CONF-9510108--49

DOE/MC/30172-96/C0582

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Contract Number:

DE-AC21-93MC30172

Conference Title:

Environmental Technology Development Through Industry Partnership

Conference Location:

Morgantown, West Virginia

Conference Dates:

October 3-5, 1995

Conference Sponsor:

U.S. Department of Energy, Office of Environmental Management,
Morgantown Energy Technology Center

PI.4

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Abstract

Characterization of surface alpha emitting contamination inside enclosed spaces such as piping systems presents an interesting radiological measurement challenge. Detection of these alpha particles from the exterior of the pipe is impossible since the alpha particles are completely absorbed by the pipe wall. Traditional survey techniques, using hand-held instruments, simply can not be used effectively inside pipes. Science and Engineering Associates, Inc. is currently developing an enhancement to its Pipe Explorer™ system that will address this challenge.

The Pipe Explorer™ uses a unique sensor deployment method where an inverted tubular membrane is propagated through complex pipe runs via air pressure. The inversion process causes the membrane to fold out against the pipe wall, such that no part of the membrane drags along the pipe wall. This deployment methodology has been successfully demonstrated at several DOE sites to transport specially designed beta and gamma scintillation detectors into pipes ranging in length up to 250 ft.

The measurement methodology under development overcomes the limitations associated with conventional hand-held survey instruments by remotely emplacing an alpha scintillator in direct contact with the interior pipe surface over the entire length to be characterized. This is accomplished by incorporating a suitable scintillator into the otherwise clear membrane material. Alpha particles emitted from the interior pipe surface will intersect the membrane, resulting in the emission of light pulses from the scintillator. A photodetector, towed by the inverting membrane, is used to count these light pulses as a function of distance into the pipe, thereby producing a log of the surface alpha contamination levels. It is anticipated that the resulting system will be able to perform measurements in pipes as small as two inches in diameter, and several hundred feet in length.

This paper presents the design goals of the Pipe Explorer™ alpha detection system, the

Research sponsored by the U.S. Department of Energy's Morgantown Energy Technology Center, under contract DE-AC21-93MC30172 with Science and Engineering Associates, Inc., 6100 Uptown Blvd., NE, Albuquerque, NM 87110; telfax: 505-884-2991.

technical approach adopted, and preliminary laboratory test results.

Introduction

The DOE is currently decommissioning and dismantling many of its nuclear materials processing facilities that have been in use for several decades. When dismantling these facilities, the DOE must act conservatively to protect the workers and the general public from inadvertent exposure to residual radioactive materials. The DOE has established policies and guidelines governing the handling of radioactive materials to ensure that an appropriate level of conservatism is consistently applied. The DOE Radiological Control Manual[1] is the primary document that establishes acceptable practices for DOE radiological control activities.

In developing work plans for these decommissioning activities, it is necessary to identify those areas where residual radioactive contamination is likely to occur, and to characterize the actual contamination that will be encountered during the clean-up activities. Traditional health physics instrumentation and procedures can be employed in most circumstances to adequately characterize such radiological contamination.

Most of these facilities, however, have extensive networks of pipes and ducts that have been used to transport radioactive materials, either intentionally or inadvertently. In some instances the isotopes and their abundances are well known, while in other cases little, if any, such information is available. Where accurate information is lacking these systems must be characterized through some kind of measurement process. If the contamination includes isotopes with significant gamma emissions, traditional health physics instrumentation can be employed from the exterior of the pipe or duct work to adequately characterize the residual contamination.

In other cases the processes were such that the residual contamination may be composed of only alpha emitters. Alpha particles are very densely ionizing and thus do not penetrate most materials more than a few tens of microns. Therefore, it is not possible to detect the presence of alpha radiation from the exterior surface of the pipe or duct. So, direct measurements of surface alpha contamination must be made from the interior, where the alpha particles may interact directly with a detector. The very nature of the pipe or duct work restricts access by traditional instrumentation to the proximity of existing openings in the system. This makes it impossible to survey the entire interior surface, which must be accomplished if it is to be adequately characterized.

In addition to the outright cost savings associated with not having to pay for disposal of materials as if they were radioactively contaminated, there are ancillary benefits to conducting these types of characterization efforts. For example, if facility process knowledge indicates that alpha emitting contaminants may be present at hazardous levels inside a piping or duct system and these levels can not be refuted through a radiological survey, then the conservative approach dictates that the worst must be assumed. This means that the workers must wear a personal protective equipment (PPE) ensemble commensurate with the assumed potential for personnel contamination. This adds, unnecessarily, to the cost of performing the work (cost of PPE, support personnel, and lower productivity, increased volumes of secondary rad-waste), as well as increasing the risk from other hazards, such as heat stress, limited mobility and vision, etc. Adequate preliminary characterization of the system would allow a more efficient work plan to be developed, requiring the higher levels of PPE only when and where they are really needed.

Additionally, if adequate characterization methods are available, it is then possible to consider decontamination of the systems in-place. This can result in significant cost savings in those circumstances where extensive excavation is required to extract the system.

The inverting membrane deployment technology employed by the Pipe Explorer™ offers a unique method of carrying radiation detectors into pipes and duct work for the purposes of characterizing residual surface beta and gamma contamination. Incorporation of an alpha measurement capability will greatly enhance the overall utility of the system.

The primary components of the Pipe Explorer™ technology and its function are shown in Figure 1. The heart of the system is an air-tight membrane that is initially spooled inside a canister. The end of the membrane protruding out of the canister is folded over and clamped to the canister outlet, which is inserted into the open end of the pipe to be entered. By increasing the air pressure inside the canister by several pounds per square inch (PSI) the membrane is forced into the pipe, inverting upon itself and unspooling as it does. This process continues until the membrane is completely off the spool. This end of the membrane is sealed and attached to any of several different detectors, which is in turn connected to a tether/signal cable, also spooled inside the canister. As the membrane continues to invert, the detector and tether/signal cable are pulled into the pipe following the membrane. In this manner the detector may be towed into the pipe a distance equivalent to the membrane length. The detector and tether/signal cable are retrieved by reducing the canister pressure and winding the tether/signal cable back onto the spool.

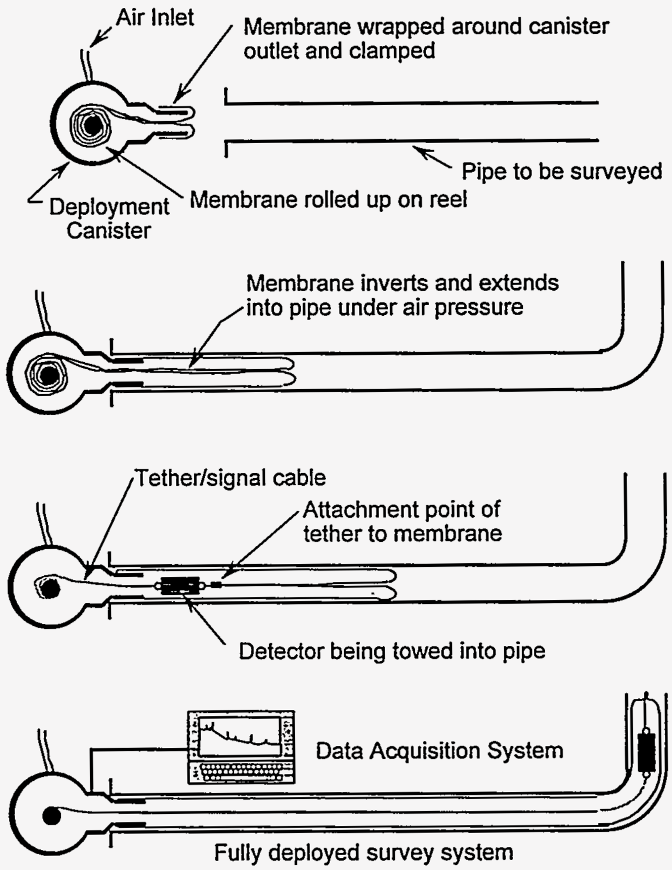

Figure 1. Sketch of the primary components of the Pipe Explorer™ system.

Objectives

The overall objective of this project is to extend the measurement capabilities of the Pipe Explorer™ to include characterization of interior surface alpha contamination of pipes and duct work. The completed enhancements to the system are expected to allow the following:

- Measurements of surface alpha contamination in pipes and ducts up to 250 ft. in length, and in a wide range of pipe diameters, 2-inch to 30-inch,
- Provide low minimum detectable activities for alpha emitters such as uranium, thorium and plutonium,
- Provide these measurements in a cost effective manner,
- Limit the potential for operator contamination to levels significantly lower than available with conventional techniques,
- Protect the detector and other expensive hardware components from potential contamination during the measurement process, and
- Limit the probability of the spread of contamination from the pipe or duct into surrounding areas.

Approach

The general approach taken for this project is to use existing, off-the-shelf, components and technology wherever possible to shorten the development time and reduce the development costs. To accomplish this and meet the performance objectives outlined above, the following technical approach to this measurement problem has been adopted.

A suitable scintillator material will be incorporated into the membrane. When such a membrane is deployed into a pipe it will be in intimate contact with the interior pipe wall, thereby placing the scintillator material into an ideal geometry with the potential surface contamination. Any alpha particles leaving the pipe wall will intersect the membrane and its incorporated scintillator. The interaction of the alpha particle and the scintillator will produce a small light pulse that is measurable by a sensitive photodetector, such as a photomultiplier tube (PMT). The PMT, equipped with a suitable light gathering fixture, will be towed down the pipe by the scintillating membrane as it inverts. This will allow a direct measure of surface alpha activity as a function of distance into the pipe.

The Scintillator - The scintillator must exhibit the following characteristics:

- Have a high light output (large number of photons emitted per alpha particle),
- Exhibit a good spectral match with existing high sensitivity photodetectors,
- Be relatively inexpensive,
- Be easily incorporated into a thermoplastic, such as polyethylene, and
- Must not be a hazardous material.

The high light output and spectral match are attributes that contribute to a high signal/noise ratio, which increases the sensitivity and reduces the minimum detectable activity (MDA) of the system. It is necessary to keep the cost of the membrane as low as possible, because the membrane will have to be disposable. Additionally, because the membrane will likely become contaminated, no hazardous materials can be used in its fabrication that would result in contaminated membrane material being considered a mixed-waste.

The Photodetector - The photodetector must have the following characteristics:

- High sensitivity and high signal/noise ratio,
- Good spectral match to the scintillator,
- Available in a variety of sizes, including one small enough to fit into 2-inch pipes,
- Good temperature characteristics, and
- Moderate tolerance to shock and vibration

The photodetector sensitivity, signal/noise ratio, and spectral match contribute to reducing the MDA of the system. Size of the detector is an important consideration given that many of the piping systems requiring characterization will be 2-inch. In order for the detector package to negotiate 90 degree bends, both the length and the diameter must be minimal. Measurements will likely be conducted in a variety of temperature environments ranging from stable indoor temperatures to the normal temperature extremes found outdoors. The photodetector must be capable of operating over these temperature ranges, as well as exhibiting a low temperature dependence of its response characteristics. And finally, the process of deploying a detector into a piping system requires that it be moderately resistant to the shocks that it will encounter negotiating the various bends and obstructions to be found in pipe systems and duct work.

The Light Gathering Fixture - The light gathering fixture must:

- Exhibit high efficiency in coupling the scintillator emissions to the photodetector,
- Be compact enough to fit into 2-inch pipes.

Due to the geometric arrangement of the scintillator and photodetector, it will be necessary to employ some kind of light gathering fixture. Figure 3 shows the basic arrangement of the scintillator, photodetector, and a light gathering fixture. This light gathering fixture must poses two main attributes. First, it must define a length segment of the pipe in which it gathers photons from scintillation events with a high efficiency, and correspondingly excludes light from adjacent sections of the pipe. Secondly, the fixture must not render the detector package so large as to be unable to negotiate the anticipated bends and obstructions.

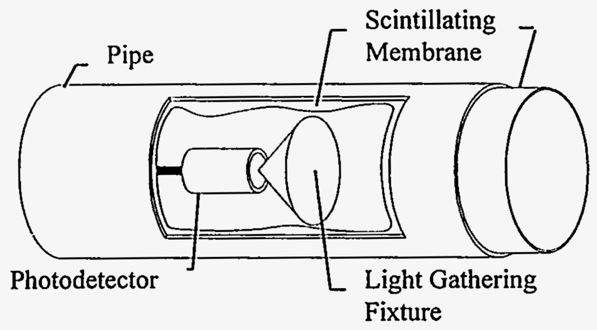

Figure 2. Sketch showing the arrangement of the photodetector, scintillating membrane, and light collection fixture.

Project Description

Two phases are planned for this project. Phase I will include development and laboratory testing of the prototype system. Phase II will include acquisition of membrane materials and field demonstrations. These two phases have been broken down into the following technical tasks. Tables 1 and 2 show the generalized schedule for Phase I and Phase II, respectively.

Phase I - Feasibility Evaluation

Task 1: Evaluate Scintillators/Photodetectors

The first task to be undertaken is to determine the best scintillator/photodetector combination for the alpha detection system from the available scintillators and photodetectors. The criteria outlined above will be used in this selection process. In general more weight will be given to selection of the scintillator rather than the photodetector, because the performance characteristics exhibit greater variability for the

Table 1
Schedule of Tasks for Phase I
Prototype Design and Evaluation

	Task Description	1995						1996				
		Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
1	Evaluate Scintillators/ Photodetectors	●	—	—	●							
2	Test Scintillator/Photodetector Combination					●	●					
3	Integrate and Test with Pipe Explorer™							●	—	—	—	●

Table 2
Schedule of Tasks for Phase II
Site Demonstrations

	Task Description	1996					1997								
		Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
4	Membrane Acquisition and Testing		●	—	—	—	—	●							
5	Site Demonstrations								●	—	—	—	—	●	

available scintillators than for the photodetectors under consideration. Samples of the scintillator material will be obtained, as well as a photodetector and any support electronics required.

Task 2: Test Scintillator/Photodetector Combination

The next task will focus on an evaluation of the scintillator/photodetector combination selected in the first task. A key element of the evaluation process is the ease with which the scintillator can be joined with the membrane material, and what the physical and scintillation properties of the resulting membrane are. An attempt will be made to fabricate a series of test samples in which various amounts of scintillator are incorporated into a thermoplastic resin. The resulting test membrane samples will be evaluated for their strength properties and scintillation characteristics. In the event that this simple admixing of scintillator and resin does not produce a membrane with acceptable characteristics, a more complex and therefore more expensive, means of incorporating a scintillator rich layer into the membrane will be evaluated.

Task 3: Integrate and Test with Pipe Explorer™

This will be the final technical task necessary to complete Phase I of the project. The individual components will be integrated with the existing Pipe Explorer™ hardware to form a complete measurement capability. A principal component of this task will be to develop a feasible approach for the light gathering fixture. The approach must allow for measurements in a variety of pipe and duct diameters. It may be necessary to develop more than one type of fixture/photodetector combination to cover the target range of diameters. The tether/signal cabling and associated electronic components will be adapted to integrate the photodetector/light gathering fixture(s). A calibration of the system response to surface alpha activity will be conducted for a variety of different pipe sizes. Several different sizes of the prototype scintillating membrane will be fabricated for use in laboratory tests of the integrated system with a range of pipe diameters. These tests will focus on the overall utility of the alpha measurement capability, and will be conducted using a plated Am-241 alpha source located at various positions along test pipe mock-ups. The results of these laboratory tests will be compiled and interpreted to establish the basic operation parameters of the measurement capability. This information will then be used to evaluate the cost effectiveness of the alpha measurement capability. A Phase I report and DOE review of the technology will occur at this point.

Phase II - Site Demonstrations

Task 4: Membrane Acquisition and Testing

Having identified the appropriate materials and fabrication methodology for the scintillating membrane in Phase I, this task will focus on identifying a manufacturer for the membranes. Once an appropriate manufacturer has been identified, a few standard sizes of the prototype membrane material will be procured in production quantities (e.g., 1,000 foot rolls). Following receipt of the membrane materials they will be evaluated for consistency in their scintillation and strength characteristics. Additional laboratory tests of the performance with the production materials will be performed. MDA levels, and deployment rates predicted from the Phase I testing will be confirmed.

Task 5: Site Demonstrations

Once the production membranes have been adequately tested, and the appropriate operational parameters have been established, the alpha measurement capability of the Pipe Explorer™ will be ready to demonstrate at DOE sites. The initial site selection process will be initiated concurrent with the early stages of Phase I activities. Efforts will be made to locate sites that have an identified need for radiological characterization in either piping systems or duct work, so that the demonstration will serve not only to demonstrate the alpha measurement capability, but also to provide genuinely useful information to the site.

Once the sites for the field demonstrations have been determined, the process of planning the demonstrations may begin. This planning process will involve close coordination with project personnel at the sites to develop detailed test plans. These test plans will include the normal logistical coordination, delineate areas of responsibility, and develop measurement objectives. It is anticipated that two field demonstrations will be conducted at separate DOE sites. It is hoped that each site would posses distinctively different types of pipe systems or duct work with different contaminant situations in which the alpha measurement capabilities of the Pipe Explorer™ could be exercised. A final report will be prepared that includes the measurement results from the field demonstrations as well as cost-benefit analyses.

Accomplishments

Since the start date of July 1995, the following progress has been made toward meeting the technical objectives of this project. Silver activated zinc sulfide, ZnS(Ag), has been selected as the scintillator material. Of the available materials that are characterized for their alpha scintillation properties, ZnS(Ag) exhibits one of the highest light outputs available. It has been widely used for many years as the alpha scintillator of choice, and therefore its behavior is well known. It is a non-toxic, non-hazardous material that is also routinely used as an electronic phosphor. Because of the large volumes of this material produced for the electronics industry, it is available at a reasonable cost (approximately $28/lb.) in large quantities. Moreover the industrial grade of ZnS (without the silver activator) is widely used as a coloring agent in polyethylene plastics. So there is a high degree of confidence that the electronic phosphor form can be easily incorporated into a standard low density polyethylene plastic suitable for blown film production.

Two types of photodetectors were considered for this application, photomultiplier tubes (PMTs) and avalanche photodiodes (APDs). A PMT equipped with a bialkali photocathode has been selected as the photodetector type. This selection was made for several reasons, but sensitivity was among the most significant. By selecting a higher sensitivity scintillator/photodetector combination the design requirements of the light gathering fixture are significantly eased.

In general the PMT is still the most sensitive photodetector available. The spectral response of a bialkali photocathode exhibits an almost ideal match to the emission spectrum of ZnS(Ag), thereby maximizing the overall sensitivity available from the scintillator/photodetector combination. APDs exhibit their highest sensitivity at much longer wavelengths, requiring a scintillator emitting in the red region to maximize their sensitivity. Additionally APDs exhibit significantly higher noise levels than PMTs, which for the low light levels that will be encountered in this application, result in poor signal/noise ratios. Another undesirable feature of APDs is the temperature dependence of both the dark current and the internal gain. While this can be overcome by the use of a thermoelectric cooler, this adds unnecessarily to the complexity and bulk of the detector package. Although the APD is inherently more rugged than the PMT, ruggedized versions of a variety of different sized PMTs are available.

An ultra-compact photosensor package, incorporating a metal channel PMT, with a bialkali photocathode, and support electronics has been purchased and set-up. Laboratory tests to evaluate the performance of the photosensor package have been initiated. This photosensor package is easily capable of being deployed into 2-inch pipe.

Four test samples of a low density polyethylene (LDPE) with varying amounts of ZnS(Ag) incorporated have been prepared. The ZnS(Ag) concentrations range up to what is thought to be the maximum practical abundance that can be achieved and still allow the material to be fabricated into a blown film. Currently, tests are underway to characterize the scintillation and strength properties of these test samples. Figure 3 shows a pulse height distribution of an AM-241 alpha source obtained with the ultra-compact photosensor and one of the test samples. The source activity was approximately 1 microcurie.

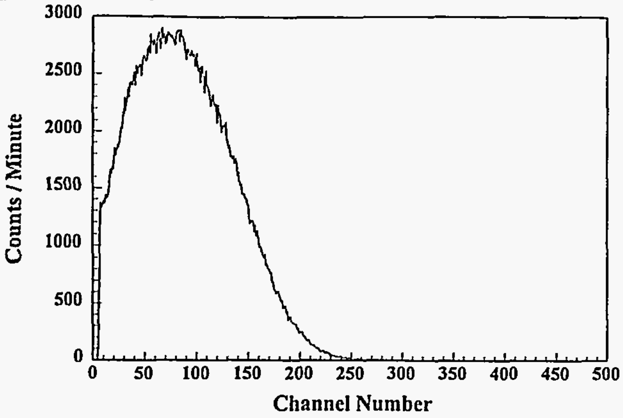

Figure 3. Pulse height distribution of an Am-241 alpha source obtained with ZnS(Ag) in LDPE and an ultra-compact PMT.

Application

As this project is still in the very early stages, no significant activities toward the application of this measurement capability have been made. Once the measurement technology is fully developed and successfully demonstrated, routine application of the measurement capabilities can be made. Most likely, this measurement capability will be utilized in decommissioning and decontamination projects to perform initial characterization measurements, or to verify decontamination activities. Another potential use is to survey air handling duct work for the purposes of identifying zones of plutonium accumulation. As the project progresses, other potential uses of this measurement capability will be identified.

Future Activities

As of this time, good progress is being made toward achieving the technical objectives outlined for this project. No significant obstacles have been identified that would seriously affect the schedule, cost, or technical goals of this project. Future activities identified at this time, generally correspond to completing the scheduled development activities outlined for Phase I of the project. Discussions have been initiated with Rocky Flats concerning the possibility of conducting a field demonstration at this site during Phase II of the project.

References

1. "Radiological Control Manual", U.S. Department of Energy, DOE/EH-0256T, June 1992.

Acknowledgments

SEA wishes to thank the METC COR for this effort, Mr. C. Edward Christy and Mr. Al Tardiff of EM-50 for their continued and enthusiastic support.