DEVELOPMENT OF NUCLEAR SECURITY TECHNOLOGIES FOR RESPONSE ON MATERIAL OUT OF REGULATORY CONTROL EVENT AND NUCLEAR FORENSICS ACTIVITIES IN JAPAN

YOSHIKI KIMURA
Japan Atomic Energy Agency (JAEA), Integrated Support Center for Nuclear Non-proliferation and Nuclear Security (ISCN)
Tokai-mura/Naka-gun, Ibaraki, Japan
Email: kimura.yoshiki@jaea.go.jp

KEN'ICHI TSUCHIYA
National Research Institute of Police Science (NRIPS), Physics Section
Kashiwanoha/Kashiwa-shi, Chiba, Japan

AYAKO OKUBO
Japan Atomic Energy Agency (JAEA), Integrated Support Center for Nuclear Non-proliferation and Nuclear Security (ISCN)
Tokai-mura/Naka-gun, Ibaraki, Japan

KOSUKE TANABE
National Research Institute of Police Science (NRIPS), Physics Section
Kashiwanoha/Kashiwa-shi, Chiba, Japan

HIDETOSHI KAKUDA
National Research Institute of Police Science (NRIPS), Physics Section
Kashiwanoha/Kashiwa-shi, Chiba, Japan

NORIMITSU AKIBA
National Research Institute of Police Science (NRIPS), Physics Section
Kashiwanoha/Kashiwa-shi, Chiba, Japan

HIROFUMI TOMIKAWA
Japan Atomic Energy Agency (JAEA), Integrated Support Center for Nuclear Non-proliferation and Nuclear Security (ISCN)
Tokai-mura/Naka-gun, Ibaraki, Japan

Abstract

Japan Atomic Energy Agency (JAEA) and National Research Institute of Police Science (NRIPS) have been working on technology development to develop the capabilities for responding nuclear security event involving nuclear and other radioactive materials out of regulatory control (MORC) in Japan. Those institutes have information exchange and research cooperation for more effective development and improvement of the national capabilities and strengthening international nuclear security. In this paper, current status and future prospects on technology development by the two institutes for contributing to the response capabilities for nuclear security event involving MORC.

1. INTRODUCTION

A nuclear security event involving nuclear and other radioactive materials out of regulatory control (MORC) has potential severe consequence on public health, environments, economics and society. Each country has responsibility to develop national nuclear security measures including the prevention and response on any nuclear security events. According to the Incident and Trafficking Database (ITDB) developed by IAEA, over 3,000 MORC incidents have been reported from member states between 1992 to 2017 [1]. By this background, nuclear security response measures including nuclear forensics have been developed in many countries in addition to physical protection measures to prevent the incidents of such events. Although the number of MORC incidents looks large internationally, the incident probability of such kind of event is quite low from the view point of each country. Therefore, one of big challenging issue for developing national nuclear security measures in single country, especially for response measures, is the appropriate resource allocation against so-called low probability incident like the nuclear security event involving MORC. For instance, it is very difficult for many countries to develop and maintain a dedicated laboratory performing signature measurement in nuclear forensics analysis and to develop nuclear material reference database as a part of national nuclear forensics library (NNFL) since the countries require much resources comparing the incident probability of MORC event. One promised approach for this issue is effective utilization of existing national resources such as universities and institutes for a nuclear forensics laboratory, and national nuclear material accountancy data for the nuclear forensics reference database. Another effective approach is to develop and maintain the national capability based on R&D activities.

The R&D activities to support the development of national capability in Japan for responding nuclear security event involving MORC have been mostly conducted by Integrated Support Center for Nuclear Non-proliferation and Nuclear Security (ISCN) in Japan Atomic Energy Agency (JAEA) which is the national nuclear research institute, and National Research Institute of Police Science (NRIPS) which is an attached organization of national police agency. These institute from different research fields have information exchange and recently initiated research cooperation project for more effective development and improvement of the national capabilities and strengthening international nuclear security. In this paper, current status and future prospects on technology development in those institute and their recent cooperation for the development of the national response capabilities for nuclear security event involving MORC.

2. NUCLEAR FORENSICS TECHNOLOGY DEVELOPMENT IN ISCN-JAEA

In the Nuclear Security Summit 2010 (Washington DC, USA), the Japanese government issued a national statement to develop the nuclear security related technologies related to nuclear forensics and nuclear detection and to share the results toward international society for contributing to implovement of international nuclear security. The ISCN was established inside JAEA based on the national statement to fulfil the mission of nuclear forensics capability development and has initiated nuclear forensics R&Ds from Japanese fiscal year (JFY) of 2011.

The ISCN currently conducts on R&Ds on nuclear forensics technology for post-dispersion event and application of less-proven technologies on nuclear forensics purpose (called as innovative technology), based on the past R&Ds on basic nuclear forensics analytical technologies and their improvement. Several analytical equipment has been introduced and signature measurement methodologies for uranium isotope ratio, impurity profile and morphology of nuclear materials have been developed (Table 1). The nuclear forensics analytical procedures with the basic measurement technologies have been tested by the occasion of international material analysis campaign such as Collaborative Material Exercise (CMX) organized by International Nuclear Forensics Technical Working Group (ITWG) [2]. ISCN has also developed prototype nuclear material reference database, so called nuclear forensics library which is used to refer to analytical results of MORC and identify the origin, for future NNFL based on material data possessed by JAEA in the past research activities on nuclear fuel cycle engineering covering uranium mining to fuel reprocessing and various types of nuclear reactors (Figure 1) [3].

TABLE 1. BASIC NUCLEAR FORENSICS ANALYTICAL CAPABILITIES DEVELOPED BY ISCN

Item	Technology/Equipment
Uranium Isotope Ratio	Thermal ionization mass spectrometry (TIMS)
Uranium Age Dating	
Impurity Elements	Induced coupled plasma mass spectrometry (ICP-MS)
Morphology	Scanning electron microscope (SEM) Transmission electron microscope (TEM)

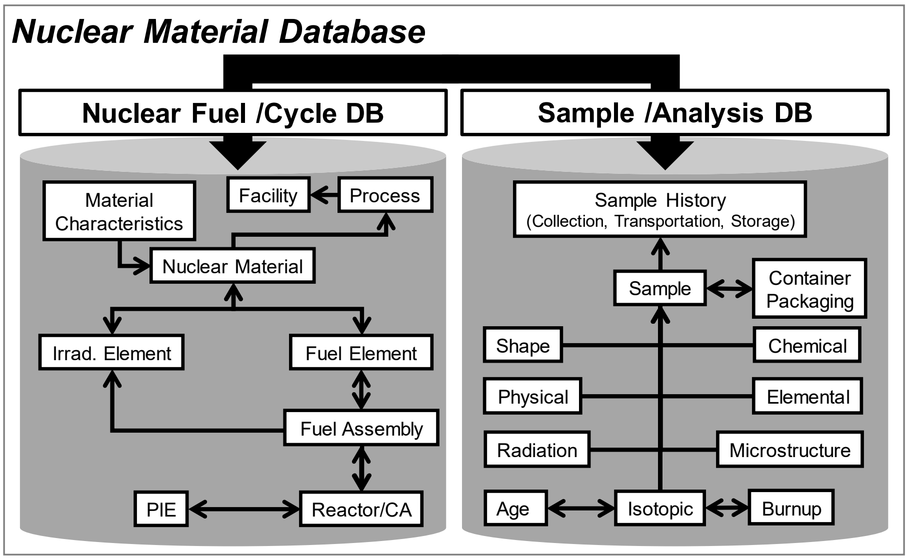

FIG. 1. *Nuclear material database in prototype nuclear forensics library developed by ISCN*

The R&Ds for improvement of nuclear forensics analysis and interpretation have been studied based on the basic analytical technology development. Objectives of the improvement R&Ds were mainly focused on improvement of reliability and speed of nuclear forensics analysis. Nuclear forensics analysis is required to ensure higher reliability since the results could be utilized in legal process, and it's more preferable if it enables to obtain timely results for supporting investigation by law enforcement. ISCN has developed in-situ age dating method which enables to measure the uranium age since final chemical separation based on $^{230}Th/^{238}U$ radiochronometer without spiking standard material (it means reducing measurement time) [4]. This new methodology uses the radioactive equilibrium of $^{234}Th/^{238}U$ and the $^{230}Th/^{238}U$ radiochronometer can be estimated based on respective isotope ratio of uranium and thorium in a sample (Figure 2). ISCN has also developed a material discrimination methodology based on particle shape distribution of uranium samples using computing image analysis on electron microscope images [5], and a sample comparative analysis methodology based on multivariate analysis approach. These works of basic nuclear forensics analytical technologies and their improvement have been conducted based on international collaborations. ISCN has research collaboration projects with DOE/NNSA of US and EC-JRC regarding nuclear forensics. Furthermore, the achievements of the R&Ds have been shared towards international society for contributing to improvement of international nuclear forensic analytical capability.

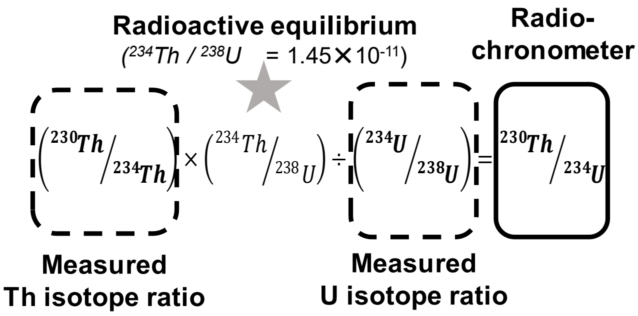

FIG. 2. *In-situ uranium age dating method*

Recently, ISCN has initiated R&Ds on post-dispersion nuclear forensics technology and innovative nuclear forensics technology. Most of nuclear forensics R&Ds have been focused on the analytical methodology targeting MORC samples seized before utilizing in terrorism attack such as a dirty bomb. Although there is no succeeded terrorism attack using MORC in the past, it is also important to develop national nuclear security capability for responding post-dispersion events. For instance, the first responders such as law enforcement would need to identify the type of causative radionuclides quickly and to figure out those scattering state in post-dispersion event scene. ISCN is carrying out R&D on a radiation measurement technology coupling low-cost and small radiation detectors with machine-learning algorism, which enables quick and autonomous radionuclide identification as one of supporting technology for first responders on post-dispersion event scene. Nuclear forensics analytical methodology for post-dispersion sample is also an important R&D topic since denaturing of signatures may be caused by contamination from environmentally existing radionuclide and detonation of chemical explosives used for dirty bomb. Regarding the innovative nuclear forensics technology, ISCN has been working on the application of less-proven technologies on nuclear forensics purpose. This includes the application of machine learning technology on the nuclear forensics interpretation to enable more reliable and objective comparative analysis, and the application of auto-radiography on contamination screening for samples to determine appropriate analytical plan collaborating with conventional forensics process. These R&Ds have been planned based on the needs identified by communication with law enforcement. ISCN will work on the technology development covering whole process of nuclear forensics activity from on-scene investigations to interpretation (Figure 3).

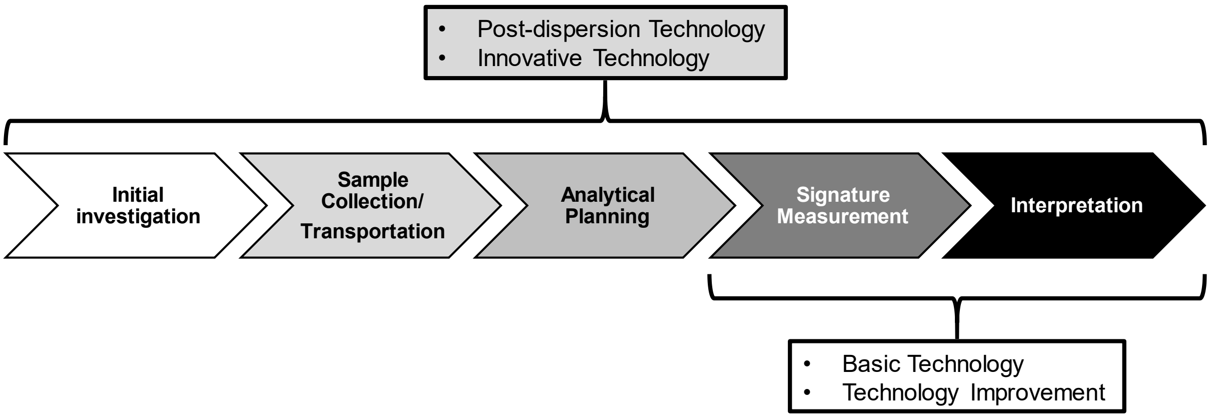

FIG. 3. *Nuclear forensics process and R&D in ISCN*

3. TECHNOLOGY DEVELOPMENT FOR FIRST RESPONSE ACTIVITIES IN NRIPS

NRIPS conducts the research in forensic science and applies it in the examination and identification of evidence collected during police investigations. The physics section in NRIPS has developed the first responder equipment for nuclear detection and for sampling and categorization in nuclear forensics.

The categorization of nuclear materials to a significant degree by measurements from portable instruments on-site are required. Also collection method of the nuclear materials or post-explosion debris for radiological incident such as a dirty bomb or a radiological dispersal device (RDD) is needed for obtaining samples for laboratory analysis. We developed portable equipment and radiation protection for radiological emergency response team to carry out emergency missions safely at the incident sites [7]. Neutron and gamma-ray dose monitoring system with 10 wireless network personal dosimeters was developed. Active dosimeters for neutron were evaluated in criticality field and in a neutron standard field [8]. We proposed several methods as means to counter radiological terrorist acts, such as dirty-bomb or silent-source attacks (hidden radioactive materials placed in a public space). The first proposal concerns a nuclear detection system using the security cameras already installed in public spaces [9]. We can estimate radiation dose from the amount of noise in CCD images caused by neutron radiation. Several dosimeters subjected to neutron and gamma ray irradiation (0.1mSv–1000 mSv) were imaged by a CCD video camera. We confirmed that the amount of noise in the CCD images varied linearly with radiation exposure. We proposed a warning system to uncover shielded nuclear materials or radiation exposure devices. The second proposal is a survey system of radiological residue using long scintillation fibers [9]. After a dirty-bomb explosion, the first responders need to search for radiological samples for subsequent nuclear forensics. We developed a position-sensitive detector with 10m plastic scintillation fibers. We were able to perform real-time measurements of distributed sources in situ. Stand-off detection using this device helps in surveying contaminated areas. Stand-off detection methods at a distance from high-activity source are also effective in situ. Gamma-ray and neutron imaging for localizing the radiation source like MORC are proposed in [10] and [11], respectively.

In recent times, NRIPS are developing two novel methods for an effective training against nuclear or radiological terrorism. First proposal is a radiation detection simulator using smartphone and Wi-Fi or BLE (Bluetooth Low Energy) beacons [12-15]. A Wi-Fi beacon transmits a data with SSID (Service Set IDentifier) from the wireless access point. A BLE beacon is used as indoor positioning system. Smartphone's software (mobile app) can detect RSSI (Received Signal Strength Indication) from their transmission. Signal strength increases as first responder with a smartphone moves closer to the beacon. We developed a mobile app "USOTOPE" (Utilizing Safety-radiation source Object + radioisoTOPE) for calculating pseudo gamma-ray dose rate from RSSI and displaying it on smartphone. We confirmed USOTOPE approximately followed the inverse-square law ($1/r^2$). It was found that this was available within at least 20m from the source position. This simulator helps the training for searching suspicious radiological sources (Figure 4) and for screening of people for contamination. Additionally, the simulator using GPS (Global Positioning System) on a smartphone is studied for control boundaries in nuclear security event involving MORC (Figure 5). This method can be used not only for countermeasures against radiological threat but also for training of nuclear disaster and radiation education.

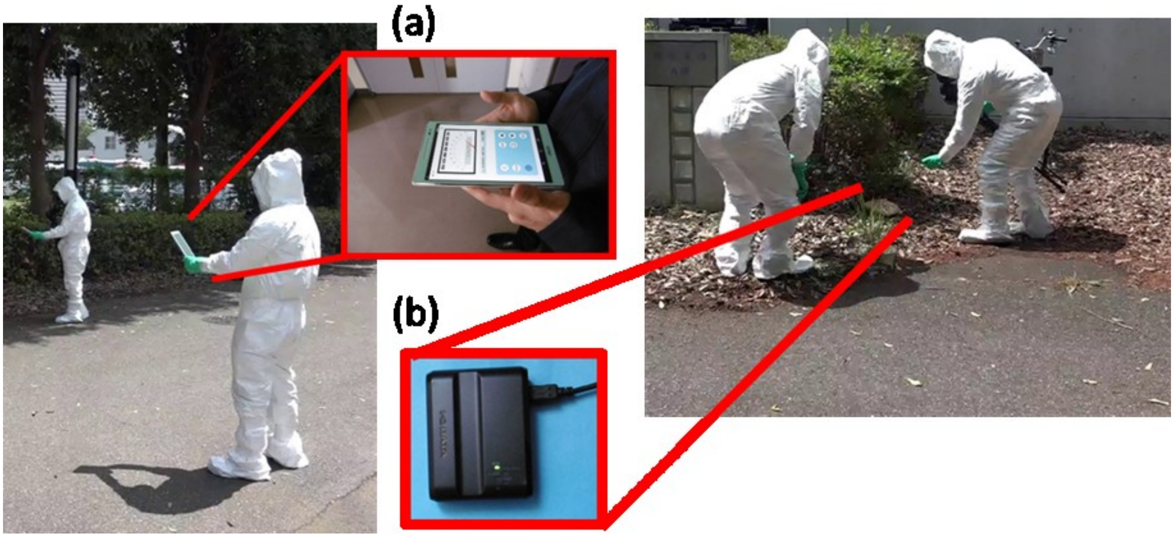

FIG.4 *Example of training for suspicious radiological source searches using USOTOPE. (a) USOTOPE on a tablet; (b) Location of pseudo radioactive source (Wi-Fi router) [15].*

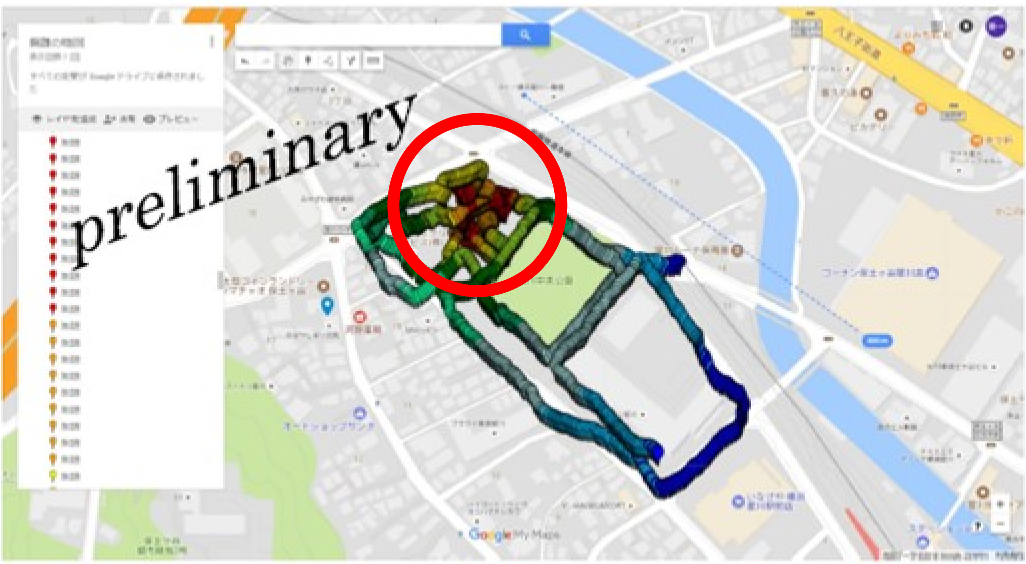

FIG.5 *Example of USOTOPE using GPS with no pseudo source. Each point shows pseudo gamma-ray dose rate. Regions in red circle show high-dose rate [14].*

Second proposal is a radiological-threat scenario producing with Monte Carlo (MC) particle transmission simulation code [14, 16]. Some existing simulation code strongly depend on weather conditions, because they assume dispersion of aerosol. Our study is intended to improve on dose estimation for surroundings of explosion centre. We suppose radiation dose depends on the distribution of radiological residue. In case of using metallic sources like industrial or medical radioisotopes, the diffusion profile will be complicated and predicting the dose distribution will be difficult. We are developing a method using MC simulation platform, PHITS developed by Japan Atomic Energy Agency [17]. We applied it into calculating the dose distribution of radiological threat. Figure 6 indicates dose intensity map for gamma-ray and neutron source. We can see significant difference behind building caused by scattering in the air. This simulator helps to produce a radiological threat scenario and to predict hot-zone with radioactive contaminated area.

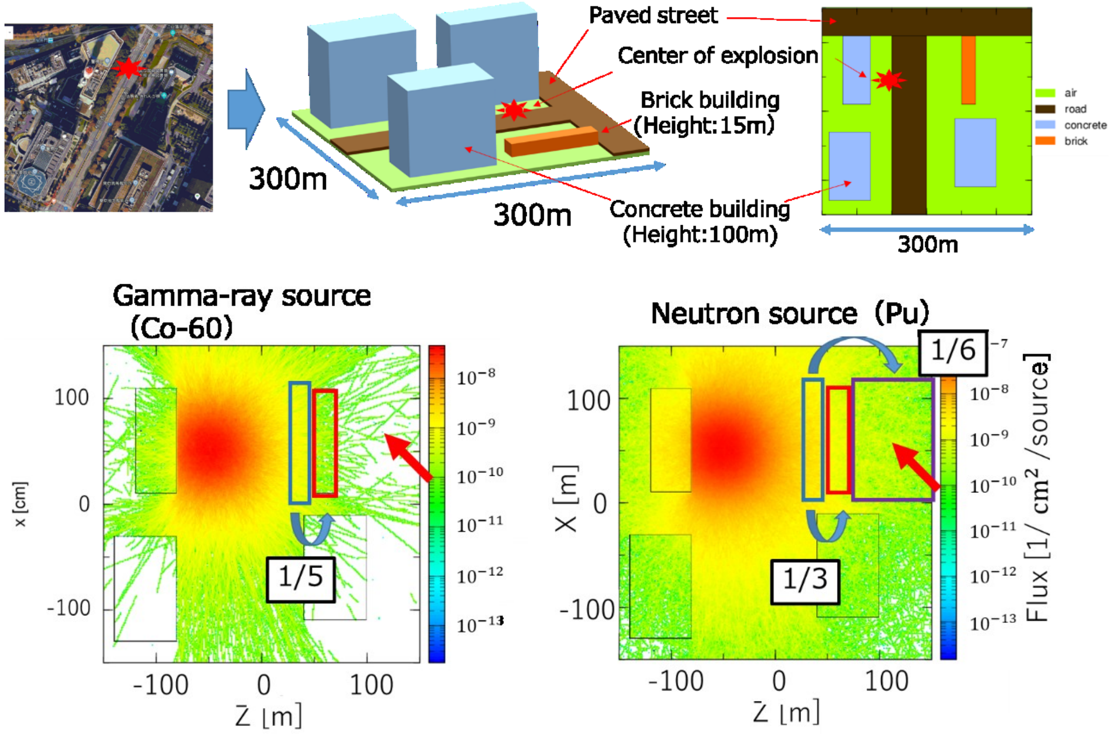

FIG.6 *Dose-distribution map for gamma-ray source (Co-60) and neutron source (Pu) [14]*

4. COOPERATIONS BETWEEN ISCN-JAEA AND NRIPS FOR EFFECTIVE CAPABILITY DEVELOPMENT IN JAPAN

It is very important for a state to have a national response plan to respond nuclear security event involving MORC, and the roles and responsibilities of competent organizations in the national plan should be defined clearly. To build a cooperative relationship within the organizations such as information exchange should be very helpful to develop a feasible framework in the national response plan. Capability building and its maintenance based on R&D activities should be one of effective approach for national capability to respond MORC event, regarding the appropriate resource allocation against so-called low incident probability event. Nuclear forensics is a technical measure to support the response activities on MORC event, and investigations by law enforcement is one of the most important activities in the context of security event response. Therefore, development of the technologies relating to the MORC event response activities, including post-dispersion event, and nuclear forensics technologies should keep in mind to support investigations by law enforcement. By integrating the needs from law enforcement at the beginning of R&D, robust relationship between competent organizations involving the national response plan can be established and the national capability for responding MORC event can be developed and maintained more effectively. Furthermore, human resource development with a focus on responding MORC event can be also successfully enhanced with active researches by universities and national institutions.

The ISCN and NRIPS have had information exchange of view about their R&D and other capability building activities regarding the response on MORC event. By sharing the status of technology development in each institute and discussions among the experts from nuclear engineering and police science, technical challenges and issues for improvement of the national capability have been well identified. ISCN has also provided an opportunity against law enforcement for testing their radiation detector equipment with actual nuclear materials possessed in JAEA. This kind of activity is also very helpful to obtain practical needs from the first responders who will actually work in MORC event scene. Recently, ISCN and NRIPS have initiated a collaborative research project regarding on-scene radiation measurement technology [6], and the both institutes have continued discussions for further cooperative research. The future potential research cooperation should also contribute to the improvement of national response capability by technologies considering the needs from law enforcement and covering all spectrum of MORC event response activities.

5. SUMMARY

The R&D activities to support national capability building for responding nuclear security event involving MORC have been conducted by ISCN-JAEA and NPRIS in Japan. The ISCN has been currently working on R&Ds on the nuclear forensics technology for post-dispersion event and application of less-proven technologies such as machine learning on nuclear forensics purpose, based on the past R&Ds on basic nuclear forensics analytical technologies and their improvements. Nuclear forensics R&Ds in ISCN have been conducted based on bilateral and international cooperation and the achievements of these nuclear forensics R&Ds have been shared to contribute on improvement of international nuclear forensic capability. The physics section in NRIPS has developed the first responder equipment for nuclear detection and for sampling and categorization in nuclear forensics. Monte Carlo based radiological-thread scenario development, real-time measurement system for radionuclide survey in event scene and radiation detection simulator using smartphones and Wi-Fi beacon for the purpose of training on first responders have been studied in recent R&Ds. Capability building and its maintenance based on R&D activities could be one of effective approach for national nuclear security capability, regarding the appropriate resource allocation against the response on MORC event. The ISCN and NRIPS have information exchange about their R&Ds and other capability building activities. Technical challenges and issues to develop national capabilities have been well identified by the information sharing and the two institute have continued the discussions to build robust cooperation relationship between experts from nuclear engineering and police science based on research cooperation projects. These activities should be helpful for the national capability improvement based on R&Ds covering all spectrum of the activities for responding MORC event including nuclear forensics.

ACKNOWLEDGEMENTS

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