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DEVELOPMENT OF DETECTION TECHNIQUES OF NUCLEAR AND RADIOACTIVE MATERIALS FOR MAJOR PUBLIC EVENTS

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ABSTRACT
In order to prevent radiation terrorism at major public events or large-scale commercial buildings, technological improvements for wide area monitoring and detection and localization of radioactive materials are required. JAEA has started developing detection techniques including mapping and imaging method. Recently, mapping technique of radiation dose/count rate using self-location recognition method, such as GPS, has come to be widely used. It is simple and handy method to find a spot that the radiation material would be placed. We have performed some preliminary tests using a CsI(Tl) scintillation detector combined a GPS. Also, a gamma-ray camera has potential for prompt localization of the radioactive source, especially if it is required to localize a highly intense source from a distance place. We are investigating a capability of a compact Compton camera under the collaboration with CLADS. In addition, neutron detection method is important for the detection of nuclear materials or particular isotopes like Cf-252 or AmBe neutron source. Basic performance tests of plastic scintillator EJ-276 have been performed at Kindai University. A project overview and preliminary experimental result of the CsI(Tl) scintillation detector will be presented.

INTRODUCTION

Nuclear security has become a matter of international concern. Strengthen of physical protection takes an important role for preventing nuclear and radioactive (N&R) materials from becoming out of regulatory controlled. Monitoring of trafficking N&R material and response are the responsibility of the state. Radiation portal monitors (RPMs) are the tool for preventing the illicit trafficking. In addition, the threat should be minimized the use of nuclear explosive devices or which radiological dispersal devices (so-called dirty bomb) in a public.

In order to prevent terrorism at major public events or large-scale commercial buildings, Integrated Support Center for Nuclear Security and Non-proliferation (ISCN) of JAEA has started development of broad-area covering rapid nuclear and radioactive material detection technologies as a four-year project (2020-2023 Japanese Fiscal Year) under the collaborations of the Collaborative Laboratories for Advanced Decommissioning Science (CLADS) of JAEA, and Kindai university. In this paper progress on a broad area surveying system and neutron detector development will be briefly presented.

BROAD AREA COVERING RAPID N&R MARTIAL DETECTION TECHNOLOGIES

The procedure of broad area covering rapid N&R martial detection is as follows: (1) find an increase of radiation field, (2) figure out the source position, and (3) identify the radioisotopes. Those are the inputs for the next action of the authorities.

An aerial dose rate mapping using Global Positioning System (GPS) would be useful for finding a trace of N&R materials outside. This technique is difficult to apply to inspection of the inside of stadiums and buildings, where GPS signals cannot reach. Therefore, requirement is incorporating a system with Simultaneously Localization and Mapping (SLAM) system using, for example, Light Detection And Ranging (LiDAR).

When an increase of counting rate is found in an area survey or mapping, the location of radioactivity has to be quickly figured out. In such a case, dose rate mapping procedure is not effective any more. Compton cameras and the other detector techniques would be useful for finding the location. A program that predicts the location from the trace of measured count would be helpful. Video devices should be combined to record the view of source object or person.

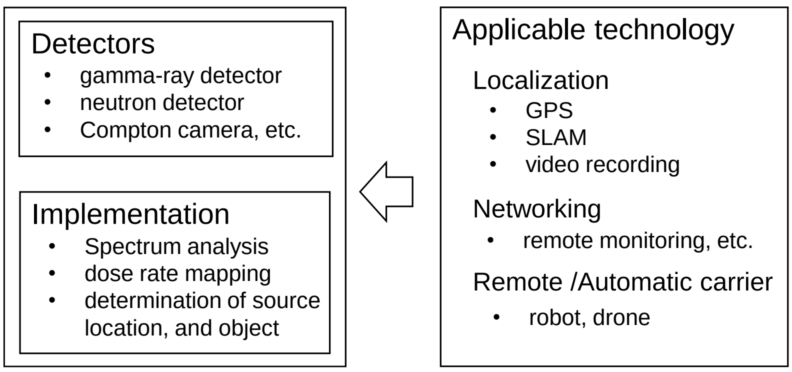

Fig. 1. Image of technological developments of a system incorporating various technologies.

In addition, identification of radioactive isotopes is required to evaluate the threat and decide the next action. Naturally occurring radioactive material (NORM), medical, and industrial radioisotopes are poetically the source of the alarm. A software for rapid diagnose of the alarming spectrum would be help the person who is not trained nor having knowledge of radiology.

Figure 1 shows an image of technologies to be applied to a rapid and broad area monitoring system. Those technologies are mixed together to improve deterrent capabilities against nuclear terrorism.

A TRIAL PRODUCTION OF A BROAD AREA SURVEYING SYSTEM

Mapping technique of radiation dose/count rate using self-location recognition method, such as GPS, has come to be widely used. It is simple and handy method to find a spot that the radioactive material would be placed. In order to confirm the applicability for broad area survey, we performed preliminary tests using a 1-inch cubic CsI(Tl) scintillation detector combined a GPS/GNSS (Global Navigation Satellite System) including QZSS（Quasi-Zenith Satellite System）of Japan determining the location with an accuracy of about 1 m. Figure 2 shows the detector, a product of TAC inc., with the size of 13×22×8 cm, and weight of 1 kg including a battery for 10-h continuous operation. The measured spectra are recorded on a memory card. The system has a USB interface to be controlled by a device outside of the detector, for example a board computer such as a Raspberry Pi. This enables monitoring the measured data remotely using network.

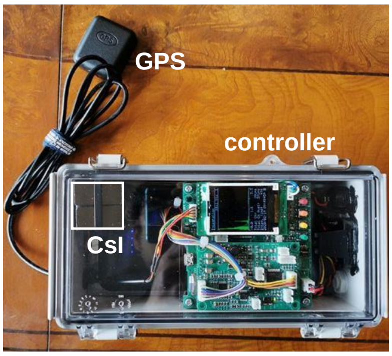

Fig. 2. A CsI scintillation detector with a GPS device.

Figure 3 shows a result of gamma-ray measurement in a field. The measurement was done walking with speed of 1-2 m/s. Measured spectrum was recorded every 1 sec. The circles plotted on the picture of Fig. 3 indicate total gamma-ray counts using mapping tool and google earth. The count rate was scaled using different colors. In the woods, the location of a hotspot of about 0.4 μSv/h was determined, where lowest environmental radiation was approximately 0.08 μSv/h. Figure 4 shows a spectrum achieved by accumulating 70 sec of the data measured at the hotspot. The 662-keV peak is from Cs-137 which was released in the accident of the Fukushima Daiichi nuclear power plant (F1 NPP), 10 years ago.

Identification of radioactive isotopes is required to decide the next action. NORM, medical, and industrial radioisotopes are poetically the source of the alarm. Development of a program for rapid diagnose of the alarming spectrum would be helpful for person without specialists, who has a knowledge of radiology. Development of such a diagnose program using machine learning method is in progress.

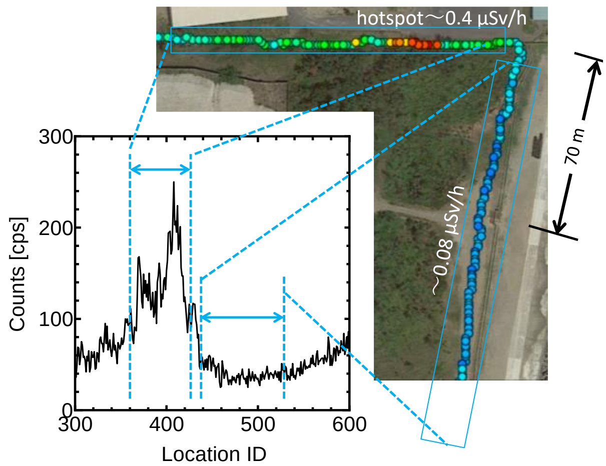

Fig. 3. A gamma-ray count rate map. Each circle indicates one second measurement.

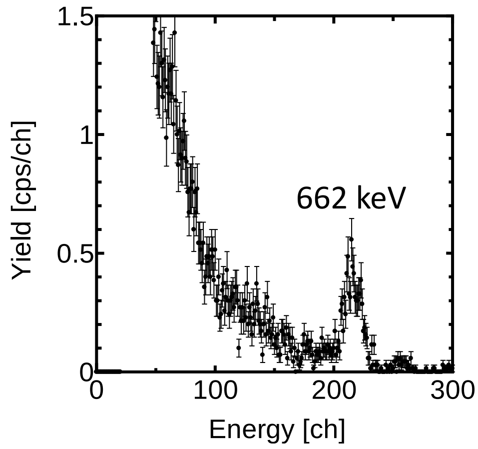

Fig. 4. A gamma-ray spectrum at the hot spot, achieved by summing the spectrum data.

Further development is planning to apply these techniques to inspection inside of stadiums and buildings, where GPS signals could not be received. Techniques of SLAM (such as LiDAR) will be incorporated.

When an increase of count rate found, the location of the radiation source should be determined. Gamma-ray camera would be useful for locating the radioactive source. Such a technological development has been carried out in an environmental dose rate measurement after the accident of F1 NPP. CLADS JAEA developed a remote detection technique using Compton camera mounted on drone for distribution measurement of Cs-137 [1]. We started a study of compact Compton camera for nuclear security application under the collaboration with them.

In addition, a video device is also considered to be an important tool for recording the situation of the place, object, and/or person, that considered to relevant to nuclear terrorism. The information would be useful to make the following decision and action.

NEUTRON DETECTOR DEVELOPMENT

Fast neutron detection is potentially useful for finding nuclear materials and neutron emitting radioisotopes, such as Cf-252 and AmBe. Because its shielding materials are different from those of gamma-rays, neutron and gamma-ray detection techniques are complementary.

Plastic scintillation detector is easy to make large size with relatively low-cost. Scintillation is mainly induced by the proton scattering in the H(p, n) reaction. The drawback of the detector is having sensitivity to gamma-rays, which induce background scintillation induced and often interfere fast neutron measurement.

Pulse shape discrimination (PSD) is a method used to distinguish neutron and gamma-ray induced signals by the decay time difference. Recently, plastic scintillator (ELJEN, EJ-276 [2,3]) can commercially available, in addition to liquid scintillators. Liquid scintillator is often avoided due to its toxicity and risk of leakage. A detector incorporating an EJ-276 plastic scintillator was tested to measure fast neutrons. Fast neutrons are expected to be measured with a good S/ N (signal to noise ratio).

A long shape EJ-276 plastic scintillator (25×25×250 mm) was used. EJ-276 was covered by Teflon tape reflector, optically shielded in an Al case. Two photomultiplier tube (PMT) (Hamamatsu H11934-100-010) was attached at the both ends. Figure 6 shows an outline of the detection system used for measurement. A digitizer (CAEN, V1730D (14 bit, and 500-Ms/s)) directly received the output of the PMTs.

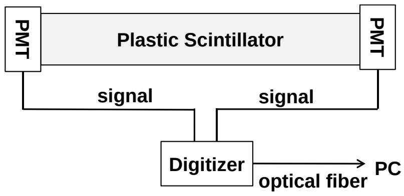

Fig. 5. A drawing of a PSD detector system.

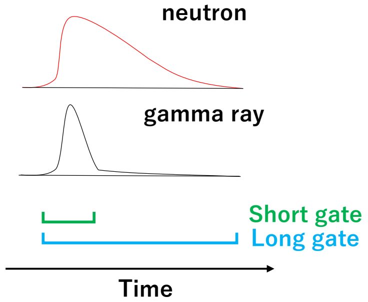

Fig. 6. Output signal of a PSD scintillation detector. The shapes induced by neutron and gamma ray are different. The digitizer Q_L and Q_S Integrating is Pulse shape in the period of long and short.

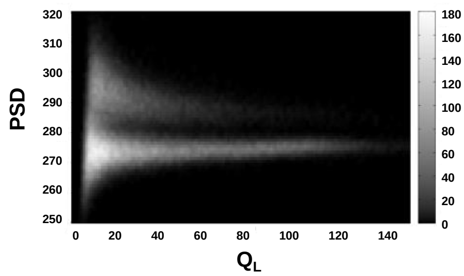

Fig. 7. Q_L v.s. PSD map. The upper part is formed by the neutron induced signals.

Figure 6 schematically shows the pulse output signals of PMT. Neutron and gamma-ray induced pulse signals differ in the decay time. The digitizer integrates digitized value of each pulse for the two period of Long Gate and Short Gate as shown in Fig. 6. The achieved Q_L, Q_S, and timestamp are sent to a computer as a list data. A PSD parameter was deduced by using the formula of $PSD = (Q_L - Q_S)/Q_L$.

A test of EJ-276 plastic scintillator was performed at the Kindai University reactor (UTR-KINKI). A Pu-Be (α, n) reaction neutron source (1.4×10^6 n/sec) [4] was used for this measurement. Before measurements, gamma-rays collimated to enter the center of the scintillator were used to adjust the voltage of both PMT making similar output pulse height from the both PMT. Figure 7 is a two-dimensional histogram of Q_L and PSD. Coincident event of both PMT was used for noise suppression. Final Q_L and Q_S were achieved by summing the both values to reduce the positional effects on the outputs. Those procedures made the PSD separation better. As seen Fig. 7, gamma ray-and neutron events are clearly separated at about PSD = 285.

We continue the experiments for angular dependent efficiency measurement, performance test using multiple detector system. Conformation study of fast neutron source search technique are being performed.

SUMMARY

JAEA has started the development of broad-area covering rapid nuclear and radioactive material detection technologies since 2020 as a four-year project under a collaboration of CLADS JAEA and Kindai University.
A portable gamma-ray spectrometer combined with GPS was tested as a base detector to be combined with SLAM system, video devices, and so on. A compact Compton camera mountable on a drone are biting developed. Fast neutron detector system aiming at finding neutron source is in progress using EJ-276 plastic scintillator.

ACKNOWLEDGMENT

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