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TITLE Long-Range Alpha Detector (LRAD)

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Long-Range Alpha Detector (LRAD)

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Abstract

Historically, alpha detectors have been limited by the very short range of alpha particles in air and by relatively poor sensitivity, even if the particles are intercepted. Of necessity, these detectors are operated in a vacuum or in close proximity to the source if reasonable efficiency is desired. In our new long-range alpha detector (LRAD), alpha particles interact with the ambient air, producing ionization in the air at the rate of about 30,000 ion pairs per MeV of alpha energy. These charges can be transported over significant distances (several meters) in a moving current of air generated by a small fan. An ion chamber located in front of the fan measures the current carried by the moving ions. The LRAD-based monitor is more sensitive and more thorough than conventional monitors. We present current LRAD sensitivity limits and results, practical monitor designs, and proposed uses for LRAD monitors.

I. INTRODUCTION

Traditional alpha-contamination-monitoring techniques are severely limited by the relatively short range of alpha particles in air. To be effective, a traditional monitor must be held within a few centimeters or in contact with the surface being monitored. All traditional techniques rely on direct detection of alpha particles as illustrated in Fig. 1. The alpha particle itself must pass through the air and still have enough energy remaining to penetrate the detector.

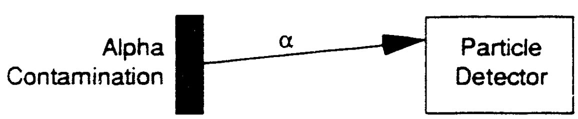

Fig. 1. Traditional alpha detection.

Direct alpha particle detection limits current alpha contamination monitors in at least four ways.

(1) Alpha particle detectors are only sensitive to contamination located directly under the detector probe. Surfaces larger than the probe must be monitored using several different measurements. If a quantitative result is required for surface contamination, the individual measurements must be summed to arrive at a final value. This technique is time consuming and imprecise. Also, if each individual reading is below the detection threshold for the particle detector, the sum will be meaningless. Large areas of low contamination cannot be monitored effectively using traditional techniques.

(2) Small alpha monitors are often scanned over large surfaces to monitor for contamination on the entire surface. This scanning is usually done by a person, so the efficiency of the scanning procedure depends on the skill of the scanner, the amount of time allotted for each scan, and the complexity of the surface to be monitored. Scanning by hand is not a mechanized process, so it is difficult to standardize the sensitivity of all scans.

(3) Because the detector must be placed close to the contamination, present alpha contamination monitors cannot detect contamination in confined spaces that are smaller than the detector itself. Research instruments can be built to fit inside any specified cavity, but the general-purpose devices used for contamination monitoring will not fit. If contamination monitors were made smaller to minimize this problem, the limitations discussed in (1) and (2) would be accentuated.

(4) Traditional alpha monitors are not sensitive enough to meet the new radiation monitoring requirements under all conditions. The monitoring technology has been developed to measure contamination of 1000 or more disintegrations per minute (dpm), rather than the few hundred disintegrations per minute that are required today.

The intrinsic limitations of standard alpha monitors have reduced or eliminated the development of many contamination monitoring systems that are presently in demand. Current requirements for environmental, personnel, equipment, and waste monitors exceed the capabilities of the direct detection technology.

II. 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[1]. 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[2].

[1] This work was supported by the US Department of Energy.

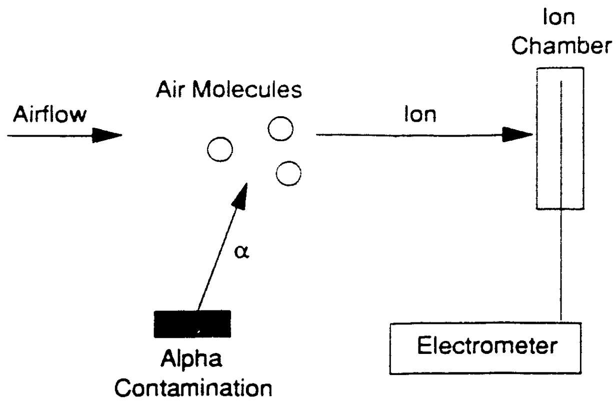

Fig. 2. LRAD alpha detector operation.

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. LRAD construction and initial test results are discussed in detail in Refs. [2] and [3]. Other LRAD geometries are possible and are documented elsewhere[4]. The prototype LRAD system is illustrated in Fig. 3.

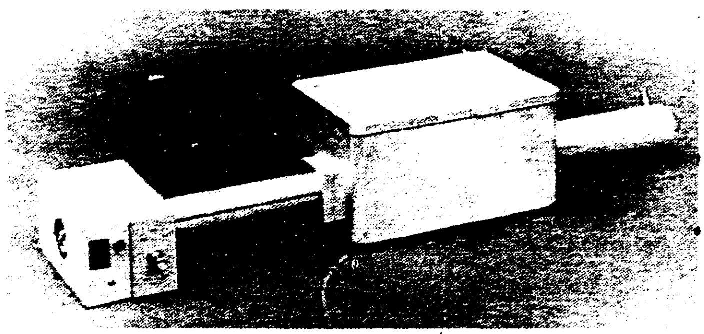

Fig. 3. Prototype LRAD alpha radiation monitor. From left to right, this figure shows the input electrostatic filter, the sample chamber, a 7-in. connecting tube, and the ion detector and fan assembly.

III. RESULTS

Since our preliminary scientific results have been published elsewhere[2,3], we will concentrate on recent results documenting LRAD sensitivity, response time, waste monitoring, and contamination control, because these results weigh more heavily in evaluating the LRAD's suitability for the applications proposed in Sec. IV.

A. Sensitivity and Response Time

The response of the prototype LRAD to 1000-dpm and 100–dpm ^{239}Pu sources is illustrated in Fig. 4. Each source was manually inserted and removed from the sample enclosure. The detector background was measured before, between, and after the source measurements. The LRAD responds clearly to both of these sources. The response time is < 1 min for the 1000-dpm source and 1 to 2 min for the 100-dpm source. Both the overall sensitivity and relatively rapid response times are important parameters in radiation contamination monitoring.

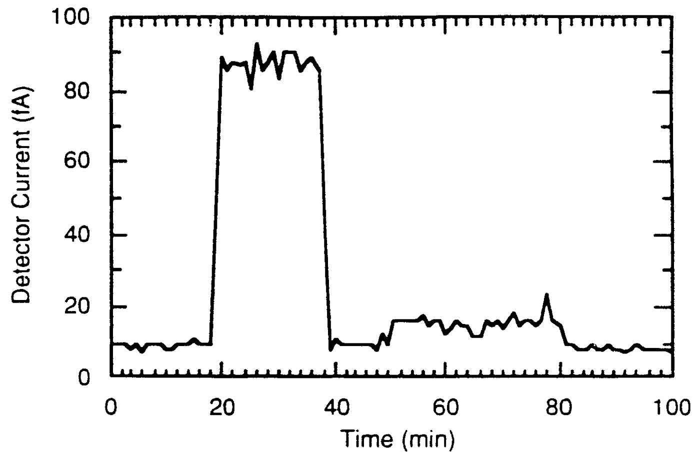

Fig. 4. Response (from left to right) of the LRAD to 1000-dpm and 100-dpm ^{239}Pu alpha sources. The detector response is averaged in one-minute intervals.

B. Solid Waste

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 5 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. Figure 6 shows these minimum detectable source strengths plotted along with the minimum detectable bare source.

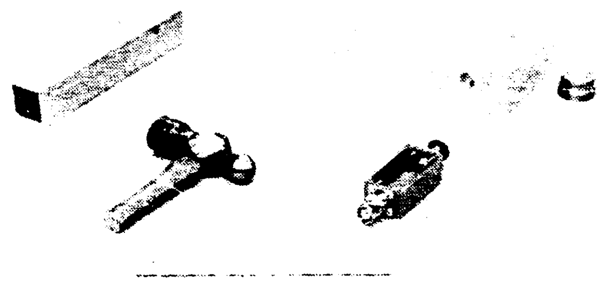

Fig. 5. Photograph of 5 typical waste configurations. Starting in the upper left corner and moving clockwise, they are a piece of pipe, an aluminum channel, an aluminum "pig" with a 1/2-in. hole drilled through it, a small Pomona® box, and a hammer head.

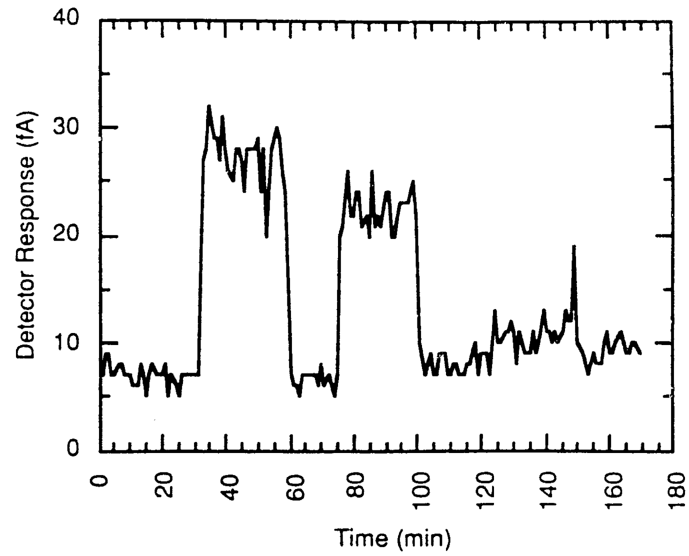

Fig. 7. Response of the LRAD system to a contaminated block (35-60 min); a 200-dpm ^{239}Pu source (75-100 min); and a relatively uncontaminated block (125-150 min). Removing the block caused the spike at 150 min. All regions between the measurements represent detector background.

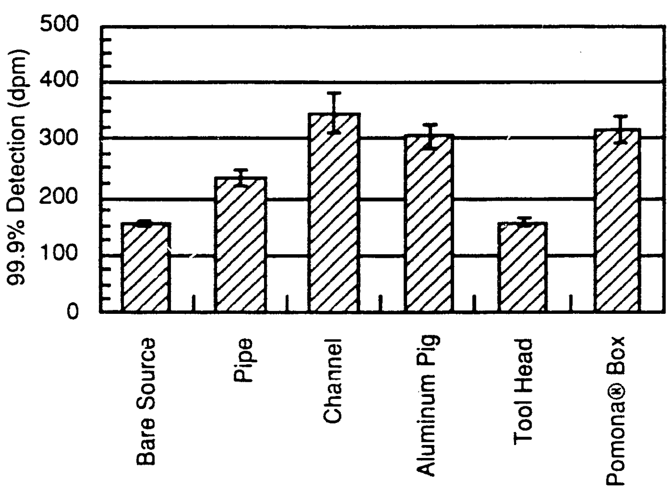

Fig. 6. Minimum detectable source strengths (with 99.9% certainty) in each of the five mockups illustrated in Fig. 5, as well as the minimum detectable bare source.

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.

C. Contamination

We have measured contamination with the LRAD system on the surfaces of a 2.5-cm by 2.5-cm by 5.1-cm tungsten carbide block. The results of this measurement, a 200-dpm reference measurement, and a measurement of a (relatively) uncontaminated block are shown in Fig. 7.

The data presented in Fig. 7 indicates that the total contamination on the five exposed sides of the block was ~300 dpm. In this case, the block was resting on the sixth face; in a final application, the contaminated object would rest on a screen so that the LRAD would be sensitive to contamination on the bottom as well.

When measured using a traditional hand-held alpha monitor, the contaminated block registered a barely detectable ≤ 100 dpm on each surface. The important feature is that the LRAD could distinguish the contaminated block in < 1 min, while traditional detection technologies took several hours. Thus, the LRAD can be used to scan a large number of objects quickly, and the contaminated ones can be set aside for more careful monitoring with other instruments.

The spectrum of the contamination, as measured with a surface barrier alpha spectrometer, is indicative of ^{238}U surface contamination. The contamination is too weak to make a more definitive measurement in a reasonable period of time.

IV. APPLICATIONS

A full discussion of every application would fill more space than is appropriate here, so we will briefly describe potential applications that take advantage of the strengths of the LRAD monitoring system. In all applications except for the radon monitor, the LRAD screening would be used as a fast and efficient method of separating the uncontaminated articles from the contaminated ones. Once contamination was detected, more thorough (and time-consuming) techniques would be used to determine the exact extent and type of contamination.

A. 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.

• Hand and Arm. A hand and arm monitor would be used after a worker has performed an operation in which only his or her 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, allowing the LRAD to detect contamination located on any part of the hands and arms.

• Whole Body. 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.

• Clothing. 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.

B. 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. 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. 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. 3 has been used as a small equipment monitor, but a larger sample chamber would be required for larger equipment.

• Hand Held. 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.

• Duct and Pipe. 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.

• Tank and Drum. This type of 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.

C. Environmental Monitors

Monitoring for contamination in the soil surrounding nuclear facilities and radioactive spills is an ongoing problem. LRAD soil sample, soil surface, and core sample monitors address some of the specific alpha monitoring problems associated with soil contamination. Indoor air quality, and particularly the presence of atmospheric radon, is a special concern for today's homeowners. In many ways, the LRAD is an ideally suited atmospheric radon detector.

• Soil Sample. A sample of soil, removed from its original location, could be spread in a thin layer on the bottom of an LRAD sample chamber. Ions generated by alpha contamination in the soil are collected in the LRAD ion detector. This method is sensitive to contamination in the entire sample, rather than just a small part of it.

• Soil Surface. In this variation of the soil monitor, the sample chamber is open on the bottom, and it is moved to the soil, rather than the soil being moved to it. The sample chamber is set on the soil surface, and all ions generated by surface contamination are collected in a single LRAD. The surface area that can be monitored in a given time is much larger with the LRAD than it is with conventional detectors.

• Core Sample. Soil core samples taken from potentially contaminated areas are often chemically analyzed to obtain an accurate analysis of the soil. Before shipment to the analysis laboratory, the core samples must be checked for surface radioactivity. An LRAD with a sample chamber designed to hold core samples would be ideal for this application because the entire surface of the sample can be monitored at one time, rather than requiring many separate measurements.

• Atmospheric Radon. The high sensitivity and flow-through nature of the LRAD make it an excellent candidate for monitoring 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.

D. Waste Monitors

All nuclear facilities generate large amounts of solid and liquid waste that are often classified as potentially contaminated because it cannot be monitored efficiently. Efficient waste monitoring would result in a significant decrease in the amount of stored radioactive waste.

- Solid Waste. Solid waste from nuclear facilities would be carried through an LRAD sample chamber by a conveyer belt or similar system. All of the ions generated by the waste would then be collected in an LRAD; thus, all of the surfaces of each article of the waste would be monitored simultaneously.
- Liquid Waste. Liquid waste streams could be exposed to the air in an enclosed tank, and the ions generated by the liquid waste would be collected in an LRAD ion detector. The response time of the LRAD is fast enough to divert contaminated liquid before it is released into the environment.

VI. CONCLUSIONS

Current Department of Energy, Environmental Protection Agency, and Occupational Safety and Health Agency regulations governing waste disposal, environmental contamination, and personnel monitoring have accentuated the need for new alpha monitoring technologies. We have presented a new alpha detector that is based on ion detection, rather than direct particle detection. Our results indicate that the LRAD technology is suitable for use in many types of alpha monitoring that were difficult to perform with traditional technologies.

VII. REFERENCES

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