Periodical Radiological Crime Scene Management Exercises in Germany

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Abstract. In order to maintain and to improve the ability to investigate a radioactively contaminated crime scene, the competent federal authorities BfS, BKA and BPOL conduct periodical exercises. During this exercise various tasks are performed like radiation detection, processing contaminated evidence etc. This exercise series is used to enhance the capabilities to deal with radiological emergencies. The paper describes the national German strategy and the roles and responsibilities developed for managing a radiological crime scene. Additionally, necessary equipment for work in a highly contaminated environment is presented and lessons learned are discussed.

1. Introduction

The Federal Office for Radiation Protection (BfS) engages in many exercises and training courses on the topic of nuclear security measures for nuclear and other radioactive material out of regulatory control [1]. It also provides assistance at major public events at the request of the security authorities [2]. The Role of BfS in the framework of the Central Federal Support Group in Response to Serious Nuclear Threats (ZUB) in Germany has been described in a previous contribution [3]. On request of a German competent authority (state or federal) the ZUB can be called upon to handle severe cases of criminal use of radioactive material.

In the case of a crime scene with possible involvement of nuclear or other radioactive material out of regulatory control, BfS together with the German Federal Criminal Police (BKA) and the German Federal Police (BPOL) within the ZUB framework will work together to safely investigate the crime scene. After the investigation of the Polonium incident in Hamburg in 2006 [4], regular crime scene management exercises were established. They are conducted at least once a year on a large scale to practice the cooperation and team work between BfS, BKA and BPOL.

2. Strategy

The need for periodical crime scene exercises arises from the fact that thankfully there are hardly any real crime scenes involving radioactive material. The German approach for dealing with such a crime scene therefore is based on a theoretical concept developed after the Hamburg incident, which has been the basis for the first crime scene exercises. The exercises in turn have shown which areas of the concept prove viable and which have to be adapted. The result is a concept that incorporates practical experience from exercises and is open to future changes if the need arises.

Since there are numerous possible scenarios for a radiological crime scene, the periodical crime scene management exercises usually focus on a particular subset in order to have all different departments involved at regular intervals. An exercise for the complete workflow of a realistic crime scene would take days and involve an extremely large number of personnel. Training scenarios are for example decontamination procedures, buried sources or data recovery from contaminated electronic devices, but will also include certain aspects which are constantly practiced, like inter-office communication, contamination measurements or general safety issues.

Within the framework of the ZUB, BfS is responsible for all aspects of radiation protection, including the radiological safety and dosimetry of all personnel involved in the actual crime scene management. To fulfil these tasks, BfS is training its personnel to take over pre-defined roles and responsibilities, developed together with the police and defined by experience gathered in different exercises, which are similar to those described in the upcoming guide NST 014 by the IAEA [5]. These roles and responsibilities are going to be defined in the following subsections.

2.1. On-scene commander (OSC) for all BfS personnel

An experienced member of BfS is in charge of all BfS personnel at the crime scene and is responsible for the dosimetry of all personnel (including police forces) as well as the radiological safety of everybody involved in the management of the crime scene. Together with a deputy, the OSC is working closely with the police officer in charge of the crime scene, determining who can enter the crime scene and for how long they can stay from a radiological safety point of view. The OSC is assigning BfS teams for all of the roles described in the following subsections.

2.2. Detection / Search teams

Ideally, there will be sufficient BfS personnel to assign at least two detection / search teams. These teams consist of two BfS members each, who are familiar with all of the necessary measurement equipment for determining the radiological situation at the actual crime scene and are accompanying the police teams assigned by the BKA crime scene unit. The teams will first of all determine whether or not there are airborne radionuclides and after that perform a sweep of the crime scene to determine if there are hidden radiological sources present and/or if there is radioactive contamination present. Communication with the police team is very important during these search excursions and remains a big challenge as BfS and BKA use different communication equipment and the teams are wearing full protection suits. In the case of the BfS personnel this includes a respirator mask, which makes conversation particularly difficult. The reason for the different equipment is on the one hand a different style of communication (radiation protection requires and uses a different ‘language’ as that employed by police) and on the other hand it is much easier to organize radiation protection and conventional crime scene management separately.

If there are sources present at the crime scene which would cause a significant dose for the personnel the teams will regroup in a safe distance and the OSC will organize a suitable shielding container for the source if possible. In such an event the source will have to be recovered before any police work can be done at the crime scene, as the police personnel are considered members of the general public and should not receive a dose in excess of 1 mSv per year. Once all major radiological sources have been removed the crime scene unit of the BKA will in cooperation with the BfS team start their search for evidence. The BfS team will measure possible evidence for radiological contamination. Contaminated evidence will then be heat sealed and transferred out of the airlock.

2.3. Airlock operators

Any crime scene that may possibly contain radioactively contaminated evidence will be sealed off with an airlock provided by BfS (see section 3). The airlock will be manned by a team of two BfS members, whose job it is to handle any evidence that needs to be heat sealed for transport to the glove box. They are also responsible for contamination measurements of all personnel leaving the crime scene and assist with containing any contamination that they may have found. At least two teams are necessary for continuous operation of the airlock.

2.4. Glove box operators

A team of two BfS members is operating a mobile glove box in which contaminated evidence can be further investigated on site. For this purpose they transfer the heat sealed evidence into the glove box, where they are unpacked and can be handled by BfS and BKA specialists. Especially in the case of contaminated electronics such as laptops or mobile phones the immediate investigation can provide timely evidence. Once the investigation in the glove box is completed, the operators of the glove box can again heat seal the evidence for storage or transfer to a facility equipped for further analysis like ITU in Karlsruhe. As with the airlock, two teams are necessary to provide continuous operation of the glove box.

2.5. Radiological advisors for the decontamination unit of the BPOL

Any personnel that has been contaminated during the investigation of the crime scene will be transferred to a specialized police unit trained in the decontamination processes. The OSC will assign a BfS expert to advise the decontamination unit of the BPOL on how to handle contaminated personnel. The advisor will make sure the measurements from BfS airlock personnel gets transferred to the decontamination unit and will give advice on how to proceed if requested or necessary.

2.6. Documentation officers

Several documentation officers are required to handle a crime scene in a manner that assures the proper documentation for a possible court case. At least three BfS members are assigned to do this job. One is standing by at the airlock to provide documentation for the evidence and as well as the contamination measurements of the crime scene personnel. Another documentation officer is assisting the OSC to make sure all the information from the search teams gets documented. One more is kept in reserve to makes sure that continuous documentation is possible at all necessary positions.

2.7. Radiological advisors on questions of risk assessment, handling and transportation of contaminated evidence

BfS experts on special subjects are available either on site or via telephone in case of arising problems. This includes but is not limited to the questions of dose estimates (including inhalation dose and calculating maximum working hours), necessary shielding requirements for transport, how to best handle certain sources and the possibility to perform propagation calculations for airborne radioactive nuclides based on atmospheric conditions.

3. Examples of Equipment

Apart from the appropriate detectors, a radiological crime scene may require some special equipment. BfS is providing the necessary tools to facilitate work in such a crime scene without spreading contamination. In order to do so, one needs to be able to isolate the rooms in question by means of an airlock. Evidence from the crime scene need to be packaged in a manner that allows to transfer them without spreading contamination. A glove box can be useful for further examination of evidence in close proximity to the crime scene in order to quickly obtain clues in connection with the crime. Should the dose rate at the crime scene be too high for working safely, a manipulator is required to handle radioactive sources. This small set of essential equipment will be described in the following subsections.

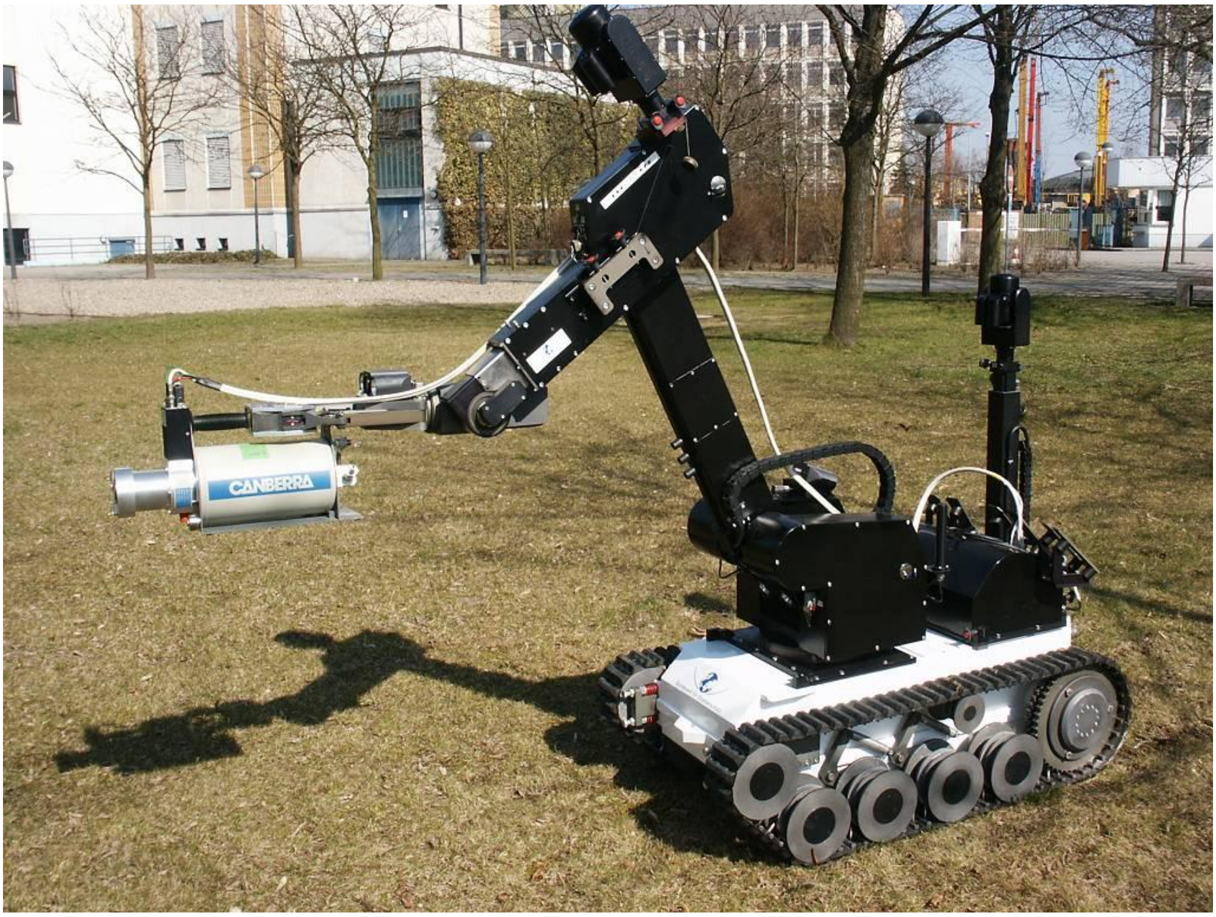

FIG. 1. The explosive ordnance disposal and observation robot (tEODor), adapted for BfS purposes. The arm is carrying a LN_2 cooled germanium detector.

3.1. Manipulator

If the search team determines that the crime scene contains a highly radioactive source which makes prolonged working unsafe, a manipulator can be brought in to salvage the source or sources in question and put them in a container with adequate shielding. For this purpose, BfS can provide the explosive ordnance disposal and observation robot (tEODor) built by telerob Gesellschaft für Fernhantierungstechnik mbH (see FIG. 1). It is remote controlled and can be equipped with different detectors, including liquid nitrogen cooled germanium detectors as well as a Target IDENTifinder, a Rad Eye gamma pager or a KSAR neutron detector. tEODor is able to work in high dose rate environments and has been tried and tested for this purpose.

3.2. Airlock

The airlock works in conjunction with a vacuum pump, which slightly lowers the pressure within the crime scene and thereby creates an airflow which is directed from the outside into the crime scene, making sure that possible airborne contamination stays within the sealed off area. The size of the airlock itself is to some extend adjustable. It is large enough for two people to work in it simultaneously. Of the personnel responsible for the operation of the airlock one is stationed outside the airlock to be able to transfer contaminated evidence via the flexible plastic sleeve attached to a feed through. The procedure is shown in FIG. 2, the plastic bag is then heat sealed by means of the heat sealing machine visible in the picture.

FIG. 2. Airlock with a plastic sleeve in which the contaminated evidence from the crime scene can be heat sealed by means of the heat sealing machine. The heat sealing machine is set up on wheels so it can be transferred to the glove box when necessary.

The second person assigned to the airlock is stationed within the airlock to assist personnel working in the crime scene. This consists of contamination measurements when exiting the crime scene and transferring the contaminated evidence into the flexible plastic sleeve. If contamination is detected the airlock operator will also assist in disposing of the contaminated pieces of protective clothing.

3.3. Glove box

FIG. 3. Glove box for the examination of contaminated evidence from the crime scene. The evidence gets introduced through the round opening visible at the front of the picture. A panel providing multiple connections for electronic equipment can be attached to the other side of the glove box in case a laptop or mobile phone need to be examined and data extracted.

Contaminated evidence that could provide vital clues need to be examined as soon as possible. Instead of transporting them to a laboratory with a hot cell, which could be hundreds of kilometers away, a first examination can be handled on-site with the help of a glove box, which can be seen in FIG. 3. Like the airlock, the glove box works in conjunction with a filter system and a vacuum pump to contain possible airborne radiation in case of damage to the glove box. The height of the actual working compartment is size adjustable to allow for comfortable working. While delicate operations are hampered by three layers of rubber gloves, it is still possible to flick through the pages of a diary for example. Electronic devices can be powered via an electric feed through and data can be extracted with the help of a USB connection.

4. Experience gathered by BfS

The periodical radiological crime scene exercises are of great importance. Only through constant training the responsible competent authorities can maintain the ability to deal with an eventual contaminated crime scene. The exercises provide valuable information, for example in the area of necessary personnel and resources. Under ideal conditions, BfS alone will need approximately 30 people to be able to deal with all aspects of radiation protection. Should the investigation last longer than a day or two, which is a very likely scenario, then the number will most likely increase to about 50 or 60 people. Necessary equipment in form of protective clothes and masks needs to be stored to have it available at the crime scene. Since the roles and responsibilities are only on a limited basis pre-assigned to specific personnel, it is very important to have written procedures available for all personnel to be able to fall back on in case they need to take over a certain part they do not usually perform.

While the actual operations during a crime scene investigation seem to run smoothly, documentation of the measurement results frequently proves difficult. The reason for this is on the one hand, that there is a problem to communicate the information due to the fact that BfS personnel inside the crime scene uses radio communication to exchange information with the OSC as well as with the documentation officers. The communication often is hampered by wearing respirator masks, which has led to the use of neck microphones. But even then the main practical problem with the communication is that only a limited number of people can work at the same time within the crime scene as a change of personnel requires contamination measurements within the airlock which have to be documented via radio communication, making it difficult to maintain radio contact to another team on the inside. Especially in light of these problems, it is important to develop specialized measurement protocols for contamination measurements, dedicated to either personnel or objects. This makes the task of documenting found contamination much more efficient and reduces communication to a minimum.

Every exercise on such a large scale always provokes interest in the higher ranks. While it is important that we can accommodate visitors and demonstrate the level of competence with which police forces and BfS cooperate for such a large endeavor, one of the most important lessons learned through periodical crime scene management exercises is that visitors need to be kept away from the personnel during the exercise. Otherwise the interaction between visitors and trainees can seriously hamper the timeframe of the exercise as well as the concentration of the personnel. For this reason, BfS is monitoring the exercise with multiple cameras, broadcasting a live feed to a closed off area where visitors can observe the exercise and discuss any questions they might have with a dedicated BfS advisor (see FIG. 4).

Maybe the most important lesson learned from these periodical crime scene management exercises is that they are necessary for developing an appreciation of what ‘the other side’ has to offer. BfS is not a law enforcement agency like BKA and BPOL and tends to operate very differently to them. For example, scientists seem to have a very different approach to certain aspects of the operation due to their work experience – if a police officer says quickly, this usually means as fast as possible (meaning minutes at most), while to a scientist quickly can be a matter of hours or days until a result is satisfactory. Also, BfS personnel do not receive the level of drill that is required for a police operation, which can be frustrating for the police while not being a sign of unprofessionalism on behalf of the scientist. It took a while for the BfS scientists as well as the professional police officers to get to know each other and understand how they work. The exercises have achieved that both sides know what their counterpart is doing and that they can rely on each other. For this reason it is very important to maintain some experienced personnel who have been through this process and can help bridge the gap for new recruits. This is especially the case on the police side of things, as they tend to change between different roles within the police force more often than BfS personnel.

FIG. 4. Observation area for visitors during a crime scene management exercise. Multiple cameras provide a live feed from the actual crime scene, allowing the trainees to exercise unhampered by visitors or supervisors while at the same time allowing for a detailed discussion afterwards.

5. Conclusion

In conclusion, maintaining an annual radiological crime scene investigation management exercise is the basis for BfS, BKA and BPOL to be well prepared in case of a radiological emergency. The roles and responsibilities have been defined by experience and personnel is being trained specifically for these tasks. The exercises are also the main tool to develop and optimize operational procedures.

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The Nuclear Forensics International Technical Working Group (ITWG): The Evidence Working Group

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Abstract. In a law enforcement investigation, evidence from the scene of a crime is critical in identifying suspects, developing tangential investigative leads, and linking individuals or groups to criminal actions. It is therefore imperative that evidence be collected, stored, and examined in a manner to best preserve those characteristics important to the investigation, the prosecution, and the defense. While the proper handling of evidence is practiced on a daily basis worldwide, evidence from a nuclear security event, that is, the addition of radioactive/nuclear material to the event site and to the evidence, can present unique and very difficult challenges to both the forensic collector and the forensic service provider.

The Nuclear Forensics International Technical Working Group (ITWG) is an informal collaboration among practitioners of nuclear forensics - laboratory scientists, law enforcement personnel, and regulatory officials - who share a common interest in preventing illicit trafficking in nuclear and other radioactive materials out of regulatory control. In 2012, the ITWG established the Evidence Working group to address common issues with the collection, storage, and analysis of evidence contaminated with or consisting of radioactive and nuclear materials. In 2013 at the annual ITWG meeting in St. Petersburg, Russia, this group met for the first time to discuss the scope of this working group and prioritized future work for its volunteers.

1. Introduction

One of the most powerful investigative tools law enforcement relies upon is the information which can be extracted from physical evidence. Finger print comparison, DNA analysis, trace evidence analysis, and questioned document examinations to name a few have become routine traditional forensic examination techniques used by law enforcement around the world because of their proven abilities to link persons or groups of persons to locations, times, or in some cases directly to criminal actions. The proper handling of evidence to undergo these traditional forensic examinations is well practiced and has been validated and established in trial law. The proper handling of radioactive/nuclear materials is also well established as seen through commercial and international organizations such as the IAEA. An area ripe for exploration is the combination of the two, that is, what about the handling, processing, and examination of evidence which contains or may be contaminated with radioactive/nuclear materials? Questions quickly arise, such as to what may be the effect of radiation on other items of evidence? Does it damage the DNA, fingerprint, hair, etc to a point where the common forensic exams are compromised? Does the difference in the requirements for safely packaging a piece of evidence contaminated with radioactive/nuclear material interfere with evidence preservation? Which should be done first, a latent fingerprint examination or radioactive/nuclear material analysis?

In 2012, the Nuclear Forensics International Technical Working Group (ITWG) established the Evidence Working group to address common issues with the collection, transport, analysis, and reporting on evidence contaminated with or consisting of radioactive and nuclear materials. The ITWG is a multinational, informal association of official practitioners of nuclear forensics - laboratory scientists, law enforcement personnel, and regulatory officials - who share a common task in responding to nuclear security events involving nuclear or other radioactive materials out of regulatory control. The ITWG was established in 1995-1996 as a result of an initiative of the G-8 (both the 1995 Ottawa Summit and the 1996 Moscow Nuclear Security Summit), largely through the efforts of concerned scientists from the national laboratories of the US Department of Energy and the Institute for Transuranium Elements representing the European Commission, with the encouragement of Government officials. Its establishment reflected heightened concerns over the threat posed by nuclear smuggling. Currently, the ITWG reports informally to the Nuclear Safety and Security Group of the G-8.

The ITWG Evidence Working group is focused on developing documents to support the radioactive/nuclear materials laboratory, the nuclear forensics laboratory, and law enforcement communities. In 2013 at the annual ITWG meeting in St. Petersburg, Russia, approximately twenty volunteers from over 10 different nations met for the first time as the ITWG.

2. Proposed List of Tasks

Prior to the meeting in 2013, the following four (4) tasks were developed by the ITWG leadership.

2.1. Proposed Task #1: Develop a document to discuss chain of custody/continuity of evidence.

The chain of custody/continuity of evidence refers to those procedures and documents that account for the integrity of physical evidence by tracking its handling and storage from its point of collection to its final disposition.[1] While forensic collectors and forensic service providers for non-nuclear event type crime scenes have well established chain of custody/continuity of evidence procedures, the added safety and surety requirements of radioactive/nuclear materials may not be compatible with existing chain of custody/continuity of evidence practices. For example, it is well known to the nuclear power industry that some plastic coated labels and printer inks are highly susceptible to certain types and doses of radiation and will degrade and fade over time. Chain of custody/continuity of evidence forms which consist of plastic coated labels attached directly to the evidence may not be appropriate when processing evidence containing radioactive/nuclear materials. Chain of custody/continuity of evidence requirements may need to be modified or deviations to standard practices may need to be put in place by the laboratory to satisfy the facilities safety requirements and the requirements of law enforcement.

The purpose of this proposed document would be to aid radioactive/nuclear material analysis laboratories which may not frequently perform forensic work. By understand the intricacies and issues associated with maintaining chain of custody/continuity of evidence, these laboratories can assess whether or not existing materials control and accountability procedures, security requirements, etc are compatible with the requirements of their law enforcement customers. For law enforcement, such a document would be helpful when they are making decisions on where evidence is to be taken for examination. Such decisions, often done under extreme time pressures, require law enforcement officials to quickly assess whether a nonstandard forensics service provider can meet their requirement for chain of custody/continuity of evidence.

2.2. *Proposed Task #2; Development of a series of topical papers on the conduct of traditional forensic examinations on evidence containing radioactive/nuclear material.*

While the characterization of radioactive/nuclear material is proven to yield valuable information, law enforcement will also expect traditional forensic techniques, such as finger print comparison, DNA analysis, trace evidence analysis, and questioned document examinations to be performed on the radioactive/nuclear material contaminated evidence as well. Whereas most traditional forensic service providers have decades of experience and robust quality assurance programs for examining evidence in the aforementioned disciplines, the presence of radioactive/nuclear material at the event site and likewise, on the evidence, presents unique challenges for both the evidence collector and the traditional forensic service provider.

The challenges can be separated in to two (2) categories:

2.2.1. Effects of radiation on the evidence to be examined

It has been shown that radiation can affect the viability of both physical evidence (ie. DNA, fibers, [2] etc.) and electronic evidence [3] (ie. computer memory storage devices). However most of the validation work (the systematic determination of efficacy of a given technique/procedure) performed to support traditional forensic techniques does not consider the effect of radiation exposure of the evidence. Thus there is a need for additional validation studies of traditional forensic examination techniques so as to determine and document the effects of dose, dose rate, and radiation type. Such validation work may be necessary to satisfy legal requirements to allow the courts to accept the results of traditional forensic techniques performed on evidence exposed to radioactive/nuclear materials.

2.2.2. Effects of radiation contamination/exposure control on the examination procedures

For non-nuclear event type crime scenes, most traditional forensic techniques are performed either at the scene or on the bench top or within chemical fume hoods at a forensic services provider. The examiners at these facilities have ready access to instruments which have undergone strict performance and maintenance checks, and these instruments are often solely dedicated to performing one specific type of examination. For example, the questioned document examiners rely upon the use of the video spectral comparator is to examine documents using various wavelengths of light and the electrostatic detection apparatus. These, and other task-specific traditional forensic instruments, are not commonly found in radioactive/nuclear materials analysis laboratories.

The presence of radioactive/nuclear materials on/in the evidence often requires facility and material specific safety and surety procedures which may be incompatible with the performance of these traditional forensic techniques or may require the placement of these highly specialized instruments in environments (ie. fume hoods, plastic enclosures, hot cells) for which they have not been designed. In addition, the traditional forensic examiners may be asked to perform their work in challenging environments, such as within restrictive personal protective equipment, strict radioactive materials contamination controls, and using limited instrumentation capabilities. Therefore, significant work (engineering, procedure modifications, quality assurance deviations, and training) is required before traditional forensic techniques can either be brought into a radioactive/nuclear materials laboratory or employed at a nuclear security event.

This series of documents would be developed for both the radioactive/nuclear materials laboratory where these techniques may be employed and for law enforcement forensic examiners, who may be bringing these techniques into a radioactive/nuclear materials laboratory or the nuclear security event.

2.3. Proposed Task #3: Development of an evidence collection plan framework document.

In the ITWG "Guidelines for Evidence Collection in a Radiological or Nuclear Contaminated Crime Scene" [4], the document emphasizes the necessity for planning prior to collecting evidence from a nuclear security event. The plan is the culmination of all of the information received from the first responders, the reconnaissance teams, and from other personnel at the scene.

This plan, to be implemented by the on-scene evidence collectors, contains information on known hazards (radiation, electrical, chemical, falling, etc) associated with the site as well as a detailed list of items to be collected. The list, annotated as to packaging requirements, provides a direct link between the law enforcement officials at the event (the items on this list should be only those probative to their investigation), the collectors who are collecting evidence and documenting what they have done, and the nuclear forensic and the traditional forensic laboratories who need to know under what conditions the evidence was collected and to determine if their facilities can accept such items.

Such a document would provide a generic framework so as to efficiently allow issues associated with collecting evidence from the event be discussed in a constructive, clear, and decisive manner between the law enforcement officials, the collectors, and the nuclear forensic/traditional forensic laboratories.

2.4. Proposed Task #4: Development of an Examination Plan Checklist.

Just as important as the Evidence Collection Plan is the Examination Plan. As called for in IAEA Nuclear Security Series No. 2[5], the examination plan is the master control of what happens to the evidence, who does what, which procedures are performed, etc. and represents an agreement between the law enforcement official and the nuclear forensic/traditional forensic service provider.

Even though examination plans are critical documents, they are often written in haste and with minimal forethought to other investigative and safety needs. By developing an Examination Plan checklist, this would provide the nuclear forensic and traditional forensic service providers a step-wise path to guide and document discussions ensuring that important points (such as destructive vs. nondestructive analysis) are brought out and agreed upon by the examiners and the law enforcement officials.

3. Results from the ITWG Annual Meetings

After discussion about the scope of this new working group and how the previous four (4) tasks are within this scope, the following points were agreed upon by the volunteers present.

3.1. Agreement Point #1

The Nuclear Forensics International Technical Working Group's "Guidelines for Evidence Collection in a Radiological or Nuclear Contaminated Crime Scene", published in 06 June 2011 is the basis for our work.

3.2. Agreement Point #2

Several volunteers agreed to begin working on Proposed Task #1 and Proposed Task #2. Volunteers for Proposed Task #1 will be using a draft version of a document begun in the ITWG Guidelines Working Group, while other volunteers will be developing Proposed Task #2 by drawing from published scientific works and personal experiences.

3.3. Agreement Point #3

Proposed Task #3 and Proposed Task #4 require further discussions and were tabled until a later date to be determined.

4. Summary

Overall, the first meeting of the ITWG Evidence Working Group was a success. It established a clear path forward for several new documents which will aid those who will handle, examine, and store radioactive/nuclear evidence. Emphasis will be placed on supporting the radioactive/nuclear materials laboratory, the nuclear forensics and traditional forensic laboratory, and law enforcement organizations.

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Galaxy Serpent: A Web-Based Table-Top Exercise for National Nuclear Forensics Libraries

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Abstract. *Galaxy Serpent* is a first-of-a-kind, virtual, web-based international table-top exercise, where teams of scientists from various countries 1) used provided public domain spent fuel compositions to formulate their own model national nuclear forensics library (NNFL), and 2) determined if hypothetically seized spent nuclear fuel is or is not consistent with their national nuclear forensics library. This table-top exercise is conducted under the auspices of the Nuclear Forensics International Technical Working Group (ITWG) and involved approximately 24 teams of scientists. *Galaxy Serpent* aimed to promote "best practices" through providing a vehicle for participants to gather key technical expertise to create a NNFL using guidelines in IAEA documents and to illustrate the potential probative benefits offered by creating such a library. During the play of *Galaxy Serpent*, many teams quickly saw the need to involve other areas of expertise such as nuclear reactor engineers and fuel experts. The involvement of such additional experts helps to mature the expertise of the nuclear forensics international community. Teams also noted that different technical approaches yielded similar analytical conclusions. In addition, some of *Galaxy Serpent* teams have used this table-top exercise experience to inform their efforts at home to develop their own NNFLs.

1. Introduction

Nuclear forensic science, often referred to as simply "nuclear forensics", is defined as "*the examination of nuclear or other radioactive material, or of other evidence that is contaminated with radioactive material, in the context of legal proceedings, including national or international law or nuclear security.*"[1] Nuclear forensics (NF) is an essential component of national and international nuclear security response plans to events involving nuclear or other radioactive (RN) material out of regulatory control. The ability to collect and preserve seized RN material as evidence and conduct NF analysis may provide information about the history and origin of material, point of diversion, and identity of the perpetrators. NF is a technical capability that will also inform the investigatory process. [1] A national nuclear forensics library (NNFL) augments these capabilities by providing an organized set of data possibly supported by a sample archive that allow comparison of illicitly trafficked material to national holdings to help determine if seized material originated in a particular country. Nuclear forensics has become an important tool to aid in identifying where loss of regulatory control may have occurred, as well as potentially excluding specific sites as a point of origin.

The *Galaxy Serpent* exercise was conducted under the auspices of the National Nuclear Forensics Libraries Task Group of the Nuclear Forensics International Technical Working Group (ITWG) and funded and organized by the U.S. Department of State with technical expertise provided by the U.S. Department of Homeland Security. The ITWG is a multinational, informal association of official practitioners of nuclear forensics - laboratory scientists, law enforcement personnel, and regulatory officials - who share a common task in responding to nuclear security events involving nuclear or other radioactive materials out of regulatory control. The ITWG conducts its work through a combination of annual meetings, task group activities, and special exercises. Participation in the ITWG is voluntary and open to competent and qualified Government participants from States having, or wishing to have, a nuclear forensics capability. [2]

2. Galaxy Serpent

Galaxy Serpent was designed with the goal of raising awareness about the technical aspects of creating and using national nuclear forensics libraries via a cost-effective, wholly web-based, platform. It also sought to increase appreciation among policymakers regarding the critical insights that can be gained by having a NNFL, even a basic one, in place prior to any investigation involving RN material. A virtual exercise afforded a means of exercising national capabilities for analyzing complex data and rendering conclusions regarding these data without having to secure and ship RN material, or perform material characterization in a laboratory. Such considerations motivated the development of a wholly web-based, technical, table-top exercise using public domain nuclear material data which would focus on developing a national nuclear forensics library without requiring laboratory measurements and would also engage a broader diversity of teams and technical experts while maturing the concept of NNFLs and illustrating their potential efficacy.

The table top exercise (TTX) involved observers and participants from 24 States, including teams from 18 States who have actively participated in the five rounds of the exercise as of April 2014. These rounds occurred between January 2013 and April 2014, noted in table 1Further details on the exercise as well as technical articles by nine teams that participated in the early rounds of the exercise and reported their experiences, findings, and lessons learned are published in a special issue of the Journal of Nuclear Materials Management (JNMM). [3] Table I lists the teams involved in each round, provides specific timeframes for individual rounds, and also identifies those teams who contributed articles for the JNMM special issue. Each round was composed of 3-4 teams, conducted over approximately 8-10 weeks, and was identical in exercise structure and tasks posed.

Table I: Summary of Teams Participating by Round

Round 1 (Feb-Apr 2013)	**Round 2 (May-July 2013)**	**Round 3 (Aug-Oct 2013)**	**Round 4 (Feb-Apr 2014)**	**Round 5 (Feb-Apr 2014)**
Australia/ANSTO	*Japan*[a]	*Hungary*	Team 13	*JRC/ITU*[b]
Brazil	South Africa/NECSA	Sweden	*Team 14*	Team 17
Canada	UK/AWE	Team 11	Team 15	Team 18
Team 4	Team 8	Team 12		

[a]Italicized text indicates the team in each round which was assigned the reactor that was the source of the hypothetical seizure.
[b]JRC/ITU is the European Commission Joint Research Centre Institute for Transuranium Elements

The objectives of the *Galaxy Serpent* TTX are to have participants organize a model national nuclear forensics library (NNFL) using provided spent fuel characteristics from three nuclear reactors ("Phase 1") and then determine if data from a hypothetical seizure of spent fuel is or is not consistent with a reactor in their model NNFL ("Phase 2"). In Phase 1 of the exercise, teams were provided existing, public domain, data sets from Spent Fuel Isotopic Composition (SFCOMPO), a database of isotopic measurements of spent fuel. [4]. SFCOMPO is data collected from public domain, published literature of isotopic compositions of spent nuclear fuels (SNF) obtained through post-irradiation experiments (PIE), which are used in the validation of burn-up credit methodologies. SFCOMPO consists of SNF isotopic compositions for 14 commercial nuclear reactors in four countries (Germany, Italy, Japan, and the US).

It includes spent fuel data exclusively from light water reactors, which use low-enriched uranium (LEU) as fuel – seven pressurized water reactors (PWR) and seven boiling water reactors (BWR). SFCOMPO was initially developed by the Japan Atomic Energy Research Institute (JAERI), and in 2002 the database was transferred to the Organization for Cooperation and Economic Development / Nuclear Energy Agency (OECD/NEA) [4].

3. Exercise Assumptions

SFCOMPO datasets had been used in a previous effort to explore the use of statistical methods to reveal patterns and associations in SNF data that had been re-purposed for nuclear forensic applications. The success of this effort demonstrated that this modified version of SFCOMPO could be used as the foundation for a table-top exercise that focused on class association involving an "unknown" SNF sample with finite, known families of isotopics. There are two specific modifications to the SFCOMPO datasets that enabled their use in *Galaxy Serpent*. First, uncertainty values for the data points needed to be determined. Since SFCOMPO data did not include measurement uncertainties, it was necessary to generate a robust set of uncertainty values. The uncertainties were a pre-requisite both to generating the set of problems, namely data sets for each of the hypothetical seizures, and to performing any forensic evaluations of the problems. Since measurements made on a sample of interest would not exactly match any one particular set of reactor fuel data, without explicit data uncertainties it would be impossible to determine if the measurements for any one fuel would fall within the limits of a single reactor fuel. Determining and assigning uncertainty values to the PIE measurements in SFCOMPO proved to be a significant task and involved including uncertainties from published references associated with SFCOMPO data or the use of "best judgment" based on traditional analytical methods for the determination of uncertainties in similar fuel matrices [5].

Secondly, based on the premise that the spent nuclear fuel isotopic compositions in the SFCOMPO database represent the entire universe of SNF for *Galaxy Serpent*, five forensics problems had been created based on actual SFCOMPO data. SFCOMPO data for a particular fuel pin measured at various positions (and burnup) were used to model the variation of the isotopic compositions as a function of fuel burn-up. This mathematical model was then used to derive (i.e., to interpolate or extrapolate) isotopic compositions at other positions or different burnup values – simulating measurements obtained on samples at different times in the irradiation history of the fuel pin. Finally, a random adjustment was applied to these values representative of measurement noise, and these adjustments were consistent with the measurement uncertainties for the corresponding SFCOMPO data [5]. While the exercise was designed using a single class of RN material, in practice any State seeking to develop or enhance a NNFL would need to consider the range materials to be included in a library.

For *Galaxy Serpent*, SFCOMPO data was adapted for a nuclear forensic application, which involved families of isotopic correlations for specified reactors. As a result, it is important to realize there is no need to average any of the PIE values from samples pertaining to the reactors. For this forensic application, the PIE data from the samples are typically treated as discrete samples from a "smeared" reactor core "entity" for each of the 14 reactors. Therefore, the geometric position data and information included in SFCOMPO for each sample is not relevant when creating the isotopic correlations that may distinguish among reactors or reactor classes. The correlations assume that the samples are representative of the isotopic compositions contained in a "smeared" reactor core as a function of exposure (i.e. neutron fluence). Actual reactor names in the SFCOMPO database were masked, re-naming each after a moon of Saturn.

4. Exercise Play

The *Galaxy Serpent* international virtual table-top exercise was designed to enable teams to use public domain data, have ample time to work on Phase 1 and 2 tasks, and reach out to appropriate expertise as needed. To enable these factors during exercise play, a web-based approach was used because it provides easy accessibility for all teams, does not involve travel or material transport costs, does not involve analytical measurements, and enables teams to engage experts that may not usually be involved in ITWG activities. An in-person table-top exercise format would not have been practical for *Galaxy Serpent*, because the Phase 1 and 2 tasks were usually not completed within hours or days, nor would the teams have been able to incorporate relevant expertise as needs arose during the exercise. Use of provided, published, public domain SNF data and information eliminated any sensitivities regarding teams from different States using their own materials data. As a result, teams only used their expertise during the exercise, and the exercise was explicitly designed not to require the use of materials data from any participating State. It is recognized that when developing an NNFL, much of the materials information exists and may have likely been collected for other purposes. By using provided data in *Galaxy Serpent*, teams directly experienced organizing a small, model NNFL from existing data and information. Additionally, constraining the "universe" of nuclear reactors to those in the SFCOMPO database helped bound the problem so that the teams would formulate results in a finite amount of time. The exercise microcosm provided a model environment where ideas, concepts, and frameworks pertaining to NNFLs could be discussed and tested, allowing teams to effectively consider the process of creating an NNFL, while also applying it to a hypothetical seizure to see the potential value of an NNFL as an investigative tool. At the conclusion of the exercise, practical ideas and lessons from this *Galaxy Serpent* microcosm could be scaled up to include lessons learned and address issues of creating or managing actual NNFLs.

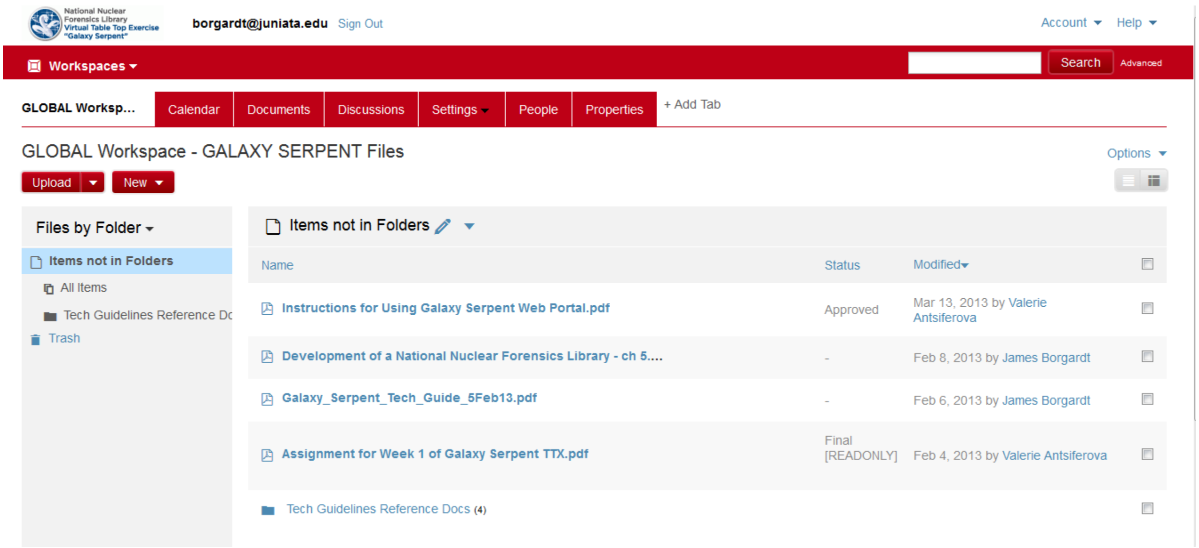

FIGURE 1: Galaxy Serpent Web Portal Workspace Example

Teams were provided with reference materials on nuclear forensics and NNFLs, including guidance documents drafted by the IAEA and the NNFL Terms of Reference from ITWG [6], but not instructions on how to construct a NNFL. Each of the 3-4 teams participating in a given round was provided, through the dedicated web portal, data sets for three different reactors. This required the use of adjusted datasets for 12 of the 14 possible SFCOMPO reactors. The reactors assigned to teams were scrambled for each round. The sole requirement was that each team be given a combination of PWR and BWR reactors. As noted, the team and reactor identities were masked: Teams were named after galaxies and the reactors named after moons of Saturn (Table 2). The web portal was designed to have two workspace levels: one public and accessible to participants and observers, and one private and accessible only by members of a given team. This was arranged so that teams, if desired, could communicate anonymously through a public discussion forum (shown in Figure 1) to exchange challenges encountered, methodologies, access reference material, and the like. The private forum served to allow teams to discreetly communicate with exercise organizers, access provided data sets, and upload progress reports. The summary of the assignment of SFCOMPO reactors used in *Galaxy Serpent*, along with their aliases is shown in Table II and III. Table II links reactor pseudonyms with their identity in the SFCOMPO database, and gives the class and number of data points for each reactor. Table III provides the pseudonym for the seizure dataset used in each round, and identifies the specific reactor of origin and the team which had this reactor as part of its model NNFL. For instance, in round 1 the Clio seizure originated from the Iapetus reactor which was assigned to the

Zwicky galaxy (Canada). The two Siarnaq reactor seizures listed are distinct seizure data sets derived from the same reactor.

Table II: Summary of SFCOMPO Nuclear Reactors and Exercise Pseudonyms (moons of Saturn)

	Reactor	**Data Points**	**Reactor Type**	**Pseudonym**
1	Calvert Cliffs No. 1	447	PWR	Anthe
2	Cooper	294	BWR	Atlas
3	Fukushima Daiichi-3	506	BWR	Enceladus
4	Fukushima Daini-2	1437	BWR	Daphnis
5	Genkai-1	123	PWR	Ijiraq
6	Gundremmingen	663	BWR	Hyperion
7	H.B. Robinson Unit 2	257	PWR	Iapetus
8	JPDR	1098	BWR	Janus
9	Mihama3	700	PWR	Mimas
10	Monticello	480	BWR	Pandora
11	Obrigheim	1035	PWR	Prometheus
12	Trino-Vercellese	1684	PWR	Siarnaq
13	Takahama-3	1227	PWR	Tethys
14	Tsuruga-1	270	BWR	Titan

Table III: Summary of Team and Seizure Pseudonyms, and Seizure Origins

Round	**Galaxy Name**	**Team**	**Seizure**	**Origin of Seizure**
1	Draco	Brazil		
1	Virgo	Australia	Clio	
1	Zwicky	Canada		Iapetus
1	Cygnus	Team 4		
2	Ursa	Japan		Siarnaq-1
2	Tucana	South Africa	Erato	
2	Sculptor	UK/AWE		
2	Hydra	Team 8		
3	Andromeda	Sweden		
3	Keenan	Hungary	Melpomene	Daphnis-1
3	Shapley	Team 11		
3	Carina	Team 12		
4	Pisces	Team 13		
4	Aquarius	Team 14	Thalia	Daphnis-2
4	Seyfert	Team 15		
5	Centaurus	JRC/ITU		Siarnaq-2
5	Pegasus	Team 17	Terpsichore	
5	Sagittarius	Team 18		

After being provided data sets, teams were given 3-4 weeks for Phase 1 in which to develop their model NNFL and were encouraged to share approaches or methodologies, as needed or desired. Some teams completed Phase 1 within one week, while others required additional time beyond the allocated time for a variety of reasons. In Phase 2, a hypothetical seizure, named after one of the Muses, was announced, and its associated data provided. In a given round, all teams were provided identical seizure data, which originated from one of the 9 (in Rounds 4 and 5) or12 (in Rounds 1-3) reactors in play during that round. Each of the five created seizure datasets discussed earlier was used in one of the rounds. Teams used their model NNFL developed in Phase 1 to determine whether the seized material was or was not consistent with material in their model NNFL using an established system of confidence levels. [7]

5. Exercise Assessment

Teams successfully reported identification of the likely reactor from which the hypothetical seized SNF may have originated, as well as an evaluated set of "possibles." These evaluated problem solutions, obtained using conventional "isotope correlation techniques" (ICT), illustrate a clear, understandable and defensible forensics capability for SNF. At least for this set of problem solutions, teams have demonstrated that the ability to identify the unknown materials from within the population of known samples is directly dependent upon the uncertainties in the data values and upon the gaps in the data values. Based on the assumptions made herein, in all cases, teams showed it was possible to downscale to a small number (to one, in some cases) of "possibles". [5]

Roughly 75% of the participant teams reported findings that were consistent with the origin of the hypothetical seizure. The remaining teams did not report inconsistent results, but rather did not complete the exercise, for various reasons. Thus, all teams completing the exercise used their model NNFL to correctly evaluate, with various levels of confidence, whether the hypothetical seizure originated from their set of reactors.

The exercise has been successful in a number of areas. Developing a NNFL containing nuclear data potentially has both national security and proprietary commercial sensitivities. The use of published, public domain data removes many of these concerns. *Galaxy Serpent* has also expanded the pool of experts aware of the use and potential efficacy of NNFLs, including reactor engineers, fuel experts, and statisticians. The web-based approach allowed a cost-effective method to advance the goals of the exercise, and also provided ITWG members with more opportunities to interact throughout a year, rather than limiting contact to ITWG annual meetings or reviewing of ITWG draft documents. A number of teams pursued parallel paths, such as statistical methods and isotopic correlation techniques, which yielded corroborating results.

While teams may have exhibited various levels of expertise and detail in working through the exercise, they were able to obtain useful and probative findings. Similar conclusions apply to the complexity of the developed model libraries; increased sophistication often facilitated greater resolution in assessing whether the seizure was or was not consistent with reactors in the model NNFL. However, it is absolutely critical to note that even a basic library proved valuable in providing critical insights as to the origin of the seizure.

The advantages and disadvantages, discussed earlier, associated with the re-purposed SFCOMPO data did impact participants ascribing confidence levels to their findings. In an actual event, the analytical and investigate work would not occur dissociated from other communities, such as first responders, law enforcement, legal representatives and policy makers. While the constrained universe, comprised of only LEU reactors, may have limited the range of sources teams had to consider, many note in their articles that the limited (in number of reactors, and samples within a reactor) and incomplete (in the variety of provided parameters) datasets presented challenges in assigning a confidence level. Nevertheless, despite these artificialities, all teams noted that the ability to compare data from a hypothetical seizure with a pre-established NNFL was essential in reaching conclusions.

6. Conclusions

The virtual, web-based *Galaxy Serpent* table-top exercise demonstrated the efficacy of NNFLs in drawing inferences about the origins of a hypothetical seizure of spent nuclear fuel. It also showed that, however useful NNFLs proved, they would be even more effective when used in conjunction with an investigative effort involving many communities within a State. A number of teams reached out to expertise outside their discipline for assistance, or in order to independently pursue multiple technical approaches. The collaborative option built into the exercise, via communication in the global workspace of the web-portal, was used by some teams to exchange methodologies and questions regarding interpretation of data sets, but was in general an underused facet of the exercise. This seemed to largely be due to the weeks-long timeframe of each phase allowing teams to progress at different paces, but may have also involved inherent sensitivities over the nature of the exercise. Several participants also preferred to communicate directly with exercise organizers to have such questions answered.

The universe of data sets were intentionally constrained to LEU reactors, which helped bound the problem for this exercise. The basic model NNFLs, composed of just three reactors, as well as their limited datasets, represented additional artificialities. Nevertheless, this exercise experience provides practical lessons as to the utility NNFLs can have, and how nuclear forensics may provide a powerful probative tool to help "rule in" or "rule out" data or information relevant to an investigation. Comparisons of the data from the hypothetical seizure with NNFLs helped each team quickly, in relation to a full-fledged inquiry, determine if the hypothetical seized SNF is or is not consistent with their holdings. Several teams also demonstrated that independently applied analytical methodologies confirmed findings. In an actual nuclear security event, the question "Is it ours?" may likely be one of the first questions asked by senior officials, and in the context of this exercise NNFLs proved to have high efficacy in addressing this key concern.

The exercise was successful in expanding the community of experts aware of nuclear forensics, and NNFLs. The web-based format also allowed an international collaboration of scientists representing, all told, over 20 States. Participants found the exercise beneficial, instructive and insightful, and many requested a follow-on "*Galaxy Serpent 2.0*" exercise based upon a different class of nuclear material. Despite noted artificialities, the exercise proved valuable in engaging and expanding the existing nuclear forensics community of experts, and advanced the concept of national nuclear forensics libraries. Finally, and most notably, the *Galaxy Serpent* exercise demonstrated that having even a basic NNFL established may provide critical and probative insights in the course of an investigation involving RN material, and in particular, answering the question "Is this material ours?"

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Tiger Reef: Cross-Disciplinary Training Workshop and Tabletop Exercise, 4-7 February 2014, Kuala Lumpur, Malaysia

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Abstract. On 4-7 February 2014, the Government of Malaysia and the Global Initiative to Combat Nuclear Terrorism (GICNT) hosted a regional workshop and exercise on nuclear forensics, Tiger Reef: Cross-Disciplinary Training and Tabletop Exercise. The Governments of Australia and New Zealand provided special support in organising the event in Kuala Lumpur.

1. Introduction

The event, comprised a one-day workshop and two-day tabletop exercise, focused on developing a common understanding on the issues involved in responding to a crime scene involving nuclear or other radioactive material, in a cooperative manner, which will ensure safe, effective and efficient operations. The workshop and exercise drew together more than 100 participants from 21 countries, primarily in Southeast Asia and two GICNT official observers, namely the EU and the INTERPOL. Participants included experts from the crime scene management and the emergency response, health, and safety communities who worked to identify cross-disciplinary training opportunities and gaps for those communities. The event clearly illustrated the importance of training crime scene managers and response experts in each other's fields so that emergency response is not impeded and to minimise the potential for evidence to be compromised. Tiger Reef ultimately reinforced the concept that a well-trained and coordinated response will save lives and identify those responsible for perpetrating a nuclear security event. It identified key best practices of the participating partners in developing a national cross-disciplinary training program.

2. Best Practices

Tiger Reef effectively demonstrated that coordination and communication among groups of experts is not just possible, but ideal. Participants recognised that a nuclear security event will involve numerous stakeholders with complementary missions, but often conflicting goals. Participants came to the following conclusions:

- Efforts to learn, coordinate, and collaborate across expert communities before an event occurs will enhance how these communities communicate and work together in a real world event.

- Important and useful training resources are currently available through many sources, including the IAEA, INTERPOL, the European Union, various centres of excellence, private industry, and bilateral government arrangements.

- Policy makers should focus on the following points of interaction between organisations or groups of experts when developing national response plans or training programmes for responding to a nuclear security event:

    - establishing radiation zones;
    - establishing access points;
    - handling perimeter and other security issues;
    - triage/rescue recovery/evacuation;
    - decontamination;
    - collecting and controlling evidence;
    - coordinating public messaging; and
    - responding to additional threats.

- Available training resources should be adapted to encourage cross-disciplinary training, or training across organisational or agency lines, to enhance coordination and communication in a crisis environment.

- Tabletop and field exercises are particularly valuable (even necessary) as part of a national cross-disciplinary training program.

- Countries should incorporate a graded approach to training and exercises, in which the complexity and scale of the training and exercises is gradually increased over time. This systematic approach to training and exercises will allow organizations and personnel to first gain the required knowledge and skills before participating in larger, more complex training events with multiple stakeholders.

3. Next Steps

Tiger Reef's participants and organisers agreed that these steps should be implemented:

- Present analogies at future events: Tiger Reef included two presentations outside the nuclear sphere—one on cross-organisation communication and one on Malaysia's national response to a biological incident. Each of these presentations allowed participants a chance to break down barriers and begin interacting openly with one another, while also providing an opportunity to think outside of their typical day-to-day work. Analogies also allow the nuclear security community to leverage lessons learned and best practices of other complex security issues.

- Promote training programs and activities of partner organisations: the GICNT will work with other partner organisations such as the IAEA and INTERPOL to uplift their current activities and collaborate to enhance training opportunities.

- Plan a follow-on event: the GICNT's Response and Mitigation Working Group and the Nuclear Forensics Working Group will hold a follow-on exercise on cross-disciplinary training in another region to draw new perspectives and continue the important work started in Malaysia.