000-dpm alpha source, as well as a background measurement in each configuration. In general, all of the responses are remarkably similar, indicating that neither gas composition, airborne dust concentration, water content, or HV polarity has a significant effect on LRAD operation. We are investigating the effects of other gas mixtures and further humidity variations in a second series of tests.

LARGE LRAD

Several types of contamination monitors (such as small equipment, hand-held, soil core sample, liquid waste, radon, and small contaminated object monitors) are well suited to the small size and low airflow characteristics of the monitor described above. Other applications (such as personnel, clothing, soil sample, and solid waste monitors) require a much larger system LRAD similar to that shown in Fig. 7. Other than the much larger size of the sample chamber, the major change from the small LRAD configuration is that the electrostatic filter, the LRAD itself, and the fan manifold are all as large as the sample chamber, rather than the small (compared to the sample chamber) devices used in the original LRAD system.

Place Fig. 7 here

Figure 8 is a simplified schematic drawing of the large LRAD monitor showing the relationships between the electrostatic filter, the sample chamber, the LRAD detector, and the fan manifold. As in the smaller design, ambient air is drawn through the electrostatic filter to remove any ions or dust particles present outside the detector. Thus, any air ions detected in the LRAD were produced inside the sample chamber, presumably by radioactive contamination. Uniform airflow throughout the chamber is provided by twenty-four 8-cm-diam fans mounted in the fan manifold. Many small fans provide a more uniform airflow distribution across the sample chamber than a single larger fan.

Place Fig. 8 here

SOIL MONITORS

Although the small LRAD monitor could be used to measure small soil samples, a larger monitor (such as that shown in Figs. 7 and 8) or a specific soil monitor (such as shown in Fig. 9) will be more efficient. When used as a soil sample monitor, a sample of potentially contaminated soil would be distributed over the bottom of the sample chamber illustrated in Fig. 9. Air flowing over the soil would transport alpha-generated ions into the LRAD. A similar system employing an open-bottomed sample chamber could be used to monitor contamination on the soil surface without removing the soil. The entire monitor would be placed over the suspect area, and any air ions are drawn from the soil surface through the LRAD.

Place Fig. 9 here

Soil core samples could be quickly monitored with a system such as that illustrated in Fig. 10. In this case, air is drawn over the surface of a core sample, and any surface alpha contamination is detected by a LRAD. If the sample enclosure is fitted to the core sample size, the enclosed air volume is small, minimizing radon and cosmic-ray backgrounds. A small air volume could also be easily swept out by the single fan of the small LRAD system, making further detector development unnecessary.

Place Fig. 10 here

To be effective in soil monitoring applications, an alpha detector should be sensitive to distributed sources of contamination, as well as point sources. Figure 11 illustrates the response of the small LRAD monitor to a single 1000-dpm ^{239}Pu alpha source and to 4 separated sources. The separated sources were

100, 210, 290, and 370 dpm (also ^{239}Pu) located on the corners of a 5-cm square. As shown in Fig. 11, the distributed sources produce a similar response to the single source.

Place Fig. 11 here

SOLID WASTE MONITOR

Although the prototype LRAD monitor can be used as a solid waste monitor, a specific design can handle many of the waste transportation problems more efficiently. The solid waste monitor shown in Fig. 12 is a conceptual drawing of a LRAD waste monitor with a conveyer-belt waste-feed system. The results presented here were obtained using the small LRAD monitor, rather than one of the solid waste monitors described above. All of the results should transfer directly to a similar waste monitor.

Place Fig. 12 here

Solid waste normally contains objects that are impossible to monitor for alpha contamination using traditional methods (such as pieces of pipe, objects with convoluted surfaces, and small boxes). Figure 13 shows a set of five "mockups" of typical waste. The mockups are small enough to fit in our prototype monitor, but are otherwise typical of waste configurations. A 1000-dpm ^{239}Pu alpha source was placed in the center of each of these mockups. The response of the LRAD to the source was used to calculate the minimum source strength that would be detectable (with 99.9% certainty) in each configuration.

Place Fig. 13 here

Figure 14 shows these minimum detectable source strengths along with the minimum detectable bare source. Both the bare source and the source located on a tool head have a minimum detectable strength of ~150 dpm as anticipated from Fig. 4. Minimum detectable source strengths in the other configurations extend to ~350 dpm. These results indicate that a solid waste monitor would be sensitive to contamination levels of 300 to 500 dpm, independent of the configuration of the waste.

Place Fig. 14 here

LIQUID WASTE MONITOR

Two potential liquid waste monitoring systems are illustrated in Fig. 15. In either case, the potentially radioactive liquid is completely isolated from the outside air. Such waste monitors would be inserted in liquid waste lines at facilities concerned with possible alpha contamination. The LRAD-based waste monitor will react fast enough to enable the operator to divert the waste stream before any release to the environment. Since alpha particles have a much shorter range in liquid than in air, liquid waste monitors are designed so that as much liquid volume is exposed to the air as possible.

Place Fig. 15 here

In the simplest liquid waste monitor, shown conceptually in Fig. 15a, the waste stream is allowed to form a shallow pond in a large detection chamber. The liquid in this pond has a much larger surface area than the same liquid contained in a pipe. The air immediately above the surface of the liquid is drawn through an LRAD, where any alpha generated ions are then detected. This technique assumes adequate liquid mixing so that the surface layer of the liquid has the same composition as the bulk of the waste stream.

Another form of liquid waste monitor, shown in Fig. 15b, forces the liquid through a nozzle to form droplets. The liquid in droplet form again has a much larger surface area than the original waste stream. In this case, the air surrounding the droplets is drawn through an LRAD, where any alpha-generated ions are then detected. A nozzle-based monitor does not require previous liquid homogenization, but does raise questions about aerosol wastes.

OTHER APPLICATIONS

In addition to the soil and waste monitors discussed in this paper, the LRAD technique has potential applications in many other types of monitors for (1) object monitoring, (2) personnel monitoring, and (3) other environmental monitoring. The following paragraphs briefly explain a few of these applications.

Object Monitors

Many pieces of equipment and tools are either too large or too convoluted to monitor efficiently with conventional detectors, and equipment that has been used in a contaminated area is often classified as potentially contaminated and cannot be used in uncontrolled areas. The LRAD-based, hand-held and equipment monitors could be used to address this problem. Many parts of nuclear facilities, both operating and decommissioned, require alpha monitoring. Both the duct and pipe and tank and drum LRAD monitors are optimized for monitoring in locations that are difficult to reach with conventional detectors.

Equipment or hand tools are placed in the sample enclosure so the total contamination level can be detected by an LRAD. The monitor shown in Fig. 6 has been used as a small equipment monitor, but a larger sample chamber would be required for larger equipment.

Very large pieces of equipment that could not be moved into a sample chamber could be monitored using a hand-held LRAD monitor. In this application, a small portable vacuum cleaner would be used to pull ambient ions into an LRAD that would detect alpha contamination near the vacuum inlet. Extensive filtering would be required to prevent dust and other contaminants from entering the LRAD along with the ions.

If an LRAD with a fan is attached to one end of a pipe or duct and an ion filter is attached to the other end, then the inside surface could be monitored for alpha contamination. This monitoring method would not require physical intrusion into the pipe or duct, which might be undesirable (because of contamination) or impossible (in a small diameter pipe or duct). The airflow required by the LRAD is small enough that contaminated dust need not be blown into the atmosphere.

The tank and drum monitor is a variation on the pipe and duct monitor; however, in this case, access to the enclosed volume is only available at one end. Both the filtered-air inlet and the detected-air outlet must pass through a single opening. The inlet air is transported to the far end of the tank in an enclosed pipe so that the ion-collecting airflow passes over the entire inner surface of the tank

Personnel Monitors

Workers in nuclear production facilities must be routinely monitored for alpha contamination. Depending on the processes the worker has performed, either a hand and arm scan or a whole body scan is appropriate. Radiation workers and plant visitors routinely wear anti-contamination (anti-C) clothing to avoid the spread of contamination. This clothing cannot be efficiently monitored with current techniques.

A hand and arm monitor would be used after a worker has performed an operation in which only the hands and arms are potentially contaminated. Presently, hand and arm monitoring is accomplished with a flat detector, and it is difficult to ensure that all portions of the hand and arm are held in contact with the monitor. A large sample chamber would have two armholes with rubber sleeves mounted in its side. If this chamber were attached to an LRAD, the system would simultaneously collect all of the ions generated by a worker's hands and arms. Thus, the LRAD could detect contamination located on any part of the hands and arms.

If the sample enclosure were enlarged to the size of a telephone booth , an individual could step into the booth for an allotted time and have all body surfaces and clothing monitored simultaneously. Traditional techniques are only sensitive to small areas at a time and require scanning the detector over the body so that each part is only monitored for a few seconds.

After use, anti-C clothing is laundered and assumed to be free of contamination. There is currently no good way to check for contamination that remains on the clothing after laundering. If several items of clothing were hung in a large sample chamber, a single LRAD monitor could detect any ions generated on all of the items.

Environmental Monitors

Monitoring for contamination moving from nuclear facilities and radioactive spills into the environment is an ongoing problem. While the LRAD soil and waste monitors address some specific alpha monitoring problems, air quality, groundwater, and contaminated object monitors are also important in reducing public exposure.

The high sensitivity and flow-through nature of the LRAD make it an excellent candidate for monitoring atmospheric radon. Ambient air is drawn into a large sample chamber through an electrostatic filter that removes any ions already present in the air. Any radon decays inside the sample chamber create ions that can be detected by an LRAD ion detector. The sensitivity of the LRAD makes direct detection of radon concentrations possible in a few minutes, whereas traditional radon detection techniques often require weeks or months.

Controlling the alpha contamination released through a stack is an ongoing environmental concern. Chemically clean emissions could be routed through an LRAD directly, while a portion of dirty exhausts could be monitored to infer the total release.

Groundwater could be monitored with exactly the same hardware as liquid waste streams. The lack of volatile components in the water would enable the LRAD to achieve the greater sensitivity required for this application.

Often potentially contaminated objects, such as railroad ties or steel girders, could be released for public use if possible contamination questions could be answered. A specially sized sample chamber coupled with a standard LRAD detector would make alpha monitoring of such objects efficient and effective.

CONCLUSIONS

We have demonstrated that the LRAD-based alpha monitor is effective in solving many of the problems associated with traditional alpha monitors. Although more work is required, the LRAD monitors are relatively insensitive to atmospheric variations and have been effective in observing "real" contaminated objects as well as laboratory sources.

LRAD-based monitors are potentially very effective for a series of solid waste, liquid waste, and soil monitoring tasks. Our results and calculations indicate that the LRAD compares very favorably with traditional alpha monitors in these applications.

We have mentioned many other potential applications in the fields of object, personnel, and environmental monitoring. Although these applications have not been tested to the extent of the soil and waste monitors, they do apply the unique features of the LRAD detector to a wide range of current concerns.

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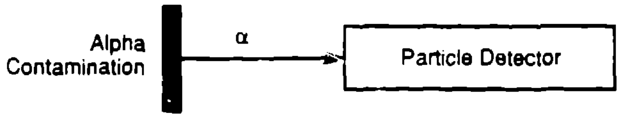

Fig. 1. Direct detection of alpha particles.

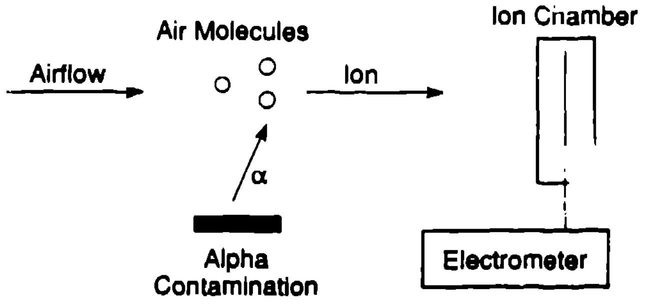

Fig. 2. Detection of air ions produced by alpha particles.

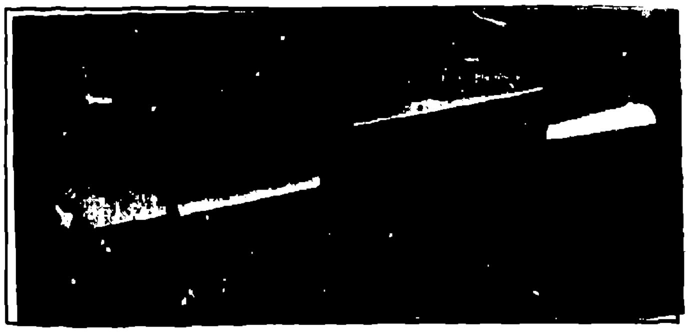

Fig. 3. Photograph of small LRAD-based monitor.

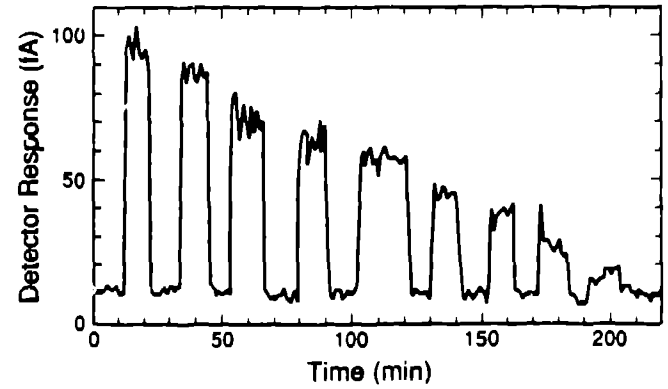

Fig. 4. LRAD response (from left to right) to 10 ^{239}Pu sources, ranging from 1100 to 100 dpm. All 10 source strengths can be read from Fig. 5.

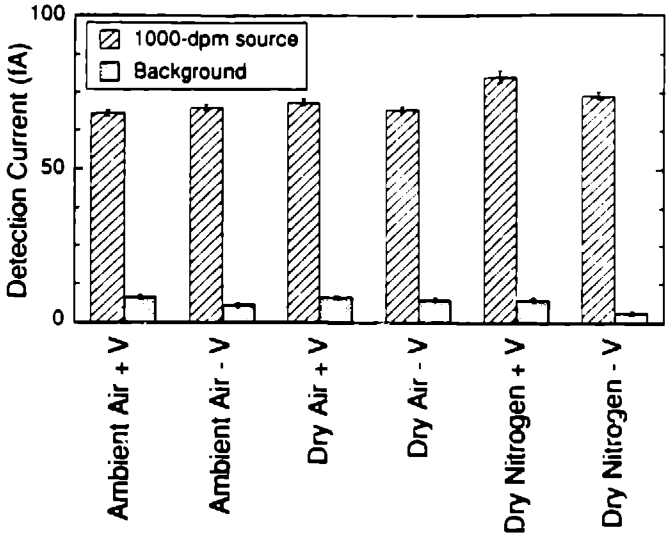

Fig. 5. Response of the LRAD detector operating with different gas mixtures and HV polarities.

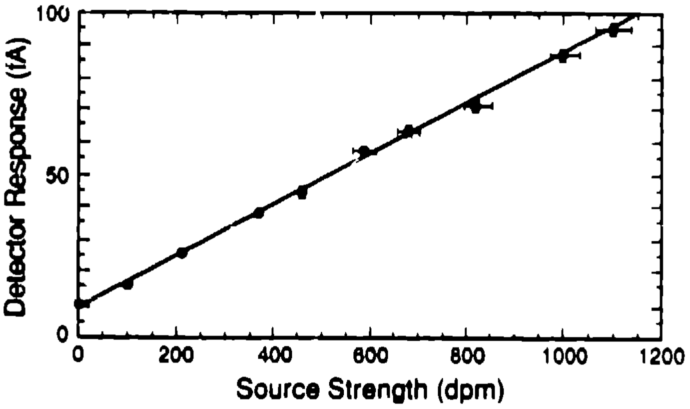

Fig. 6. Detector responses (source and background) of Fig. 4 analyzed and plotted as a function of source strength.

Fig. 7. Photograph of large LRAD fan manifold, detector, and sample chamber

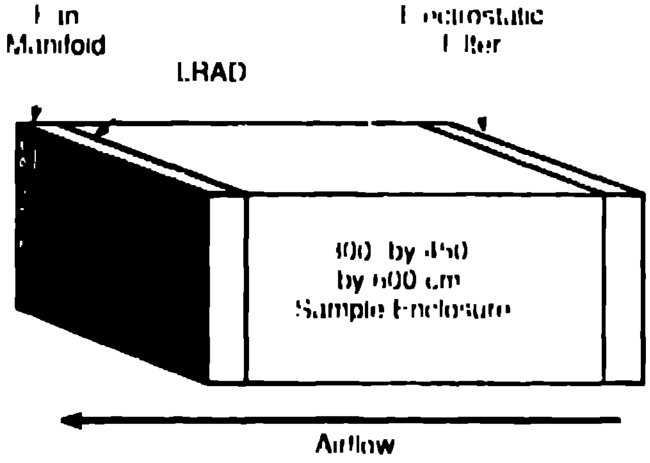

Fig. 8. Simplified drawing of large LRAD monitor system

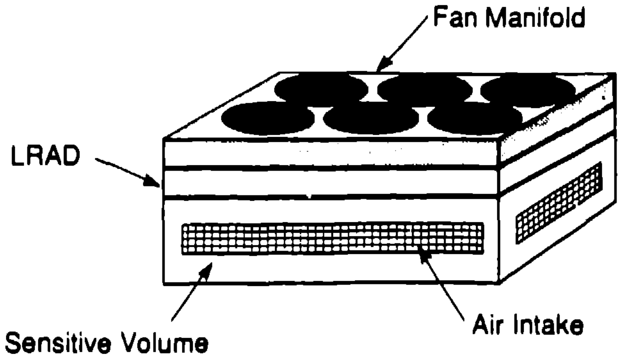

Fig. 9. Conceptual drawing of a soil monitor.

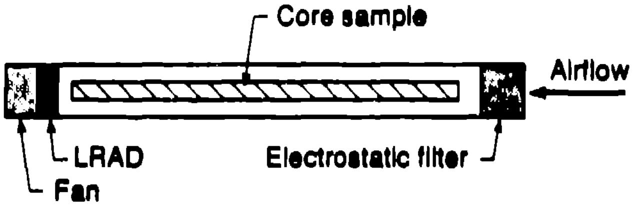

Fig. 10. Conceptual drawing of a core sample monitor.

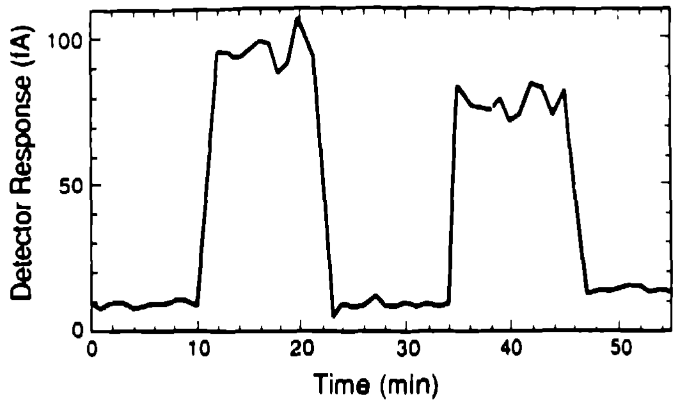

Fig. 11. Response of the small LRAD monitor to a single 1000-dpm alpha source (left peak) and to 4 spaced alpha sources totaling 970 dpm (right peak).

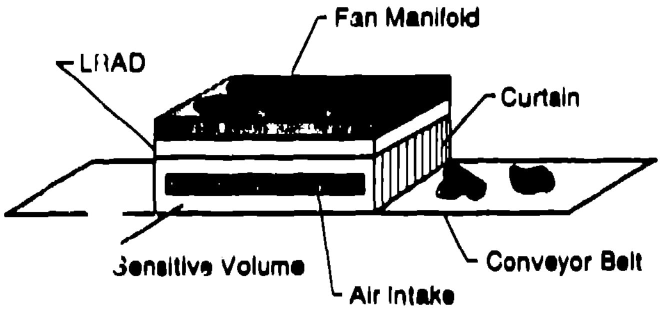

Fig. 12. Conceptual design of solid waste monitoring system.

Fig. 13. Photograph of five typical solid waste configurations. Starting in the upper left corner and moving clockwise, they are a piece of pipe, an aluminum channel, an aluminum "pig" with a 1/2-in. hole drilled through it, a small Pomona® box, and a hammer head.

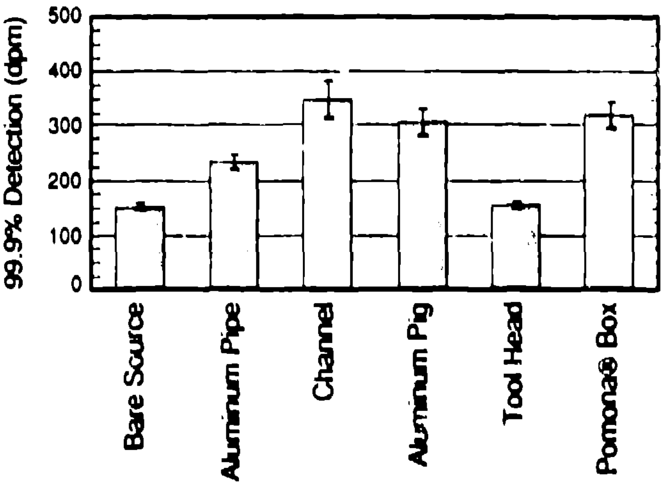

Fig. 14. Minimum detectable source strengths (with 99.9% certainty) in each of the five mockups illustrated in Fig. 13 as well as the minimum detectable bare source.

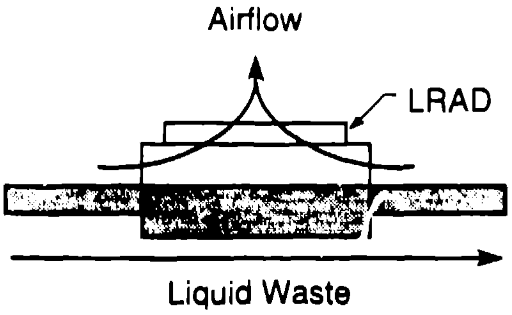

Fig. 15a. Conceptual drawing of a liquid waste monitor. In this design the waste stream flows through a large volume so that a large surface area is exposed to the air. The LRAD collects the air ions.

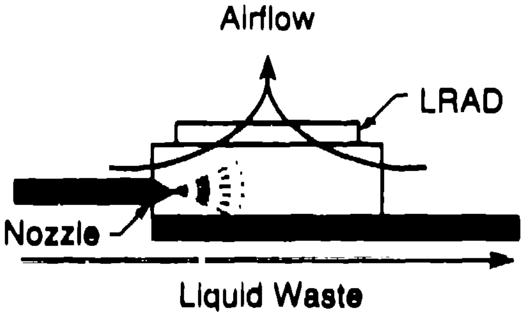

Fig. 15b. Conceptual drawing of a liquid waste monitor. In this design, the waste stream flows through a nozzle;a large surface area of the droplets is exposed to the air. The LRAD collects the air ions.