Conf-950216--69

LA-UR- 95-174

Title:

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Submitted to:

Waste Management '95 Conference
Tucson, AZ
February 27 - March 3, 1995

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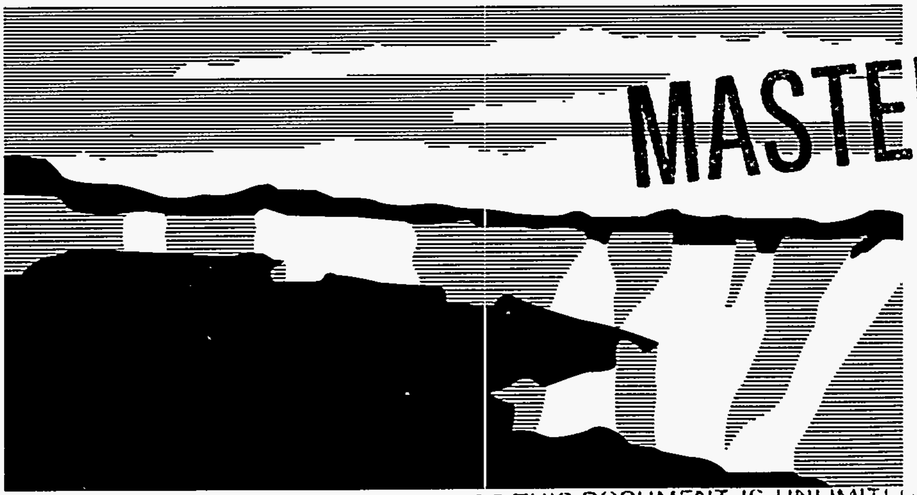

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ALPHA CHARACTERIZATION INSIDE PIPES USING ION-TRANSPORT TECHNOLOGY

S. P. Rojas, M. W. Rawool-Sullivan, K. G. Williams, and J. A. Vaccarella

ABSTRACT

Many DOE facilities have several miles of waste pipe systems that are internally contaminated with various and often undetermined radio nuclides. Unfortunately, currently acceptable alpha detection technologies are inefficient, time consuming, and do not address the problems presented by small diameter or curved pipes. In general, the problem of detecting alpha contamination on the inside surface of pipes is complicated by the fact that alphas do not penetrate the pipe walls. Unlike their conventional counterparts, alpha detectors based on ion transport technology sense alpha particles by collecting the ions created in ambient air as the particle loses its kinetic energy. The ions inside the pipe are transported by a fan-generated air current to an electrode inside the detector, which is attached to one end of the pipe. The collected charge at the electrode is proportional to the number of ions created inside the pipe, which in turn is proportional to the number of alphas emitted.

Typically, monitoring for alpha contamination inside pipes or ductwork involves disrupting the operation to access as much surface area as possible for standard alpha monitoring. The detector based on ion transport technology effectively minimizes such disruption and in many circumstances will allow for *in situ* monitoring of a system that might otherwise not be practically accessible to standard methods.

INTRODUCTION

According to a recent call for decontamination and decommissioning (D&D) proposals by DOE, “A method is needed for performing non-destructive, *in situ* measurements to detect radioactive contamination inside enclosed volumes. These volumes may include, but are not limited to, pipes, ducts and process equipment.” Currently acceptable technologies cannot address the problems presented by alpha contamination located in small-diameter pipes, complex process equipment, and inaccessible volumes. Yet every DOE facility has waste pipe systems or equipment or both that is internally contaminated with possibly undetermined radio nuclides. In addition, gaseous-diffusion plants, like the one at Oak Ridge, Tenn., will require significant internal radiological characterization of their process equipment. Clearly, some kind of internal volume monitor (IVM) is required.

Los Alamos National Laboratory (LANL) is currently developing various IVM detectors, based on ion transport technology,[1] which use airflow for ion collection. For such detectors, an air current (generated in the enclosed volume by an external fan) transports the ions to the electrode inside the IVM. The current that is measured is directly proportional to the number of ions (either positive or negative) in the enclosed volume which, in turn, is directly proportional to the total contamination level on the interior surfaces.

Understanding the relationship between the following six parameters is crucial to the future success of monitoring both large and small volumes with IVMs: ion lifetime, grid voltage, airflow, pipe geometry, and detector response. These parameters are empirically investigated in this paper for one specific IVM currently under development at LANL: the pipe IVM. This detector is designed to non-intrusively detect contamination in pipes and ducts ranging in size from less than 1 cm to greater than 1 m. Most gases can be used for ion transport so pipes and ducts filled with various gases, as well as with ambient air, can be monitored effectively. In addition, because ions can pass through almost any convolution in the pipe, complex plumbing can be readily monitored. This document summarizes the results from laboratory tests performed at LANL in 1994. Over this time, the relationship between the six parameters mentioned above was studied using a prototype pipe IVM.

EXPERIMENT SETUP

The basic mechanical components that constitute a pipe IVM include the grid and associated standoffs, a fan, a spacer to isolate turbulent back flow, and a filter. This hardware is assembled into a detector system and attached onto the end of a length of possibly contaminated pipe as shown in Fig. 1. A spacer filled with flow-straightening straws is required to prevent turbulent back drafts from the fan from affecting the collection of the ions at the grid and effectively lowering the response. A 3M Filtrete™ filter (G-100) at the end of the pipe opposite the detector is also necessary to prevent ions from the room from getting inside the pipe volume. (For stronger sources, such a filter was not necessary because of the large difference between detector response and ambient background.) The single-grid pipe monitor used for collecting the data presented here is shown in Fig. 2.

Two basic pipe IVM designs were tested: the single-grid IVM and the double-grid IVM. As shown in Fig. 2, the grids used for ion collection are basically perforated circular copper disks. For the single-grid design, the signal is taken directly off of the lone grid, to which a nominal 300 V is applied. In contrast, for the double-grid design, the ions are collected on one grid that is kept at ground while the other grid receives the 300 V necessary for sweeping ions onto the collection grid. In both cases, primary ion transport is accomplished by fan-generated airflow through the entire length of the pipe. Comparisons under like conditions (e.g., same airflow and pipe length) between the single-grid and double-grid designs yield a single-grid response that is approximately twice the double-grid response. (The pipe used for this test was 2 ft, or ~ 61 cm, long.) For this reason, the single-grid design was chosen as a benchmark for studying the relationships between response and voltage, airspeed, pipe geometry, and source strength. In addition, the single-grid pipe monitor was used to estimate ion lifetime and study the effect of pipe geometry and airflow on the lifetime of ions within the pipe.

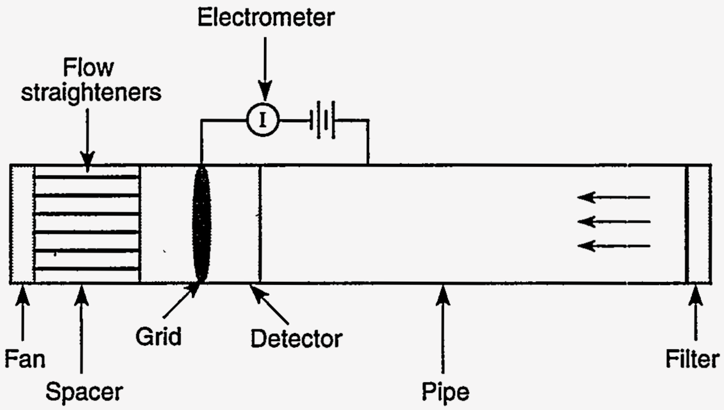

Figure 1. Schematic of the pipe monitoring test set-up.

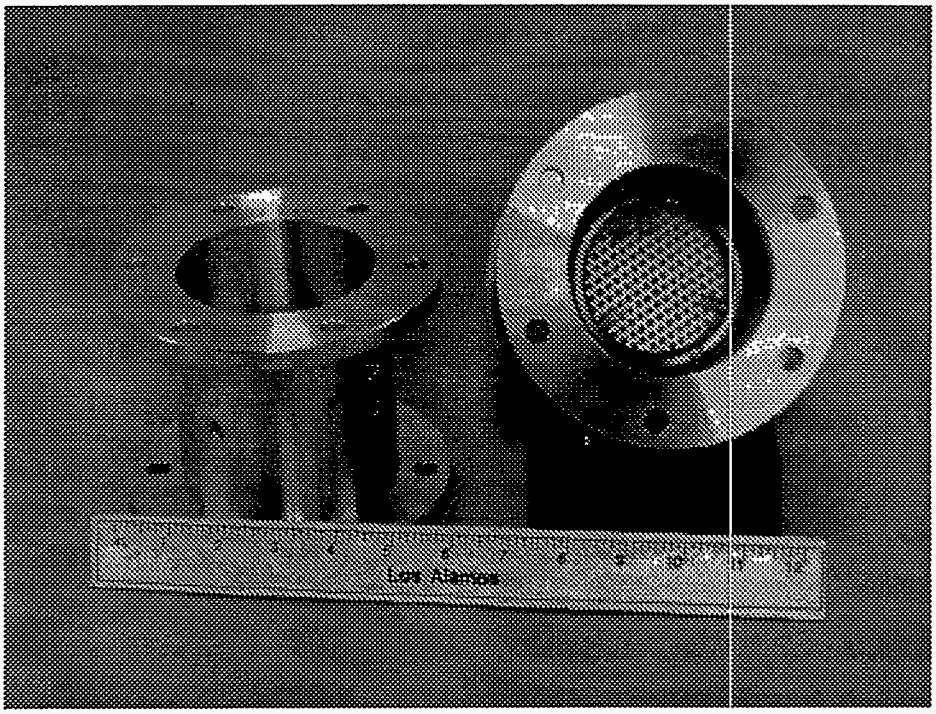

Figure 2. Photograph of the 3.5-in. (~ 9 cm) single-grid pipe monitor.

RESPONSE VS VOLTAGE

This test was performed using a 20-ft-(~600 cm) long straight pipe with the goal of determining the optimal voltage for ion collection. The schematic diagram of the experimental set-up is shown in Fig. 1. For this test we used a 217,642 dpm ^{238}Pu source and varied the voltage from 25 V to 1100 V. The airspeed at about 6 in. (~15.2 cm) from the grid was kept at a constant 180 fpm (.35 m^3/min) and the source was placed 18 ft (~548 cm) from the detector as the voltage was varied. Plotting response in fA ($1x10^{-15}$ A) vs voltage, yields a curve that plateaus at approximately 600 V. The experiment confirmed predictions that if voltage is too high, an unusable large signal results from grid-voltage-induced ionization. Traditionally, ion transport detectors have used 300-V batteries because they are commercially available; however, the test results indicate that the optimal voltage that does not ionize surrounding air, yet collects the ions efficiently, is approximately 600 V. This optimal voltage is a function of grid material and geometry.

RESPONSE VS SOURCE POSITION

This data was taken to see how the response from a given source varied as a function of the distance between the grid and the location of the source within the pipe. Figure 3 is one such data set, which clearly illustrates the powerful utility of ion transport technology. As shown in Fig. 3, a clear distinction can be made between a 1000 dpm source and a 2500 dpm source from a distance of 18 ft (~548 cm). Another feature that is apparent in this plot is that, as expected, the sensitivity is lower at 18 ft (~548 cm) than at 2 ft (~61 cm) corroborating the notion that most of the ion losses are caused by interactions with the walls of the pipe.

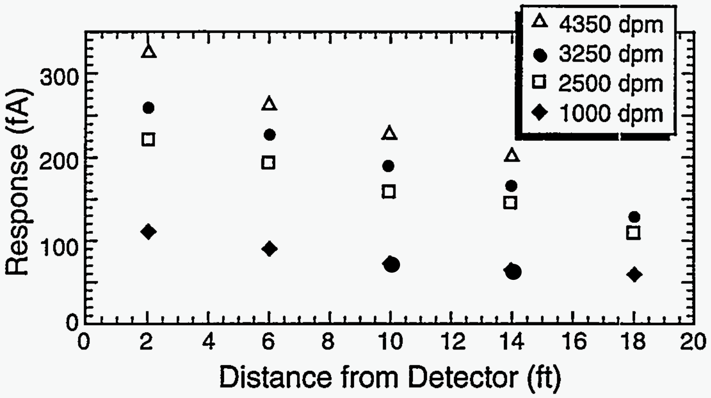

Figure 3. Response vs distance at various source strengths.

ION LIFETIME

Similar data involving detector response and source distance was taken using a 217,000 dpm source to calculate the lifetime of the ions. For our purposes, ion lifetime is defined as the time (distance/air speed) at which the response falls to half the value of the number of ions obtained when the source is placed directly next to the grid inside the pipe. For an airflow of 180 fpm (~.35 m^3/min), ion lifetime was calculated to be 8.4 s. Figure 4 shows one such plot of the ion lifetime and a fit obtained using the function

$$N = \frac{N_0}{\left[1 + \left(\frac{1}{\tau}\right) \times t\right]}$$

where N_0 is the initial number of ions, τ is the life time of the ions and t is the time. Ion lifetime varies as a function of air flow and pipe geometry. Initial experiments indicate that ion lifetime is also a strong function of the radial position of the source within the pipe. A source placed at the center line of the pipe will generate alpha particles that will last much longer than those generated from a source placed at the bottom or top of the pipe; a result which makes sense considering that the velocity profile inside the pipe is maximum at the centerline and minimum at the outer diameter walls.

RESPONSE VS AIRSPEED

For the next set of tests, the grid voltage and source strength were held constant and the airspeed was varied. Figure 5 shows one data set from these tests in which 300 V was applied to the grid using a 217,000 dpm ^{238}Pu source. As shown in Fig. 5, the highest airspeed used was 400 fpm while the highest response was obtained at a setting of 180 fpm (~0.35 m^3/min). This data seems to indicate that after a certain high velocity, the ions are simply getting swept through the grid without being detected. The previous data sets discussed have indicated that the probability of capturing an ion on the grid is proportional to airflow and applied voltage. The optimal value of each of these parameters has been determined using the single-grid pipe IVM. We suspect that response is also directly proportional to the grid surface area and that increasing the surface area will yield a higher optimal value for the airflow (and perhaps grid voltage). It is our thought that using a parallel plate "venetian blind" grid design will counter the effect of response degradation at higher airspeeds and also enable detection distances greater than 18 ft (~548 cm). Whether the surface area directly facing the flow ("wet" surface) or the total surface area in contact with the flow is of primary interest will be determined in future tests using the second prototype pipe IVM with a venetian blind grid. Experiments conducted using a monitor fitted with a parallel-plate, venetian blind grid design do indicate increased detection efficiency so application of the concept to pipe monitoring may prove very beneficial.

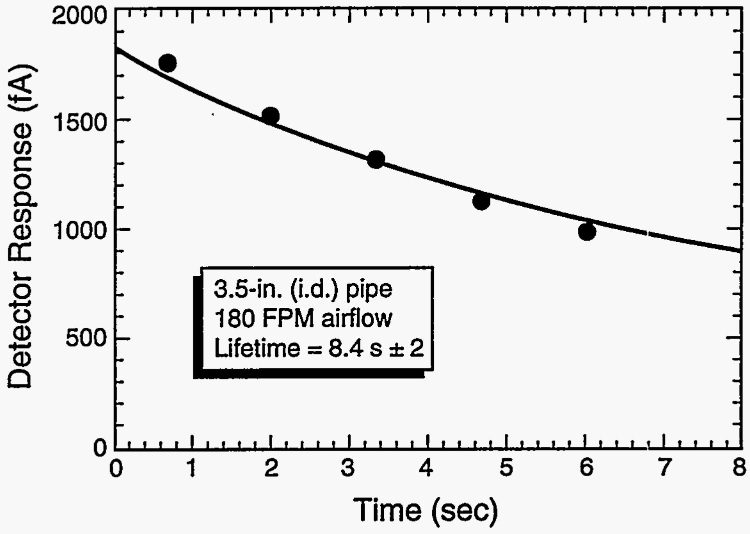

Figure 4. Ion lifetime within the pipe.

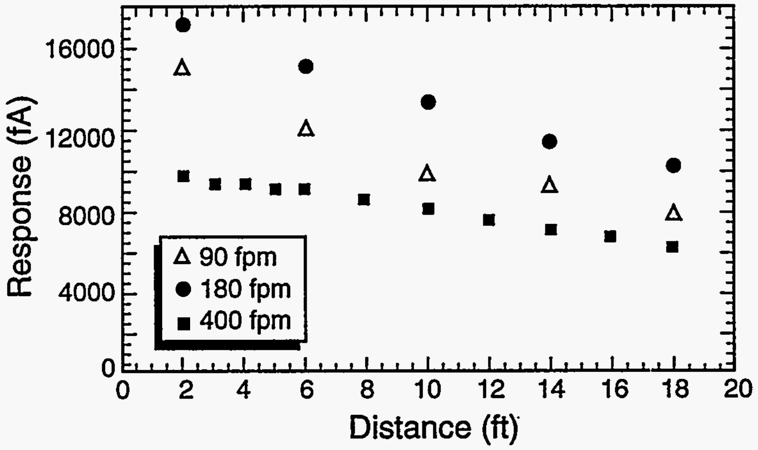

Figure 5. Response vs distance at various air speeds.

In another set of similar test runs we observed that there were ranges of velocity over which detector response was constant. This range was fairly wide at 2 ft (~61 cm) and narrower at 18 ft (~548 cm). This suggests that in the limit as source distance decreases to zero, primary ion transport is no longer from airflow, but rather from the electrostatic field around the grid.

RESPONSE VS PIPE GEOMETRY

The next set of data involved placing a 217,000 dpm ^{238}Pu source at four different positions along a pipe with a 90° bend in it. The pipe used was 4-ft long with a 90° bend in the middle and four holes drilled into it. The first and second holes, which were before the bend, were 1 ft (~30.5 cm) and 2 ft (~ 61 cm) away respectively. The third and fourth holes, which were after the 90° bend, were 2 ft 8 in. (~81.2 cm) and 4 ft (~122 cm) away from the detection grids respectively. A grid voltage of 300 V was used along with a 180-fpm (~.35 m^3/min) airspeed. A plot of response vs distance is shown in Fig. 6. The decrease in the response between 2 ft (~61 cm) and 2 ft 8 in. (81.2 cm) mainly comes from the increased distance between the detector and the source rather than the bend in between. This particular observation is crucial for facilitating monitoring in bent pipes or process equipment and suggests that such monitoring may be limited by the traditional parameters discussed earlier (e.g., airflow and grid voltage) rather than pipe geometry if laminar flow can be maintained in all sections. In other words, wall recombination effects do not appear to be any more significant in curved pipes than in straight pipes if laminar flow is achieved.

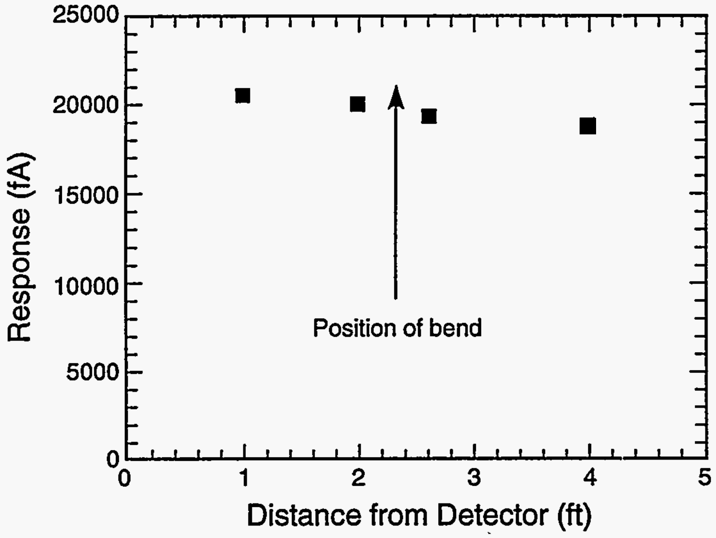

Figure 6. Response vs distance in a bent pipe.

FUTURE DIRECTIONS: SOURCE LOCALIZATION

We are entertaining two ways of localizing sources within pipes. The goal is to be able to pinpoint the location of a point source within a pipe. This may ultimately lead to the ability to detect large concentrations of accumulated material in a pipe containing an otherwise uniform distribution of contamination.

The first method attempted involved shuttering a source to determine the time for the signal to reach the grid. Knowing the airflow and measured time, we can then calculate the distance from the source to the grid. The accuracy of this measurement will depend on the time resolution of our data acquisition system and the accuracy of the airflow measurement. A simple proof of principle test using a fan and the pipe IVM was performed to investigate the ability to localize the position of a source inside a pipe. A ^{238}Pu source was placed at the end of the pipe and the time between source placement and signal observation was recorded. This time was then used to back-out the approximate position of the source in the pipe. The calculated distance of 16 ft compared very well with the actual distance of 20 ft considering the coarseness of the experiment. These results seem to suggest that with a more refined setup, source positions could be determined to within ± 2 ft using this preliminary method. Prior to conducting this experiment, a similar attempt was made at determining the source position by pulsing the fan at a very low airspeed (~170 fpm). The negative spike caused by pulsing the fan made it very difficult to see the negative signal caused by the source. If source localization is to be made field-ready, such problems will have to be addressed. Two possible solutions include digital signal processing of the grid signal to separate out fan effects from the actual source response or a double monitor configuration utilizing a detector at each end of the pipe. Such solutions will be investigated and the general feasibility of source localization with temporal data will be researched further.

The second method involves taking data from one end of the pipe and then moving the detector to the other end of the same pipe and taking data again. By looking at the responses at the two ends one should be able to tell at what section of the pipe the source is located. This particular method will localize contamination but it might pose practical drawbacks in real life. For example in some D&D scenarios the pipe might be accessible from only one end. Therefore we believe that further exploration into both methods of localization is quite necessary at this point. Also differences in the response from different ends of the pipes will vanish when we start using higher airflow with venetian blind designs for grids. Thus depending on the application we might want to retain a single-grid design for pipe monitors along with the pipe monitors with venetian blind grids.

CONCLUSIONS

In conclusion, with further development we believe that we can provide nondestructive, *in situ* and real time measurements for contamination within the pipes. A fully developed pipe monitor technology should be capable of characterizing pipes ranging in diameter from 1 cm to very large pipes. In addition to the straight pipe, we should be able to give reliable information on curved pipes. Moreover, localization of the contamination appears possible to some degree. It is important to note that the ion collection technique using airflow within pipes is the simplest case for detecting contamination within more general internal volumes. Other possible volumes include glove boxes[2] and truck trailers filled with cargo. (In fact, we are studying assay of glove boxes.) In addition the pipe monitors shown in Fig. 1 have been used to assay weapon cartridges.[3]

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