Xenon Ionization Detector for Cone Penetrometer Applications

G. Tepper (gctepper@saturn.vcu.edu; 804.827.4079)
Sentor Technologies, Inc.
9467 Manorwood Drive
Mechanicsville, VA 23116
&
Virginia Commonwealth University
Department of Chemical Engineering
Richmond, VA 23284

R. Palmer (rpalmer@ucsd.edu; 858.822.1037)
Sentor Technologies, Inc
1876 Burnt Maple Way
Vista, CA 92083
&
University of California, San Diego
Department of Applied Mechanics & Engineering Sciences
San Diego, CA 92093-0411

Introduction

Site characterization and monitoring are key elements in the DOE's remediation and containment strategy. However, with regard to radioactive contaminants, sub-surface *in situ* measurement with current detector technologies is difficult and imprecise. Moreover, because radioactive contamination often consists of a complicated mix of contaminant species with widely varying concentrations, the accuracies needed in real field environments are often even more stringent than is needed in the laboratory. Environmental, practical, and cost considerations preclude the use of high-resolution solid-state detectors. On the other hand, scintillation based detectors such as sodium iodide lack sufficient energy resolution for reliable identification based on gamma-ray spectroscopy. Thus, there exists the need for a radiation detection means that is both adaptable to field use in applications such as cone penetrometer probes, and has the required energy resolution and sensitivity.

Over the past two years, Sentor Technologies has been working under DOE/NETL sponsorship to develop high-pressure xenon ionization detectors for use in cone penetrometers. Earlier developments have proven the technology capable of much better energy resolution than scintillators, while also being capable of efficient detection to higher energies than solid-state detectors and without the need for cryogenic cooling. The goal of this DOE program has been to adapt this technology to the environmental and space constraints imposed by the cone penetrometer probe. During the first phase of the program, detectors of small diameter to essentially replace the one-inch diameter sodium iodide scintillator detectors have been designed, built, and tested. During the current phase of the program, two detectors and their associated electronics are being prepared for calibration and testing with cone penetrometer field test system. The U.S. Army Corps of Engineers will conduct the calibration and simulated field tests with assistance from Sentor Technologies.

Objective

The ultimate objective of this project is to develop and test a new spectrometric gamma-ray detection system for use with the cone penetrometer in surveying radioactive waste and contamination sites *in situ*. This new technology is based on a high-pressure xenon ionization chamber. Success criteria are defined based on the goal of providing the improved detection sensitivity needed to resolve isotopic species of interest at DOE designated sites where radioactive contamination of soil is a concern. Specific criteria include improved energy resolution, improved detection efficiency, and improved ease of use (e.g., temperature, calibration, stability, etc.). Success will ultimately be measured in terms of the ability of the new technology to resolve the characteristic gamma-ray energy spectra of those radioisotopes of interest to DOE relative to currently existing technologies for detection.

Approach

Currently available technologies for spectrometric detection of gamma-ray sources utilize either scintillation detectors (e.g., NaI) or solid-state detectors (e.g., Si and Ge). Scintillators typically have energy resolutions no better than about 8-9% at 0.662 MeV, decreasing to a limiting resolution of about 4% at higher energies. A common characteristic of scintillation detectors is their temperature sensitivity, which makes use in uncontrolled environments very problematic. For photon detection, scintillation detectors rely on photomultiplier tubes, which are fragile and unstable with regard to gain. Nevertheless, scintillator/photomultiplier combinations are the current method of choice where the temperature environment can be controlled and where moderate energy resolution is acceptable. Solid-state detectors on the other hand, have extremely good resolution, better than 1%, but require cryogenic cooling. Another problem with solid-state detectors is their small atomic number and low density, which makes their cross-section for energetic gamma rays too small for many applications.

Gamma-ray detection based on ionization chambers using high-pressure xenon offers many advantages over both scintillators and solid-state detectors. Ionization chambers are typically used for detection of particle radiation because the low-density of the working gas severely limits the detection efficiency for more penetrating forms of radiation. However, the nuclear and physical properties of xenon make it possible to largely overcome this limitation. First, the high atomic number of xenon (54) gives it an intrinsically high detection cross-section. Second, the phase diagram of xenon, which has its critical point near room temperature and fifty-seven (57) bar of pressure, makes it feasible to operate a xenon ionization chamber at acceptable densities and pressures. However, in order to enable the use of gas-filled ionization detectors for spectroscopic use, it is necessary to ensure near-complete charge collection. In practice this means removing all electron-attaching impurities in the gas such as water, oxygen, etc. down to a total impurity level on the order of parts per billion. Sentor Technologies is one of only a few organizations worldwide that has developed the designs, facilities, and methods for consistently achieving and maintaining this degree of gas purity in its xenon ionization detectors.

Xenon ionization detectors are capable of much improved resolution relative to NaI; in the range of 2-4% measured resolution at the standard reference energy of 0.662 MeV (Cesium-137). Like solid-state detectors, an ionization chamber is a direct conversion device that requires no secondary detection device such as a photomultiplier. However, the high ionization potential of xenon (12.1 eV), allows it to be operated at room temperature and above, unlike solid-state detectors that require cryogenic cooling to reduce leakage current. This inherent simplicity of operation has a distinct advantage, especially for field use in applications such as the cone penetrometer. Another major advantage of xenon ionization detectors, especially compared to scintillators, is temperature stability. Because the gamma-ray detection properties of xenon are not temperature sensitive over the extremes of ambient temperatures, the problems of temperature control or calibration in the hostile cone penetrometer application are eliminated. In addition to greatly improved resolution and ease of use, other success considerations will be the projected cost, ruggedness and durability, and longevity of the detectors when used in conjunction with the cone penetrometer and similar field use applications.

Project Description

Sentor Technologies has been working under DOE/NETL sponsorship since August 1998 to engineer, build, and test xenon gamma-ray spectrometers for utilization with cone penetrometer site survey equipment. Sentor Technologies is being assisted in this development program by the Army Corps of Engineers, Waterways Experiment Station, which operates the SCAPS cone penetrometer field test facility, and by the Special Technologies Laboratory, which has responsibility for development of the field electronics equipment. During the first phase of the program, a total of three high-pressure xenon gamma-ray spectrometers were built. These detectors were tested in the laboratory using isotopic gamma-ray sources and demonstrated the expected improved resolution compared to sodium iodide scintillator detectors. However, mechanical reliability has proven to be a problem and two of the detectors suffered internal breakage during various phases of the testing. The two detectors have subsequently been rebuilt and are now undergoing final laboratory testing prior to calibration and simulated field tests with the SCAPS field test facility. During the current phase of the program, two detectors will be delivered to WES for integration into cone penetrometer housings and calibrated using isotope/soil mixtures. The conclusion of this phase will be to perform a simulated field tests using the SCAPS system.

Results

Figure 1 shows the main components of a xenon gamma-ray cone penetrometer detector prior to final assembly.

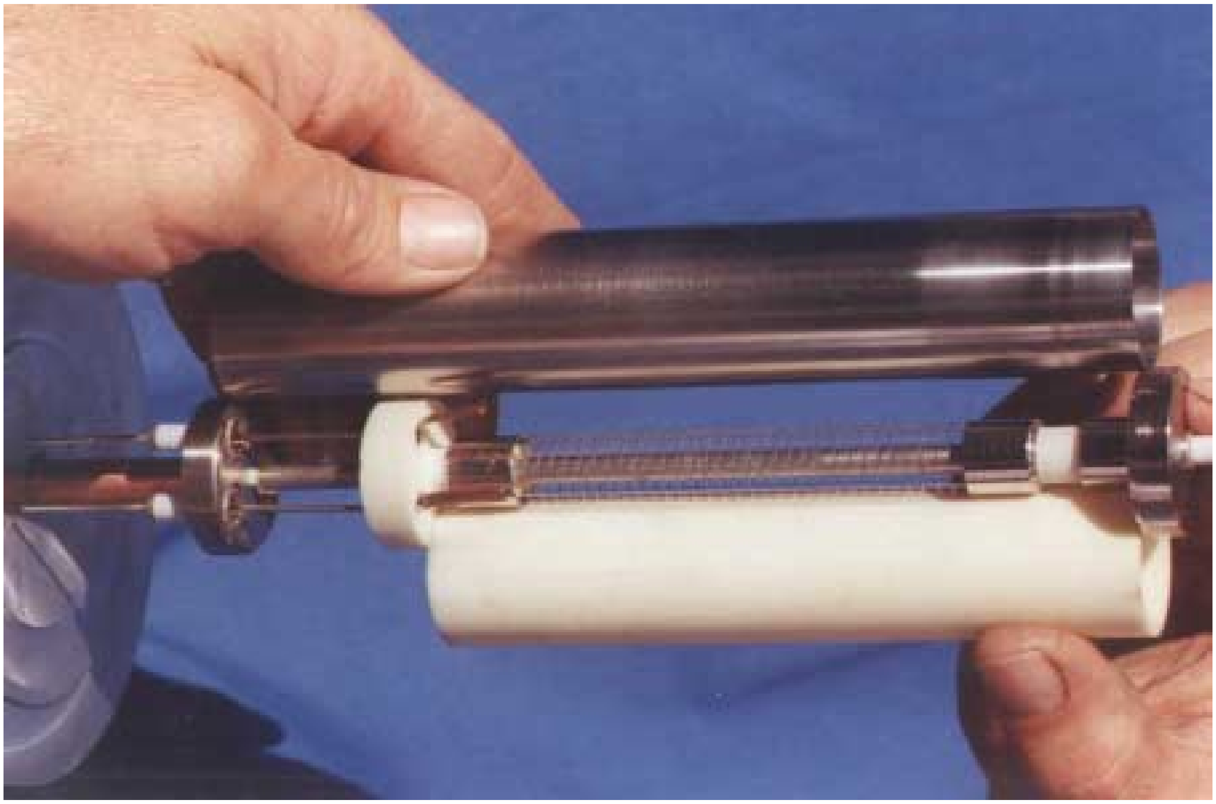

Figure 1. Xenon gamma-ray detector prior to final assembly

The outer stainless steel tube is 1.125” in diameter, compatible with the inner dimensions of the cone penetrometer housing. The materials used in the construction permit baking to high temperatures for achieving ultra-high vacuum conditions prior to filling to a pressure of fifty atmospheres with ultra-high (parts per billion) purity xenon.

Figure 2 shows the low level preamplifier and line driver electronics package mated to the detector. These electronics are necessary to provide robust signal transmissions up to the aboveground recording and analysis equipment. The detected gamma-ray pulses are sorted according to pulse height, which corresponds to their energies, and the resulting pulse height distributions displayed as energy spectra. Analysis of these spectra allows unique identification of the radioactive source.

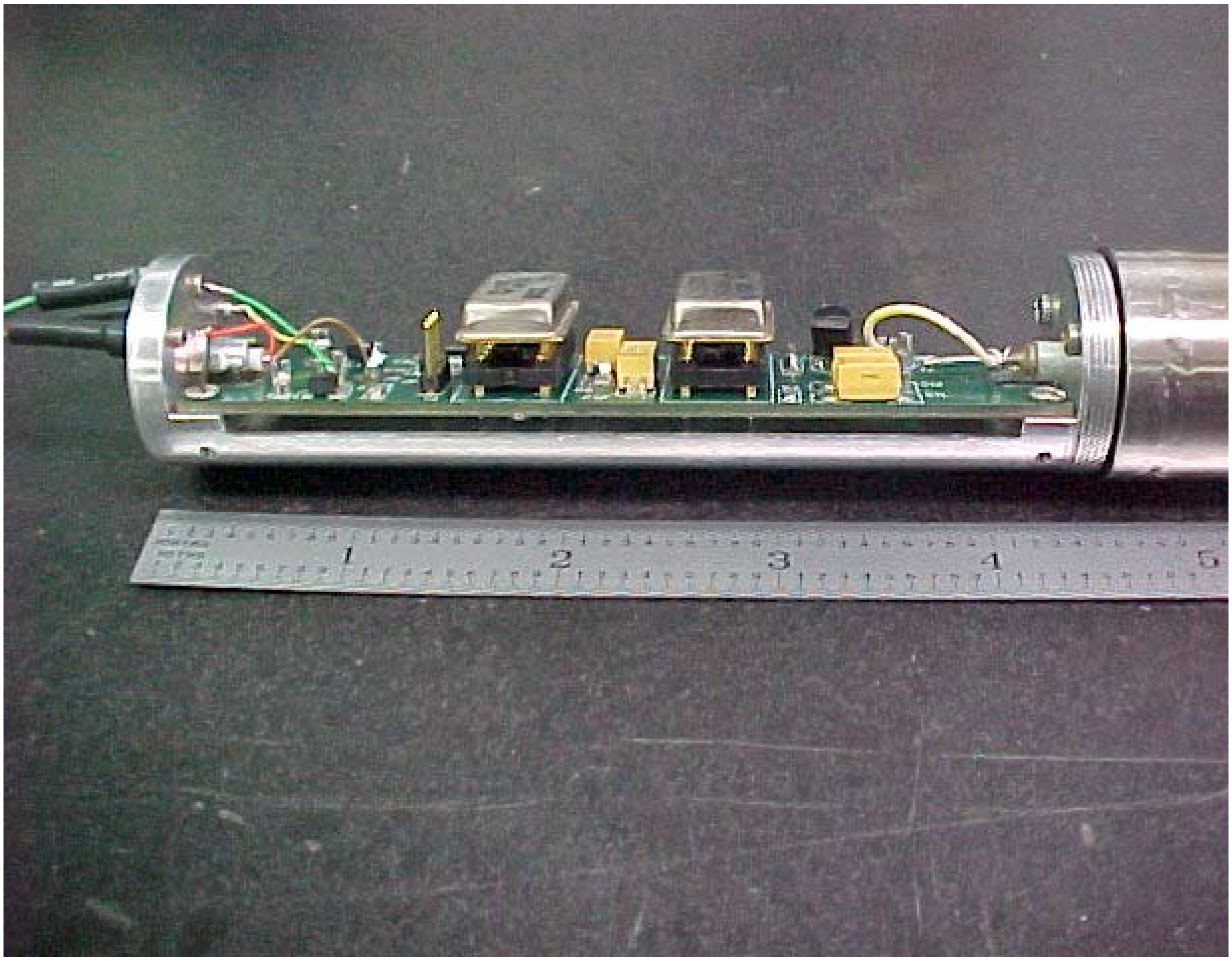

Figure 2. Detector with electronics module affixed

Future Activities

The two xenon ionization detectors built for actual deployment in cone penetrometers are close to completion. All the necessary design modifications and repairs have been completed and, with these improvements, they are expected to be able to withstand the rigors of field deployment. However, after their refilling with xenon, the detectors are not showing the expected energy resolution, which is presumed to be caused by low-level gas impurities. To solve this problem, both detectors will need to be evacuated to UHV levels and refilled with repurified xenon. Once the detectors demonstrate the expected performance in the laboratory, they will be delivered to Waterways Experiment Station for integration with the cone penetrometer probes.