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Investigation to design, fabricate, and integrate a mobile radiation monitoring system in ocean

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Abstract. Ocean radiation monitoring and warning systems are essential in monitoring radioactive species' contamination levels in an oceanic environment and predicting the radioactive materials propagation caused by nuclear incidents in a marine area. Since the Fukushima nuclear disaster, different types of mobile radiation monitoring devices have been investigated based on modern technologies in electronic - communication. Those types of equipment can directly measure the radioactive contamination in the ocean instead of the traditional laboratory method. This study presents a complete process of researching, designing, manufacturing, and integrating a mobile radiation monitoring system (MRMS) in the ocean. The integrated radiation sensor can both measure radiation dose rate and identify radioactive isotopes on a floating device. The measured data from the sensor is processed and displayed on the electronic block by developed software, or it can be transmitted directly to the mainland by one of three different communication devices. This prototype system is the first product in Vietnam in the development of the MRMS, which is highly promising in terms of performance, low cost, and maintenance.

Keywords: ocean radiation, mobile radiation monitoring system, marine buoy, nuclear accident, radiation waring network.

Classification numbers 3.2.2, 3.4.4

1. INTRODUCTION

Since the Fukushima nuclear disaster, there has been an increase in the attention of the national community related to the monitoring of oceanic contamination with radioactive species [1, 2]. Hence, numerous studies and various equipment have been conducted to measure the contamination levels of radioactive species in an oceanic environment [3, 4, 5]. Along with the increment of installed nuclear power plants along the coast and the new installation of float nuclear power plants (FNPP) in the islands, danger to the environment and the risk of a nuclear accident are increased [6]. In normal operation, a huge amount of radioactive waste from those nuclear power plants would affect the oceanic environment and lead to a high probability of a nuclear accident in the marine. Therefore, it is necessary to perform different methodologies frequently to evaluate the radioactive contamination of the oceanic environment and monitor radiological accidents.

Sampling analysis is the traditional method used to measure the radioactive contaminants in the marine environment [7, 8]. Oceanic water samples are collected and returned for sequence analysis in the laboratory. This method can provide high-accuracy results by using modern laboratory equipment. However, it has many disadvantages, including the requirement of a long time to collect the sample, high cost for analysis facilities, and lack of the capability to provide immediate results. The analysis information is only available for a week after taking sample time, so it is inaccurate in real-time measurement [9]. This analysis is only meaningful for monitoring and evaluation in oceanic areas with no risk of nuclear incidents and no possibility of radioactive contamination. Therefore, it is essential to develop a measuring tool capable of real-time monitoring and analysis of contaminant levels on-site [10 - 12].

This paper presents a complete process of researching, designing, and manufacturing a mobile radiation monitoring system (MRMS) in an oceanic environment. The system consists of four main parts: (1) a marine buoy, (2) an electronic and power adapter block, (3) the antennas, (4) and a radiation sensor. The commercial radiation detector can measure both the gamma dose rate and the spectrum. The proposed system also combines multimodal data transmission and developed software for data processing, signal transmission, and system control. This device can measure the radioactive contaminants directly on-site and display the results on the electronic block or transmit them directly to the mainland. The proposed configuration system has potential applications in terms of performance, low cost, and maintenance.

2. MATERIALS AND METHODS

2.1. Materials and radioactive sources

The buoy and accompanying components were fabricated using stainless steel SUS 316 material to prevent the affection from marine weather. All electronic and telecommunication equipment integrated inside the electronic and power adapter block was covered by a nanolayer to ensure they deploy in the oceanic environment.

The standard radioactive sources, including ^{60}Co, ^{137}Cs, and ^{131}I were provided by the Military Institute of Chemical and Environmental Engineering for experiments.

2.2. System design

Figure 1 illustrates the designed concept of the MRMS system which consists of five main parts: (1) the buoy body, (2) the electronic and power adapter block, (3) the antennas, (4) the cable lines, and (5) the radiation detector and its canister.

The buoy comprises three main components: the buoy body, the sensor canister, and the structures for changing the deep of the radiation detector. The buoy body has a cylinder shape with three main parameters: outer diameter, length, and mass are 310 mm, 1000 mm, and 30 kg, respectively. The Inox SUS-316 material was used to fabricate those structures to prevent the influence of the oceanic environment. The radioactive detector is contained in a hollow cylinder with holes around it to help circulate water in and out while measuring in the sea. The antennas integrate three different antennas corresponding to the 4G modem, VHF modem, and satellite ground transceiver. The following section illustrates the electronic and power adapter block in detail.

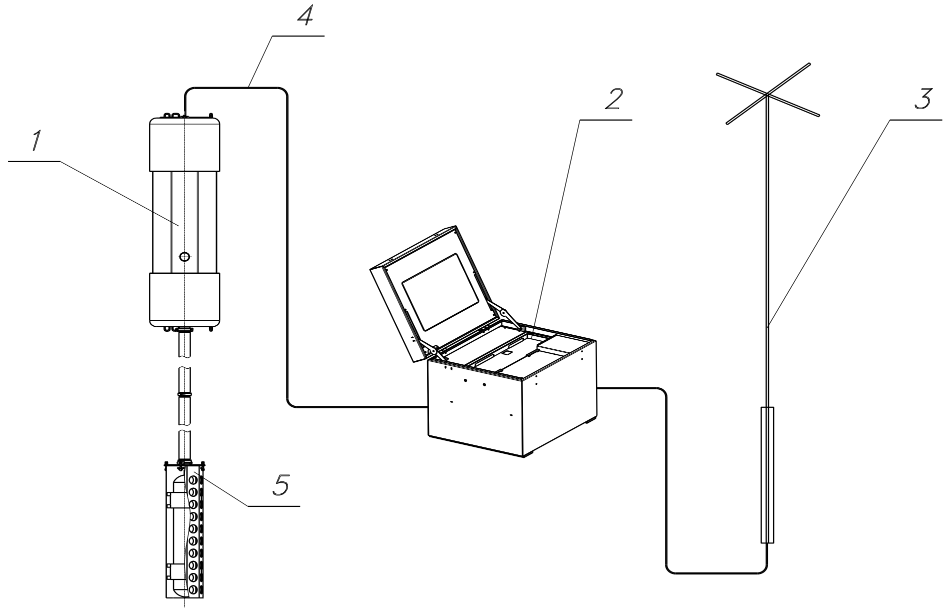


Figure 1. The design concept of the MRMS system: (1) the buoy body, (2) the electronic and power adapter block, (3) the antenas, (4) the cable lines, and (5) the radiation detector and its canister.

2.3. The design of electronic and power block

Figure 2 describes the schematic of the electronic and power adapter block, which can be grouped into three main parts: the power control and supply, the marine PC with peripheral, and the communication.

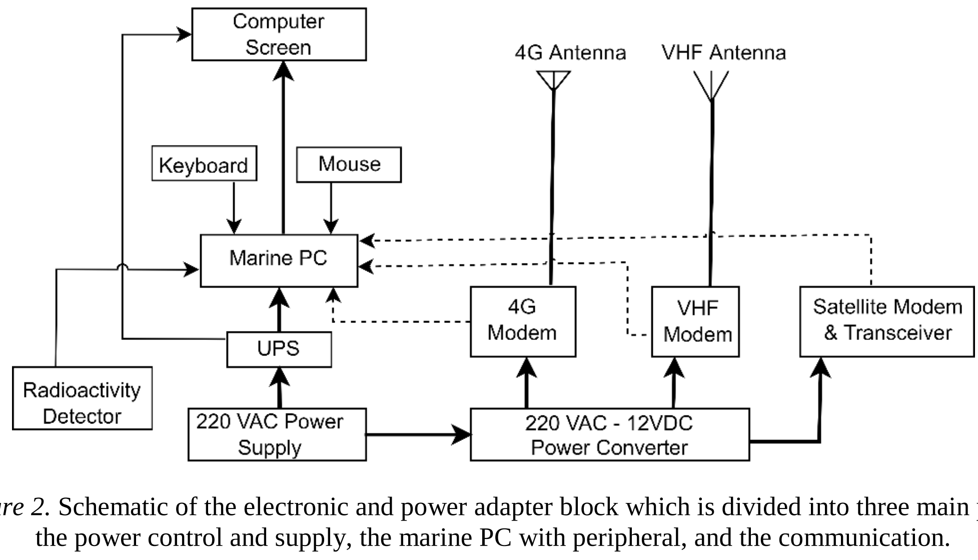


Figure 2. Schematic of the electronic and power adapter block which is divided into three main parts: the power control and supply, the marine PC with peripheral, and the communication.

The power control and supply unit include a UPS and a DC-DC converter with integrated over-voltage over-current protection. This power section supplies power to electronic devices with two power lines, 220 VAC and 12 VDC. The marine PC is designed to optimize electronic parts' endurance in the oceanic environment. In addition, it has an integrated GPS receiver. The communication unit has three communication links supported by a 4G modem, VHF modem, and satellite ground transceiver. The satellite ground transceiver uses the Iridium satellite constellation communication service. The VHF modem is the MV-8S modem from the Raveon company, and the GSM/4G modem is the GW1000M. These three-communication links have different priority levels. In a typical working scenario, only one communication link is used depending on the communication facilities where the system is deployed.

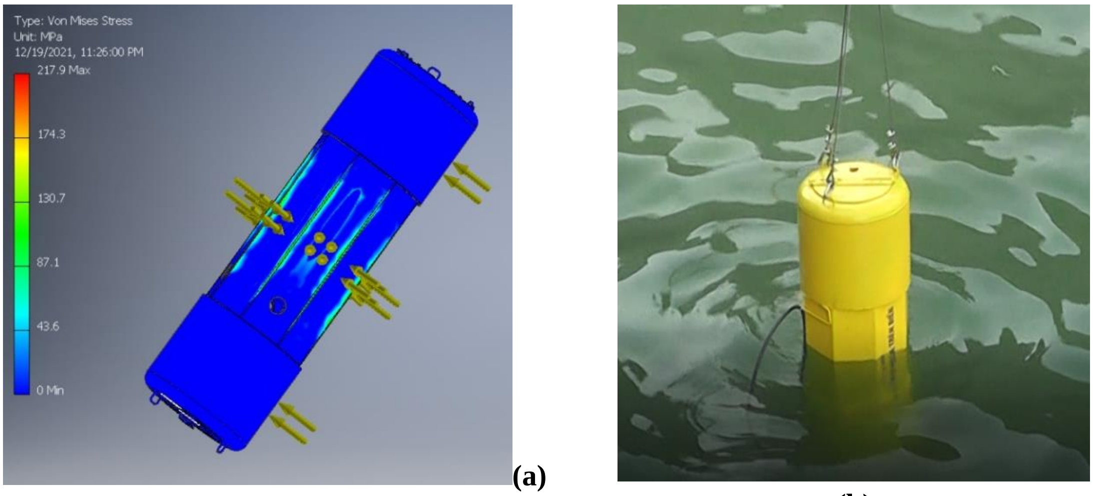
The measured data from the MRMS system is transmitted to a station deploying on the coast. Then, it can be conveyed to regional stations or Radiological Emergency Response Centres via internet. The priority level in using communication links is GSM/4G, VHF link, and the satellite ground transceiver, respectively. The 4G network normally is the highest priority level, and the satellite link is the lowest one. In a typical working scenario, only the highest-priority communication link is used. The system will automatically change to a lower priority level link if the current one is unavailable. An acknowledgement process is used to detect the loss of communication.

2.4. The radiation detector

The radiation detector is the main part of the MRMS system. It is a commercial product and was purchased from GIHMM Company, Austria. It is an all-in-one integrated detector which including a NaI spectrophotometer and a GM dosimeter for measuring radiation spectra and dose rates. All sensors integrated with electronic elements and the power supply are packaged in IP68 standard aluminium blocks and covered by cylindrical hard plastic to ensure the detector can deploy to accommodate a harsh oceanic environment [13].

3. RESULTS AND DISCUSSION

3.1. Simulation results



(a)

(b)

Figure 3: (a) The simulation result with the buoy and (b) The product installation in the Ha Long Bay for testing and measuring.

A simulation procedure was conducted intensively to optimize all parameters for the fabricating process. The Inventor software was used to design and simulate the buoy and accompanying components. In addition, the finite element simulation tool inside the Inventor is used to calculate the durability of the product which causes by external forces. Figure 3 (a) shows the simulation result of the buoyancy stress when subjected to a pressure of 0.1 MPa. The stress generated in the shell body when subjected to the maximum pressure is 217.9 MPa < 520 MPa. Figure 3 (b) shows the capture's image of the product installation in the ocean for testing and measuring in Ha Long Bay.

3.2. The products after fabrication and integration

a. The marine buoy

Figure 4 shows the established connection of the radiational detector to the buoy preparing for actual testing. Those parts will be floated in the sea and the cable connected to the electronic and power adapter block as illustrated in Figure 1 for measurement. The system has been designed in different modules to facilitate deployment in practice. The buoy is painted yellow for easy identification at sea. Corrosion factors by oceanic salt were also taken into account in the designing and material section.

Figure 4. The image of completed MRMS system in the actual testing.

b. The electronic and power adapter block

The frame part of the electrical block was designed and optimized for dimension to increase installation flexibility. There are three layers inside the box: the first for the keyboard and mouse, the second for PC and communication components, and the third for power control/supply elements. Figure 5 depicts the electronic and power adapter block after fabrication and integration. Figure 5(a) is a capture of the electronic and power adapter block in actual measuring. All information about the MRMS system, including the radioactive level, the location, the power energy, etc., is displayed on the screen. Figure 5(b) illustrates the electronic block in vibration testing at the Defense Department for Standards, Metrology, and Quality. Different tests were conducted, including a squirrel vibration test, humidity test, and temperature operation range test, to ensure the operation of the prototype system.

(a) (b)

Figure 5. The electronic and power adapter block after fabrication and integration: (a) in actual measuring and (b) in vibration testing.

3.3. The measurement with radioactive sources

a. Measurement with radioactive source in laboratory

The radiation detector was evaluated with different radioactive sources in the laboratory to assess its detection range. Figure 6 shows the measured spectrum of the ^{137}Cs radioactive source sample at a distance of 10 cm from the probe, and the measured dose rate is 2886 nSv/h. The gamma spectrum has two significant peaks, one at 662 keV peaks of ^{137}Cs (235th channel) and another at the X-ray photopeak (33rd channel).

Figure 7 illustrates the variation of the measured dose rate at various distances with a ^{137}Cs radioactive source in the air. The curve describing the variation in the number of counts on different distances shows remarkable similarities to that obtained in the study [14].

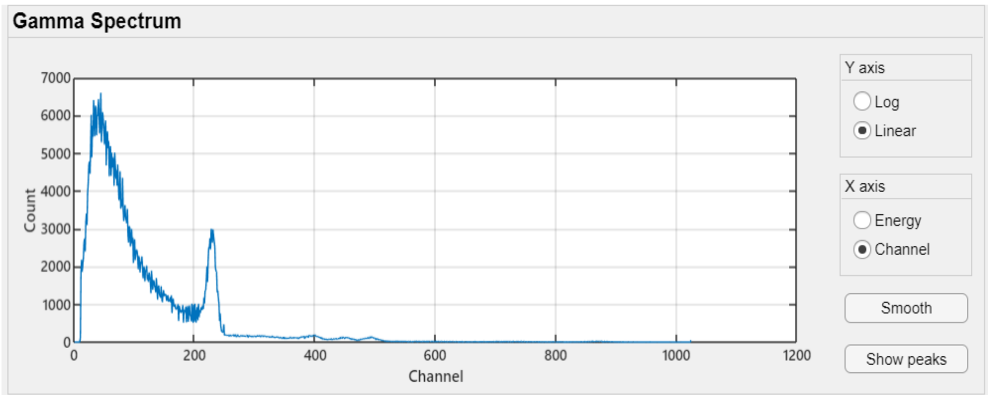


Figure 6. Gamma spectrum measured with the ^{137}Cs sample at a distance of 10 cm from the probe.

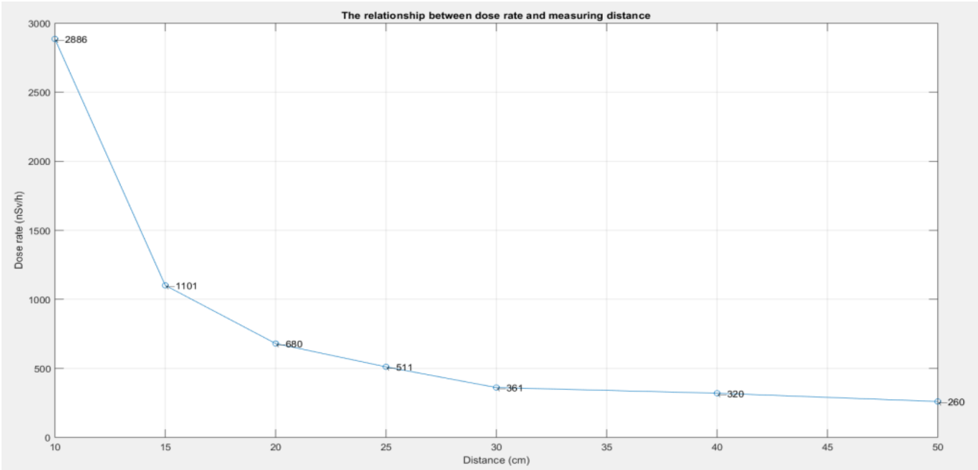


Figure 7. The variation of the measured dose rate at a different distance.

4. CONCLUSIONS

In summary, this paper presents a complete process of designing, manufacturing, and integrating an ocean mobile radiation monitoring system. The system consists of a radiation detector, a marine buoy, electronics circuits, a power supply, and telecommunication devices. The system has been tested with standard radioactive sources to measure gamma dose rate and radiological spectrum. Multimodal data transmission and various programmed software for data processing, signal transmission, and system control were also developed to build a complete system. This prototype system is the first product in Vietnam in the development of the MRMS which is highly promising in terms of performance, low cost, and maintenance. Therefore, the proposed configuration system has potential application in the early warning radiation network.

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Credit authorship contribution statement. Tien-Anh Nguyen: Methodology, Investigation, Funding acquisition. Toan Van Nguyen: Formal analysis. Duc-Tan Tran: Formal analysis, Supervision.

Declaration of competing interest. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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