Journal of Environmental Radioactivity 111 (2012) 120–125

Contents lists available at SciVerse ScienceDirect

Journal of Environmental Radioactivity

journal homepage: www.elsevier.com/locate/jenvrad

Development and deployment of an underway radioactive cesium monitor off the Japanese coast near Fukushima Dai-ichi

J.A. Caffrey*, K.A. Higley, A.T. Farsoni, S. Smith, S. Menn

Oregon State University, Corvallis, OR 97331, USA

ARTICLE INFO

Article history:
Received 14 October 2011
Received in revised form
15 December 2011
Accepted 18 December 2011
Available online 3 January 2012

Keywords:
Fukushima
Dai-ichi
Radiocesium
Seawater
Monitor
Flow-through

ABSTRACT

A custom radiation monitoring system was developed by Oregon State University at the request of the Woods Hole Oceanographic Institute to measure radioactive cesium contaminants in the ocean waters near Fukushima Dai-ichi Nuclear Power Plant. The system was to be used on board the R/V Ka'imikai-O-Kanaloa during a 15 d research cruise to provide real-time approximations of radionuclide concentration and alert researchers to the possible occurrence of highly elevated radionuclide concentrations. A NaI(Tl) scintillation detector was coupled to a custom-built compact digital spectroscopy system and suspended within a sealed tank of continuously flowing seawater. A series of counts were acquired within an energy region corresponding to the main photopeak of ^{137}Cs. The system was calibrated using known quantities of radioactive ^{134}Cs and ^{137}Cs in a ratio equating to that present at the reactors' ocean outlet. The response between net count rate and concentration of ^{137}Cs was then used to generate temporal and geographic plots of ^{137}Cs concentration throughout the research cruise in Japanese coastal waters. The concentration of ^{137}Cs was low but detectable, reaching a peak of 3.8 ± 0.2 Bq/L.

1. Introduction

On March 11, 2011 the Tohoku Earthquake and resulting tsunami devastated much of the eastern Japanese coastline. The resulting damage and power loss at the Fukushima Dai-ichi Nuclear Power Plant (FDNPP) led to meltdown in three of the six reactors on site (IAEA, 2011). In the massive effort to cool the leaking reactors, a substantial inventory of fission products was released to the environment in the form of contaminated cooling water. Due to the plant's immediate proximity to the Pacific Ocean, much of this inventory was drained directly to the sea. Additional radioactive releases to atmosphere (Bowyer et al., 2011) and the surrounding land occurred due to venting and hydrogen explosions in the reactor containment buildings (IAEA, 2011), providing an additional source of radioactivity to the Pacific Ocean.

Radionuclide concentrations in the waters immediately surrounding Fukushima Dai-ichi were sampled regularly by the Tokyo Electric Power Company (TEPCO) and, later, the Ministry of Education, Culture, Sports, Science and Technology-Japan (MEXT). Concentrations of radioactive ^{137}Cs and ^{134}Cs in seawater effluent at the plant's outlet reached maximum levels in early April and gradually declined thereafter (TEPCO, 2011). Dilution in seawater dramatically decreased radionuclide concentrations at locations further from the power plant and later sampling yielded levels not exceeding detection limits in most locations offshore from FDNPP (MEXT, 2011).

The Woods Hole Oceanographic Institute assembled an oceanographic research team, sponsored by the Gordon and Betty Moore Foundation and the National Science Foundation, in an effort to characterize the migration and concentration of radioactive contaminants in Japanese coastal waters. As part of this effort the Department of Nuclear Engineering and Radiation Health Physics at Oregon State University (OSU) was requested to construct a system capable of analyzing the concentration of radioactive cesium while underway in the Japanese seawaters.

In response to this request, OSU developed a flow-through monitoring tank to house a NaI(Tl) scintillation detector. A portable high voltage power supply, digital multichannel analyzer (MCA), and spectroscopy interface were developed in-house for use in this effort. A graduate student was enlisted to operate the system during the research cruise and to perform health physics surveys to minimize exposure to cruise participants.

Due to the uncertain status of the reactors at the time that this project began, it was imperative to create a system capable of alerting researchers to any sudden changes in radionuclide

* Corresponding author. Department of Nuclear Engineering and Radiation Health Physics, 100 Radiation Center, Oregon State University, Corvallis, OR 97331, USA. Tel.: +1 541 227 4295.
E-mail address: caffreyj@onid.orst.edu (J.A. Caffrey).

0265-931X/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jenvrad.2011.12.015

concentrations that might compromise the safety of the crew. For this reason, a custom spectroscopy interface was employed to monitor the count rate within a targeted region of interest. An audible alarm would alert researchers and crew to the presence of elevated levels of radioactivity in the seawater.

2. Materials and method

2.1. Flow-through chamber

The flow-through monitor cavity was constructed using readily available PVC materials. The lower portion of the chamber consisted of a large 8″ pipe bonded to a solid PVC plate while a large reducing coupler created a top. The sodium iodide detector was placed in a smaller 2.5″ diameter sealed PVC tube that had been bonded within the small end of the reducing coupler to provide a sealed housing. Small inlet and outlet pipes on either side of the cavity allowed seawater to flow in through the bottom and out near the top. In this manner, the gamma detector would stay dry while immersed in a constant volume of continuously flowing seawater (Fig. 1).

2.2. Detector

A 2″ × 2″ NaI(Tl) scintillation detector (802–335, Canberra Industries, Inc. Meriden, CT USA) was selected for gamma counting due to its high efficiency and ready availability. A 3″ × 3″ NaI(Tl) was preferred, but delays in shipment and the inherent time constraints of the research cruise precluded its use in this design.

2.3. Electronics

A user-programmable digital multichannel analyzer (Avicenna RX-1200 Digital MCA, Avicenna Instruments, LLC. Corvallis, OR USA) was programmed in-house to perform pulse processing and send spectral information to a PC through its USB connection. The small size and light weight of the device were ideally suited for travel or shipment, especially in comparison to NIM-based MCA systems (Fig. 2).

A high voltage supply was also required to provide bias voltage to the detector, but size and weight constraints again prevented the use of a NIM-based system. A portable high voltage power supply was therefore constructed in-house, with the internally adjustable voltage set at 1400 V to match the ideal operating bias for the detector (Fig. 2).

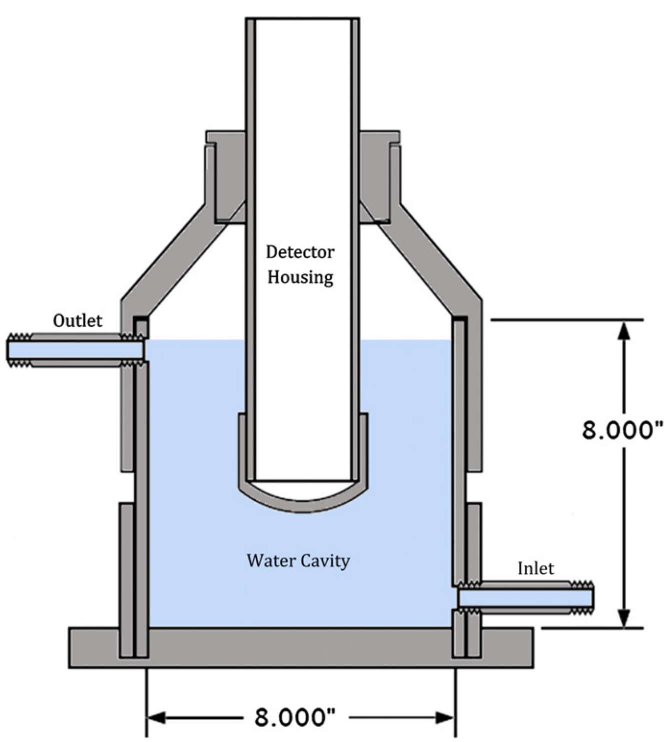

Fig. 1. Cutaway of flow-through monitor.

2.4. Software

Construction and analysis of the pulse height spectra required a PC and software designed to integrate with the MCA system. Avicenna's RayPanel graphical user interface is a software package included with purchase of the RX1200 Digital MCA. It is built in the Visual Basic language and links directly to the MCA through a USB connection. Pulses are processed through the MCA and transmitted to the interface along with energy information so that a spectral plot of counts as a function of energy is constructed on-screen. To analyze the activity of a given isotope a specific region of interest (ROI) may be selected. An ROI rate history panel was added to the interface in preparation for the research cruise, allowing the user to monitor and plot the count rate within the specified region of interest over the duration of the count. This modification also included the audible alarm which could be adjusted to activate at a threshold count rate of the user's choice (Fig. 3).

3. Initial calibration

A rough calibration of the detector was performed prior to the research cruise. A bucket and PVC detector enclosure were used for this purpose to prevent contamination of the flow-through monitor prior to field-use. A ^{137}Cs source was placed near the detector to determine energy calibration and region of interest for analysis of seawater. A series of spectra were then taken while sequentially increasing the concentration of ^{137}Cs from 1 Bq/L to 50 Bq/L in 7 L of fresh water. It was known at the time that this calibration would not be sufficient for accurate analysis of radiocesium concentrations, and that a post-expedition calibration would therefore be required. Regardless, this initial calibration provided an opportunity to test the system before collecting data in the field.

Fig. 2. Avicenna RX1200 Digital Multichannel Analyzer (left) and high voltage power supply (right).