CHARACTERIZATION OF RADIOACTIVE CONTAMINATION INSIDE PIPES WITH THE PIPE EXPLORER™ SYSTEM

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Characterization of Radioactive Contamination Inside Pipes With the Pipe Explorer™ System

OBJECTIVES

The objective for the development of the Pipe Explorer™ radiological characterization system is to achieve a cost effective, low risk means of characterizing gamma radioactivity on the inside surface of pipes. The goal for the contract effort is to show that:

- The internal surface of pipe can be characterized to differentiate between clean and contaminated piping, according to DOE contamination standards.
- The internal surface of pipe can be characterized in a manner that protects expensive radiation detectors from contamination.
- The characterization process protects personnel from coming in contact with contaminated material.
- The system can be used without difficulty in a range of environments, in both removed and in-place piping.

BACKGROUND INFORMATION

The SEA pipe inspection system performs a radiological survey of the internal surface of a pipe by transporting a gamma detector through the pipe using an inverting membrane deployment method. The system is versatile in that it can negotiate bends and limited obstructions, can travel both horizontally and vertically, and can inspect pipes of smaller diameter than is capable with current pipe crawler technology.

The unique feature of this inspection system is the use of a pneumatically inflated impermeable membrane which transports the detector into the pipe as it inverts (Figure 1). The membrane's internal air pressure tows the detector and tether...
through the pipe. This mechanism isolates the detector and its cabling from the contaminated surface, yet allows measurement of radioactive emissions which can readily penetrate the thin plastic membrane material (such as gamma and high energy beta emissions).

The detector travels slowly down the length of the pipe, continuously recording count rates to map areas of high surface activity. After the survey is completed, the detector can be located at hot spots during the retrieval for detailed spectroscopic measurements.

The DOE has established radioactive contaminant threshold levels above which material must be considered contaminated (Table 1). The activity levels range from 20 to 10,000 disintegrations per minute (dpm) per 100 cm$^2$ (depending on the source of the radiation and if it is either fixed or removable). Given the limitations of scintillation detectors and likely background radiation levels, gamma detection limits as low as 20 dpm/100 cm$^2$ will not be likely achievable with portable detectors. The threshold value of 1000 dpm/100 cm$^2$ is considered viable depending on the extent of background radiation and the gamma production efficiency of the radioisotope.

**PROJECT DESCRIPTION**

To develop and demonstrate the Pipe Explorer™ system, a two-phased approach was employed. In Phase I, an initial survey of DOE facilities was conducted to determine the physical and radiological characteristics of piping systems. The inverting membrane deployment system was designed and extensively tested in the laboratory. A range of membrane materials was tested to evaluate their ruggedness and deployment characteristics. Two different sizes of gamma scintillation detectors were procured and tested with calibrated sources. Radiation transport modeling evaluated the measurement system's sensitivity to detector position relative to the contaminated surface, the distribution of the contamination, background gamma levels, and gamma source energy levels. In the culmination of Phase I, a field demonstration was conducted at the Idaho National Engineering Laboratory's Idaho Chemical Processing Plant. The project is currently in transition from Phase I to Phase II, where more extensive demonstrations will occur at several sites.

**RESULTS**

A. Deployment System

The emphasis of the inverting membrane deployment system design was to allow for the capability to remotely operate the deployment and retrieval of membranes in piping systems with minimal operator intervention. The deployment system components are depicted in Figure 2. The control system allows the operator to select either deployment or retrieval at a specific rate. The system then controls the process within preset operational parameters until fully retrieved or deployed. Operational parameters monitored continuously include tether tension and membrane pressure. The control system was tested extensively during the lab scale tests as well as at the Phase I demonstration and proved to work as desired.
Table 1. Summary of Maximum Allowable Surface Radiological Contamination (Reproduced from “DOE Radiological Control Manual,” DOE/EH-0256T, June 1992)

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Removable (dpm/100 cm²)</th>
<th>Total (Fixed + Removable) (dpm/100 cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>U-natural, U-235, U-238 and associated decay products</td>
<td>1,000 alpha</td>
<td>5,000 alpha</td>
</tr>
<tr>
<td>Transuranics, Ra-226, Ra-228, Th-230, Th-228, Pa-231, Ac-227, I-125, I-129</td>
<td>20</td>
<td>500</td>
</tr>
<tr>
<td>Th-natural, Th-232, Sr-90, Ra-223, Ra-224, U-232, I-126, I-131, I-133</td>
<td>200</td>
<td>1,000</td>
</tr>
<tr>
<td>Beta-gamma emitters (nuclides with decay modes other than alpha emission or spontaneous fission) except Sr-90 and others noted above. Includes mixed fission products containing Sr-90.</td>
<td>1,000 beta-gamma</td>
<td>5,000 beta-gamma</td>
</tr>
<tr>
<td>Tritium organic compounds, surfaces contaminated by HT, HTO and metal tritide aerosols</td>
<td>10,000</td>
<td>10,000</td>
</tr>
</tbody>
</table>

Figure 2. Integrated Pipe Inspection System, Showing Pressure Canister and Instrumentation System
Testing of the deployment system included 1.5- to 6-inch-diameter pipes at a maximum length of 200 feet. Several deployment system limitations exist with regard to piping system geometry and pipe size. The primary limitation is the number of elbows encountered in a pipe run. The elbows used in the lab scale tests and for the Phase I demonstration were drain line 1/4 bend 90 degree elbows for water service. It had been determined early in lab scale tests that for small diameter pipe, 4 inches or less, the deployment system could not manage the short radius straight or vent 90 degree elbows commonly used for high pressure gas service. For 2-inch pipe (200-foot length), the maximum number of elbows readily negotiated with the actual tether and detector assembly is two. For 3- and 4-inch pipe the maximum number of elbows is 4. These limitations are dependent on the location of the elbows with respect to the pipe entrance and the total pipe length. If shorter pipes are to be inspected, more elbows can be negotiated. Lighter weight tethers also allow more elbows to be negotiated. For example, up to six elbows were negotiated in a 2-inch, 200-foot-long pipe with a lightweight rope as the tether. Qualitative information was obtained with regard to pipe obstructions and inline valves. Initial lab scale tests performed on 2- and 4-inch pipes proved the ability of the deployment system and detector to negotiate 25 percent cross-sectional area obstructions with little or no difficulty.

The membranes selected for deployment are typically oversized by 20 to 50 percent of the pipe diameter. This enables the membrane to negotiate corners more easily. The best general purpose membrane used for deployment has proved to be a 0.004-inch thick, 100 percent low density polyethylene (LDPE). The LDPE provides a relatively high burst pressure to pipe diameter ratio when compared to other polyethylene blends. LDPE is also elastic and tear resistant which is desirable when encountering sharp edges or obstructions which could destroy a membrane. Costs for this material range from $0.03 to $0.05 per lineal foot. Typically, a 200-foot membrane costs less than $10 and consumes less than half a cubic foot in volume. Consequently, it is less expensive, and produces less secondary waste, to consider the membranes disposable after each use.

B. Radiological Measurements

The Phase I demonstration at the INEL/ICPP and laboratory tests of the Pipe Explorer™ demonstrated the utility of the system to deploy gamma scintillation detectors into a variety of piping configurations. These were successfully deployed with the system and were shown to have the sensitivity required to make very low level measurements inside of pipes. For example, a laboratory test was conducted where a Co-60 source with an NIST traceable calibrated activity of 1000 dpm/100 cm² was placed inside of a 3-inch schedule 40 steel pipe. A 2- by 2-inch NaI detector was used to survey the pipe and the results are shown in Figure 3. The data shows that low activity radioactive sources are distinguishable from the background radiation.

![Figure 3. Results of a Survey of a 1000 dpm/100 cm² Co-60 Source Inside of a 3-inch I.D. Schedule 40 Steel Pipe](image-url)
FUTURE WORK

The laboratory tests and the Phase I field test demonstrated the capability of a Pipe Explorer characterization system to emplace in a range of pipe diameters and pipe configurations. The limitations of the systems operation identified in both the laboratory tests and the field demonstration are primarily related to the maximum number of elbows negotiable by the detector transport system and a maximum total length of the emplacement systems capability. Several design enhancements will facilitate ease of use and diagnostics capability of the system during its normal use. Minor changes associated with slack indications of the tether, control switches and indicators will enhance the operability of the system in field use. One instrumentation change recommended for implementation prior to the next field demonstration applies to the way that the counts from the radiation detector are monitored and recorded by the data acquisition system. As currently configured, the multichanneled analyzer card accepts the count pulses from the scintillation detector over a defined window, called the region of interest (ROI). While this methodology is good from the standpoint of allowing us to collect multiple ROIs and also do spectral determinations continuously, it is a time consuming process and results in limited spatial resolutions of the activity as a function of depth in the pipe. What is planned for implementation prior to the next field demonstration is to use a ratemeter, which provides counts as a function of time over a relatively narrow time period such as 10 to 30 seconds. This would allow us to send the output from the rate meter directly into the analog/digital conversion card running under LabView software to more readily give us a plot of counts versus depth in the pipe in real time. This will be implemented by using a conventional nuclear measurement bin type design.
which allows us to install multiple rate meters and multiple power conditioning equipment in one modular package. This has the added benefit of allowing simultaneous use of different sensors, as well as applying pulse shaping amplifiers that enhance the versatility of the electrical measurement system. For example, the small diameter detector CsI(Na) has limited resolution in its present configuration. This device can be expected to resolve energy differences on the order of 30 percent. With adjustments in signal conditioning, such as using a pulse shaping amplifier, the energy resolution of this detector can be improved to a level of about 15 percent instead of the current 30 percent. The bin type approach is a modular one that allows addition of signal conditioners for various specific applications. We are considering implementing a beta detector in the Phase II demonstration that requires a different type of ratemeter than would currently be applied to our CsI(Na) or NaI(Tl) detectors. The bin system would allow us to purchase a ratemeter custom designed for the beta detector along with ratemeters designed for use with scintillation counters.

Field activities proposed for Phase II are intended to provide additional experience at different sites and under different radiological conditions to qualify the Pipe Explorer™ system. Further demonstrations at the Idaho Chemical Processing Plant at INEL as well as field demonstrations in at least one other DOE site are planned.

REFERENCES