IAEA-TECDOC-1896
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IAEA-TECDOC-1896

EDITORIAL NOTE

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NUCLEAR FORENSICS: BEYOND THE SCIENCE
IAEA, VIENNA, 2020
IAEA-TECDOC-1896 (SUPPLEMENTARY FILES)
ISBN 978–92–0–0–100920–3
ISSN 1011–4289

Produced by the IAEA in Austria
January 2020

PAPERS PRESENTED AT THE MEETING

TECHNICAL SESSION I

NUCLEAR FORENSICS PRACTICES AND EXPERIENCES: NATIONAL AND INTERNATIONAL PERSPECTIVE

NUCLEAR FORENSICS AT JRC – FROM AD-HOC ANALYSIS TO FULL-GROWN DISCIPLINE

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Abstract

The paper will review how nuclear forensics was started at the Joint Research Centre Karlsruhe over 25 years ago and how it has evolved throughout the years.

1. INTRODUCTION

At the beginning of the 1990's, incidents of illicit trafficking of nuclear materials caused a serious concern and an unexpected new threat appeared at the horizon. For the first time law enforcement authorities were interested in nuclear material analysis, seeking support for their investigations. Apart from the need of determining the nature of the illicitly trafficked materials and their intended use, the authorities wondered about their origin. In 1992 the first nuclear forensic sample was analysed at JRC Karlsruhe. During the following three years, 21 investigations of materials seized in Germany were performed. The discipline of nuclear forensic science was still in its infancy and analytical and interpretational capabilities had to be developed. With its range of advanced chemical and isotopic analytical techniques and methods that had been established for nuclear safeguards purposes, as well as using its expertise on nuclear materials, JRC Karlsruhe was in an excellent position to efficiently develop a nuclear forensic tool-set. This helped addressing the new nuclear security challenge in Europe.

A dedicated research related to nuclear forensics started at JRC Karlsruhe in 1997. The research concentrated first on signatures of uranium fuel pellets as the majority of the seizures involved them. This included e.g., analysis of trace elements as process indicators, determination of the 18O/16O isotope ratio to gather information on the location of the production site, and surface roughness characterization in connection with grinding processes.

In parallel the development of "age" determination (i.e. the date of last chemical separation) methods for U and Pu was started in order to narrow down the number of possible production places. The age determination method for Pu was developed using multiple parent/daughter ratios by mass spectrometry and it was also demonstrated to be applicable for individual particles. In the beginning of 2000's, the work was extended to uranium age dating using mass spectrometric and radiometric methods.

Later, research was started on investigating potential new signatures of the geological origin in natural uranium and they have been tested using a comprehensive set of uranium ore concentrate (UOC) samples around the world. The studied signatures include e.g. rare earth elements (REE), anionic impurities and stable isotope ratios (e.g. Pb, Sr, S and Nd). Also the propagation of nuclear forensic signatures in various natural uranium materials has been studied recently.

Links between nuclear forensics and traditional forensics (e.g. fingerprint, DNA) was given a close consideration at JRC Karlsruhe in the preparation phase of the 2006 FIFA World Cup in Germany. The issue, how to collect and examine radioactively contaminated evidence, e.g. after a dirty bomb explosion, was raised. Together with the German Federal Criminal Police (BKA), a dedicated glove box was designed and set up, where fingerprints on radioactively contaminated items can be developed following the established protocols of the police. Subsequently, procedures for DNA extraction and separation (from radioactively contaminated samples) were developed. Moreover, installations were developed and tested for retrieving digital information from electronic devices.

Today, more than a quarter of century later, the discipline of nuclear forensics has matured considerably. Besides as an emerging response measure for illicit trafficking, nuclear forensic analysis has been applied also to other cases of radioactive materials out of regulatory control, such as unauthorized disposal of radioactive waste. A number of examples and case studies will be shown to illustrate the progress made in nuclear forensics throughout the years.

CONVENTIONAL FORENSIC SCIENCE SUPPORT TO A NUCLEAR SECURITY EVENT

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Abstract

The paper gives an overview of the specialist capabilities that have been developed in the United Kingdom to enable conventional forensic science examinations to be conducted both at the radiological crime scene and in the laboratory.

1. INTRODUCTION

A key objective within the PURSUE national work strand of the United Kingdom's Countering Terrorism Strategy (CONTEST) is the ability for law enforcement to investigate terrorist activity [1]. The presence of nuclear or other radioactive material at a crime scene presents several challenges for law enforcement, particularly around the ability to process the scene, recover items of investigative value and subsequent scientific examination [2]. To resolve these challenges the United Kingdom (UK) has ensured law enforcement can investigate a nuclear security event through the adaptation of procedures and processes and the development of specialist capabilities for use at the scene and in the laboratory.

UK law enforcement has taken well established crime scene management procedures and through collaborative partnership with the relevant scientific technical authorities, has adapted these procedures to enable their use in a radiological crime scene. As a result, specialist forensic officers supported by science can safely process the crime scene, including the recovery of items contaminated with nuclear or other radioactive material outside of regulatory control. The adapted procedures include the ability to perform conventional forensic science activities, such as the examination of digital devices (e.g. mobile phones). The ability to perform examinations at the scene ensures that forensic intelligence can be quickly generated to assist the ensuing investigation. To enhance the scene-based forensic science activities, law enforcement and AWE Plc, have been funded to develop a highly mobile capability to enable the detailed examination of over-sized items, e.g. a car, which could not be sent to a laboratory. The Mobile Forensic Analysis Capability (MFAC) is based around a traditional forensic tent but has been modified with the addition of an inner containment liner that enables the safe examination of the over-sized item contaminated with nuclear or other radioactive material. A broad range of conventional forensic science activities can be undertaken in the MFAC, including chemical treatments for fingerprint development. The MFAC will provide a useful addition to law enforcement's forensic tool-box and compliments the laboratory-based Conventional Forensic Analysis Capability (CFAC).

Beyond the forensic science activities undertaken at the scene, the CFAC at AWE was developed to enable detailed laboratory examinations of the recovered contaminated items in the appropriate environment [3]. As a result, the CFAC houses two bespoke-built glovebox units that facilitate a range of conventional forensic science activities from the ability to search for and recover biological material (e.g. blood) for subsequent DNA analysis to the development and imaging of fingerprints. To ensure the CFAC continues to provide the appropriate level of scientific support to an investigation of a nuclear security event, the glovebox units have been subjected to several recent upgrade modifications. This is to enhance the ability to exam digital devices (e.g. mobile phones, memory cards and USB sticks) and the ability to utilize digital microscopy to support the screening of an item for the presence of biological material. Of equal importance, is the verification and validation of the methods associated with the different forensic science activities. As a result, validation plans have been developed, and subsequent studies initiated. These validation activities are complimented with exercises that test the ability for the CFAC to receive items from a scene and support the examination requests from the leading law enforcement entity. All these activities ensure that the scientific support provided in the CFAC to an investigation are to the standard expected by the United Kingdom Criminal Justice System.

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TWENTY YEARS OF COLLABORATIVE MATERIALS EXERCISES (CMXS) OF THE NUCLEAR FORENSICS INTERNATIONAL TECHNICAL WORKING GROUP (ITWG)

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Abstract

The paper will discuss the advancement of the science and state of practice of nuclear forensic analysis over the 20-year history of Nuclear Forensics International Technical Working Group (ITWG) Collaborative Materials Exercises (CMX).

1. INTRODUCTION

The Nuclear Forensics International Technical Working Group (ITWG) is a forum for technical collaboration among official nuclear forensics practitioners with a common interest in preventing illicit trafficking of nuclear and radioactive materials out of regulatory control. Together, this informal community of scientists, law enforcement officials, and regulators work to advance the best practices of nuclear forensics largely through the participation in a series of Collaborative Materials Exercises (CMX), formerly known as Round Robin exercises.

The ITWG Exercise Task Group (ETG) is responsible for facilitating Collaborative Materials Exercises (CMXs). These exercises are designed as learning experiences rather than performance tests for the scientific community. These exercises utilize well-characterized materials of a known history and origin and are taken from specific process locations within the nuclear fuel cycle. These “real world” materials are used as the basis of exercise materials, as opposed to laboratory-generated pure phase certified reference materials, in order to fully consider the potential significance of process-derived heterogeneities and characteristics suggestive of the material history. While individual laboratory results are held in confidence, a summary of the major outcomes from each exercise are published in the open literature. To date, the ITWG has carried out five Collaborative Materials Exercises with the sixth (CMX-6) scheduled to complete by 4 June 2019. This presentation will discuss the advancement of the science and state of practice of nuclear forensic analysis over the 20-year history of ITWG CMX’s.

IMPROVED INTERACTION OF TECHNICAL EXPERTS AND STATE LAW ENFORCEMENT AGENCIES FOR THE PREVENTION OF ILLICIT TRAFFICKING OF NUCLEAR AND RADIOACTIVE MATERIALS

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Abstract

The legal norms and legislation in Kazakhstan determine the procedure for participation and involvement of the expert and scientific centers in assisting the law enforcement agencies in the activities on prevention of illicit trafficking of nuclear and radioactive materials beyond the regulatory control.

1. INTRODUCTION

The effectiveness of the measures for combating illicit trafficking of nuclear and radioactive materials considerably depends on the level of interaction between the various agencies and organizations involved in various stages of detection, suppression and response. The legal norms and legislation in Kazakhstan determine the procedure for participation and involvement of the expert and scientific centers in assisting the law enforcement agencies in the activities on prevention of illicit trafficking of nuclear and radioactive materials beyond the regulatory control.

In this regard, the specialists of the Institute of Nuclear Physics (INP) have developed, implemented and continue to improve the methods of interaction with state law enforcement agencies in this area.

Thus, in addition to training of the law enforcement officials on the basics of radiation safety, the rules for NM/RS handling and the practical application of primary radiation monitoring equipment, the specialists at INP regularly provide assistance for the law enforcement agencies in organizing the activities on illicit trafficking of nuclear and radioactive materials.

In particular, the technical experts are directly involved at the site of the radiological incident, in order to assess the radiation risks and provide radiation safety; they perform primary study of the object and its identification, make recommendations for package and temporary storage of the seized items or substances, and also perform transportation of NM/ RS for the special study, the results of which are used for preparing the report, submitted to the investigating authorities and referred to the criminal case as evidence.

The Institute considers the following points as high priority areas for development:

- Improvement of the regulatory framework;
- Establishment of the national database of nuclear and radioactive materials;
- Development of expert, research laboratories;
- Unification of the special studies of NM/RS;
- Establishment of the storage site for NM/RS seized from illicit trafficking; and
- Establishment of the Nuclear Forensic Center in INP.

TECHNICAL SESSION II
NUCLEAR FORENSICS PRACTICES AND EXPERIENCES: CASE STUDIES

NUCLEAR FORENSICS IN PRACTICE: A RECENT CASE AND ADVANCES IN NON-DESTRUCTIVE ANALYSIS IN THE FIELD

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Abstract

The paper will detail recent experience and advances in nuclear forensics at the Federal Office for Radiation Protection in Germany. The challenges of maintaining a deployment-ready capability will be summarized and shared in this contribution, in order to contribute to lessons learned and good practice. In order to further this exchange, the equipment of the measurement team and the training and exercise programme of the BfS for nuclear forensics will be presented.

1. INTRODUCTION

The German Federal Office for Radiation Protection (Bundesamt für Strahlenschutz, BfS) has gathered considerable experience over the last decade in the identification and characterization of nuclear and other radioactive materials at the scene of a nuclear security event. This experience has been gained through numerous exercises, alarm exercises, training situations and deployments. This experience, together with technical capabilities and expertise, allows the BfS to support other police or radiation protection authorities, on the request of those authorities, during the response to nuclear security events [1]. The measurement team structure of the BfS has been presented previously [2].

In this contribution, two aspects of recent nuclear forensics work at the BfS will be presented. Firstly, practical experience gained by the BfS since 2015 during the location, identification and analysis of playing cards contaminated with iodine-125, both at the scene and in the laboratory, will be detailed. The experience has been gained partly through the support the BfS has provided to the Brandenburg Criminal Police Office (LKA-Brandenburg) and the Berlin Criminal Police Office (LKA-Berlin) during their investigation of contaminated playing cards found in Brandenburg and Berlin, see Figure 1. The aim of the work of the BfS is to contribute to the radio-logical forensics of the cards, which is a subtopic of nuclear forensics for the investigation of nuclear security events [3, 4].

Figure 1: The police ("Polizei Berlin") posted this picture of radioactively contaminated playing card pieces to social media in November 2017.

Secondly, technical aspects of the identification and characterization of nuclear and other radioactive material out of regulatory control at the scene of a nuclear security event via non-destructive means will be presented. Non-destructive analysis gives initial results directly from the scene that could be useful for a nuclear forensics investigation. It is required that a nuclear forensics analysis be carried out within the bounds of an over-arching police investigation. A destructive analysis of the nuclear or radioactive material may not always be possible, even in the laboratory, as material may have to be preserved as evidence and/or undergo additional traditional forensic analysis. An example of the type of information that can be gained at the scene from californium-252 sources (both sealed and unsealed) via non-destructive methods (in this case gamma spectroscopy) will be presented and the use of the information gained to support a nuclear forensics investigation will be discussed [5].

The challenges of maintaining a deployment-ready capability for the identification and characterization of nuclear and other radioactive materials in the field will be summarized and shared in this contribution, in order to contribute to lessons learned and good practice. In order to further this exchange, the equipment of the measurement team and the training and exercise programme of the BfS for nuclear forensics will be presented.

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NUCLEAR FORENSICS CASE STUDY: URANIUM BASED GAMMA DEFECTOSCOPE

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Abstract

The paper illustrates the methods used for characterization of uranium based gamma-defectoscopes available in the safeguards depository of IFIN-HH, for nuclear forensics purposes. Gamma Spectrometry and x-ray fluorescence (XRF) were used to determine the isotopic composition of the cylinders and the type of alloy present in the casing materials. The results obtained within this study are presented in the context of a legal investigation and outlines the role of the National Nuclear Forensics Library (NNFL), as a scientific tool that preserves the knowledge of subject matter experts and supports the legal investigations.

1. INTRODUCTION

Depleted uranium (DU) was used as fuel for nuclear reactors (breeder type) or as "armour protection or armor piercing penetrators on artillery shells" in military applications [1]. Almost 200 kg of DU are produced per each kilogram of enriched uranium for defense applications, while between 5 to 10 kilograms for commercial use. Therefore, without a meaningful utilization, DU has to be disposed as radioactive waste. Due to its high density and low toxicity when compared with lead, the U.S. Department of Energy, Office of Technology Development began to study the benefits of using DU as radiation shielding [1]. Considering its physical properties, it has been used for storage and transportation of contaminated materials, or in the fabrication of canisters and cylinders to shield highly radioactive sources. For instance, industrial devices use radioactive sources with activity up to few terabecquerels (TBq) such as iridium-192 and cobalt-60 for various applications such as radioactive gauge measurements and gammagraphy. [2]

Nuclear and other radioactive materials found outside regulatory control are mainly a result of thief or loss due to improper physical protection within the facilities the materials are stored and/or used. However, cases of highly enriched uranium or plutonium samples are quite rare, due to the difficulty to obtain these materials and to handle them safely. Moreover, the physical protection of special nuclear materials is much stricter than for industrial devices that use radioactive sources. Depleted uranium containers are often encountered outside regulatory control, mostly originating from industrial or medical facilities that seized their activity without ensuring the physical protection of the radioactive materials within their holdings according to the national safeguards system of accountancy and control.

The present study uses the non-destructive capabilities of the Romanian Nuclear Forensics Laboratory to determine the relevant nuclear forensics signatures of DU cylinders contained in the gamma-defectoscopes used for industrial applications. The research is supported by the necessity to prevent these materials to fall outside regulatory control and to include relevant information in the NNFL, such that to be used by nuclear forensics experts to perform comparative analyses between seized materials and those included in the state's holdings.

Gamma-defectoscopes devices available within the Safeguards Department of IFIN-HH were selected for this study. Moreover, it will be illustrated how the results of this research were successfully used within a real forensic investigation.

2. NON-DESTRUCTIVE ANALYSES

Non-destructive techniques were used to characterize U based gamma-defectoscopes from the Safeguards Department of IFIN-HH for nuclear forensics purposes.

The study's aim was to determine the key nuclear forensics signatures such as the isotopic composition of the uranium cylinders and the major elements present in the casing materials by using high resolution gamma spectrometry and X-Ray Fluorescence (XRF). While the nuclear physics methods provide a quick and reliable characterization of the material, the visual inspection reveals elements (text dimension and spacing, color, etc.) with investigative value from investigation perspective that could be used for origin assessment. Elements of traditional forensics were included in the examination plan ensuring a synergy between the nuclear and traditional forensics methods.

The results obtained from the present study of DU materials used in gamma-defectoscopes allowed us to contribute and add relevant nuclear forensics signature information in the NNFL. Relevant nuclear and traditional forensics parameters identified within this study were used by judicial authorities and scientific experts in the context of a legal investigation of U based sample found outside regulatory control.

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RADIOLOGICAL CRIME SCENE – FROM THE ARENA TO THE LABORATORY

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1. INTRODUCTION

The Israeli National Nuclear Forensics Laboratory (INNFL) was established in 2011, as part of the Israel Atomic Energy Commission (IAEC) contribution to the national response plan to cope with nuclear and radiological terrorism. The role of the INNFL is to assist law enforcement authorities in investigating illicit trafficking of radioactive materials and help bring the perpetrators to trial.

The INNFL is based on cooperation between the IAEC nuclear research centers (Soreq Nuclear Research Center (SNRC) and Nuclear Research Center Negev (NRCN)), and the operational government bodies responsible for investigating and handling such events – the Israel Police and the IAEC first responder's unit. This cooperation relies on the complementary experiences of the Israel Police (handling forensic investigations) and of the nuclear laboratories (investigating radioactive materials).

The INNFL is involved in the different scientific fields required for building nuclear forensics capacities: radiological measurements, radiography, analytical chemistry, particle analysis, mass spectrometry and operational issues.

The nuclear forensics capabilities of the INNFL are supported by scientific research conducted continuously on a variety of topics, mostly focused on different methods of attribution relying on the specific expertise of the two research centers.

The nuclear forensics capabilities can be divided to two different categories. The first category is the examination of radioactive and nuclear materials. Recent investigations involving such capabilities were conducted following discoveries of shipments with an Am/Be neutron source in Ashdod Port and a Ra/Be neutron source in Haifa Port. The second category is the classical forensic examination of radioactively contaminated evidence, such as fingerprints and DNA.

The seizing of radiological abandoned sources (Ra-Be, Am-Be) at Haifa and Ashdod sea ports will be described. Scientific effort towards characterization of the Ra-Be source will be presented in detail. Insights regarding difficulties encountered will be shared with the audience. The Ra-Be source is presented in the figure below:

Fig.1: Ra-Be Source (At the arena on the left, Radiography on the right)

The INNFL team is taking part in international organizations and activities intended to promote cooperation, technical capabilities and worldwide nuclear security, such as the Global Initiative to Combat Nuclear Terrorism (GICNT) and the Nuclear Forensics International Technical Working Group (ITWG).

INVITED PERSPECTIVES I

NUCLEAR FORENSICS AND CRIMINAL PROSECUTION

IMPLEMENTING NUCLEAR FORENSICS IN A CIVIL LAW SYSTEM COUNTRY: CASE STUDY ROMANIA

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Abstract

The paper presents challenges associated with the implementation of nuclear forensics within the national legal framework with the purpose to collect, analyse, and interpret evidence of illicit activities involving nuclear or other radioactive materials found out of regulatory control. It provides an overview of the main aspects related to the integration of nuclear forensics into the criminal investigation while focusing on the specificities of the civil versus common law systems. A “Country Case Study: Romania” is taken as an example of successful implementation of the nuclear forensics capabilities within the national legal system.

1. INTRODUCTION

The IAEA recommends that member states develop nuclear forensics capabilities according to their nuclear security related needs [1]. However, after such needs are identified and technical capabilities are established, it can prove challenging to implement nuclear forensics as a functional tool to prevent and respond to Nuclear Security Events on a national level. One of the reasons for this, is the specificity of national legal provisions, while the existing international guidance on this matter is mainly addressed from the common law systems’ perspective. The question remains “can a guidance which matches all the law systems be developed or rather it has to be an individual approach?”

2. OVERVIEW OF MAIN LEGAL SYSTEMS

Most law systems in the world belong to either civil law or common law, or are a mixture of the two, while in a few other cases Islamic law applies. When implementing new scientific tools like those offered by nuclear forensics within the scope of the criminal investigation, the peculiarities of various legal systems have to be taken into consideration.

3. NUCLEAR FORENSICS WITHIN CIVIL LAW

Nuclear forensics is employed within the criminal investigation in a similar manner to other traditional forensics’ domains and has to be utilized in legal procedures in conformity with the national legal framework of the specific country. Nuclear forensics can help criminal investigation bodies find the truth about a specific incident concerning unlawful activities with nuclear or radioactive material. Regulatory bodies or other national stakeholders possessing information of nuclear or other radioactive materials available in the country, might provide informational support together with subject matter expertise for forensics experts.

As reported in this paper and, as envisaged by the findings of comparative law, in civil law systems it is usually the judicial authorities that decide on the prosecution or even investigation of a case, or the exchange of information and cooperation with foreign entities in order to secure evidence. However, in practice, when establishing points of contact in different states for the purpose of exchanging information or promoting the use of nuclear forensics, there is many times an oversight of these peculiarities by the international organizations and donors, who tend to associate the response to illicit activities involving nuclear or other radioactive materials, only with main national authorities competent to regulate, control and authorize activities in the nuclear field, or lead agencies responsible for security. This confusion leads to unwanted consequences i.e. lack of awareness about the nuclear forensics capabilities and nuclear security issues among judicial entities like prosecutors, judges and judicial police, ineffective handling of situations where nuclear or radioactive materials are involved, lengthy delays and inadequate exchanges of relevant information. The main consequence can lead to the failure of opening criminal cases when appropriate or impedes conducting proper investigations.

4. CASE STUDY: ROMANIA

Romania has a well-established legal framework for nuclear safety and security, which is in accordance with international treaties and IAEA recommendations. Nevertheless, though during the last 30 years around 40 cases of incidents involving nuclear or other radioactive materials have been counted by the regulatory body [2], there were virtually no criminal cases opened. The Romanian Government together with the GICNT organized two regional exercises aimed to test the existing legal framework and procedures, which resulted in establishing of a close cooperation between DIICOT (Prosecutor’s Office) and IFIN-HH (Nuclear Forensics Lab), which lead to increased efficiency of the national response to nuclear security events. As a result, there were 5 criminal cases opened and 6 nuclear forensics reports provided to the judicial authorities to advance the criminal investigations in 2017-2018.

The paper will provide conclusions relevant for the international nuclear forensics community as well as civil law countries. The most relevant conclusion is perhaps that every seizure of material out of regulatory control (MORC), insofar as it represents an illicit activity punishable by the criminal law, should be followed by opening a criminal investigation and subsequent prosecution. This would allow the competent authorities to fully investigate the event and to enforce legal sanctions as appropriate, while also employing all the cooperation instruments available.

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TECHNICAL SESSION III
NUCLEAR FORENSICS INITIATION AND SUSTAINABILITY: NATIONAL CONSIDERATIONS I

NUCLEAR FORENSICS CAPABILITY BUILDING IN HUNGARY

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Abstract

The paper describes the establishment of nuclear forensics capabilities in Hungary including the role of relevant organizations, nuclear forensics expertise, technical background, analytical methods developed and mobile capabilities.

1. INTRODUCTION

Nuclear forensics started in the early 1990s in Hungary following several confiscations of smuggled uranium-containing materials at the Hungarian borders.

Officially, the MT EK (i.e. the former Institute of Isotopes) has been designated by Hungarian Government with the task of the analysis and origin assessment of confiscated nuclear and other radioactive materials by a Governmental Decree (17/1996 - updated recently as, 490/2015). The Hungarian Government and the Hungarian Atomic Energy Authority (HAEA) - as the responsible national authority – have always supported strongly nuclear forensics activities in Hungary.

The basis of nuclear forensics examination was gamma-spectrometry and neuron detection. Nuclear physics and longstanding research and experiences in gamma-spectrometry was available already from the 70's at MTA EK.

For nuclear forensics capacity building, MTA EK started to build strong cooperation with the International Atomic Energy Agency (IAEA) and the Nuclear Forensics International Technical Working Group (ITWG)

During the past several years, nuclear forensics activities have been methodically expanded at the MTA EK. In 2014, a new nuclear forensics laboratory was established to include state-of-the-art instrumentation and analytical methods. A new Mobile Laboratory was equipped with handheld radioisotope detection devices as well as large sensitive remote detector systems. A mobile expert support team was also established to help the authorities in radiological crime scene management. Key elements of capacity building and maintaining sustainable nuclear forensics knowledge and expertise were the continuous participation of MTA EK in inter-laboratory comparison exercises in the field of nuclear forensics organized by the ITWG from 2001, and in specific coordinated research projects (CRPs) of IAEA.

National field exercises have also been organized in Hungary during the past decades to simulate the detection and confiscation of nuclear and other radioactive materials with the participation of the relevant Hungarian authorities at the Hungarian border crossing locations as well as within the country. MTA EK has further organized a number of high profile scientific events in the context of international nuclear forensics. Requests for training in nuclear forensics have increased during the last few years and, as a result, MTA EK has implemented several courses in cooperation with the EC JRC Karlsruhe Institute and the IAEA. The development of a National Nuclear Forensics Library (NNFL) aiming at the interpretation indicative of the origin and history of nuclear and other radioactive materials encountered out of regulatory control is also in preparation.

Close cooperation with responsible Hungarian Authorities and organizations (e.g. HAEA, Hungarian Police, Traditional Forensic Research Institute, Counter Terrorism Centre, Ministry of Foreign Affairs, Hungarian Army, Intelligence Office, National Tax and Customs Administration) started in 2015 to combat nuclear terrorism. The MTA EK and HAEA initiated a formal working group with these authorities and organizations to foster better national level communication leading to a more effective response to a nuclear security event. National Response Plan and preparation of a national exercises following the scenario after a terror attack using radiological materials are in progress. There are common projects with the Hungarian Police supported by the Ministry of Interior (e.g. Development of Common Standard Operating Procedure for Radiological Crime Scene Management).

Following all these activities and longstanding co-operation with the IAEA, MTA EK was nominated the first IAEA Collaborating Centre for nuclear forensics in 2016. MTA EK gains advantages through even closer cooperation with IAEA and Member States in the Central-Eastern European region strengthening the common international efforts and actions against nuclear terrorism potentially affecting the region. MTA EK shares knowledge, experiences and capabilities with Member States. Hungary has already several bi-lateral agreements with other Member States in the region to co-operate in the field of nuclear forensics.

The main tasks of the IAEA Collaboration Centre in Hungary is to provide technical assistance for other Member States; to participate in scientific programs in the field of nuclear forensics and to host different IAEA training programs, like the 1 week Practical Introduction Training Course or 2.5 month long Residential Assignment Program. The first one is an introductory laboratory based hands-on course, piloted in Hungary in 2014. The Residential Assignment Program is the most advanced training program of the IAEA in nuclear forensics. The program in Hungary includes a nuclear forensics examination in the real time-frame (2 months) following the international guidelines and standards of IAEA and ITWG. It contains a team exercise based on hypothetical scenarios and follows the examination from evidence collection, through material characterization at the laboratories until data interpretation, origin assessment and answering the questions of the investigator.

MTA EK's mission is to extend and develop capabilities in nuclear forensics to strengthen the Hungarian national nuclear security system as well as to share knowledge and experiences with other states regionally and internationally to help and co-operate with them.

SUPPORTING DEVELOPMENT OF KENYA'S NUCLEAR SECURITY INFRASTRUCTURE VIA CAPACITY BUILDING IN FORENSICS RESEARCH

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1. INTRODUCTION

Due to the distinctive characteristics of the nuclear fuel cycle, there are special nuclear security educational requirements for developing a national nuclear security infrastructure to realize a proliferation-free nuclear power program. This paper recognizes and discusses the low levels of nuclear security educational capacity at Kenyan universities and identifies appropriate strategies for remedying the situation, chief of which is the current effort at the University of Nairobi supporting developing educational capacity in nuclear security via research in nuclear forensics.

Nuclear forensics is an essential component of the national nuclear security infrastructure because it helps to address the threat of nuclear material being found out of regulatory control. Due to the lack of staff and experimental facilities, it is not currently feasible to launch a full-fledged educational program in nuclear security at any of Kenya's universities.

Nuclear forensics research is discussed as a means to both foster scientific innovations in nuclear security and to support non-proliferation by enabling the identification of high-confidence nuclear forensic signatures. Because nuclear forensics draws upon analytical techniques and interpretation of distinguishing characteristics of nuclear and radioactive materials to understand its origin and intending authorized use, the research line in nuclear forensics at Nairobi involves photonics-based spectral imaging and microanalytical method developments in support of nuclear security. Among other techniques laser induced breakdown spectroscopy (LIBS) spectral/imaging and confocal laser Raman spectromicroscopy are exploited to elucidate comprehensively the isotopic, molecular and elemental composition, as well as microstructure of nuclear materials (each step in the fuel cycle creates and/or modifies these nuclear forensic (NF) signatures).

Some results will be reported and the link between nuclear forensics and nuclear security examined in detail in the context of the results. Finally, the paper reports how experience gained so far suggests that progress in educational capacity building in nuclear security may be realized by stronger involvement of stakeholders in the nuclear fuel cycle, demonstrating the great significance of nuclear forensics in nuclear security infrastructure development of a nation.

CAPABILITIES AND EXPERIENCE OF THE INSTITUTE OF NUCLEAR PHYSICS IN THE REPUBLIC OF KAZAKHSTAN IN NUCLEAR FORENSICS

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1. INTRODUCTION

The Republic of Kazakhstan is a unique country and combines its current non-nuclear status and a serious nuclear past. At the time of independence, Kazakhstan had nuclear military capabilities and appropriate infrastructure for its use, and afterwards the country refused its application on a voluntary basis. There are a large number of radiation-hazardous objects of different types located on the territory of the Republic of Kazakhstan: the sites of nuclear testing, the research and nuclear power plants, the uranium- and oil- mining and processing plants. Large volumes of nuclear and radioactive materials in Kazakhstan cause serious risks of illicit trafficking and nuclear smuggling. At the same time, it is necessary to take into account the geo-political position of Kazakhstan, the country that is located in the very center of Eurasia close to such countries as China, Russia, Kyrgyzstan, Uzbekistan, Iran, and Afghanistan. Kazakhstan considers the issues of combating illicit trafficking of nuclear and radioactive materials, including nuclear forensics to be of great importance.

The activities of nuclear forensics are mainly performed in the Institute of Nuclear Physics (INP). One of the main activities of the Institute of Nuclear Physics is development and application of the nuclear physical methods for analysis of the environmental objects including mineral raw materials. Having retained the intellectual and scientific capabilities through the collapse of the Soviet Union, in recent years the Institute was able to upgrade the scientific instruments and methodological frameworks in this area and to gain the valuable experience in development of the instrumental methods of elemental and radionuclide analysis. Currently, the complex of nuclear-physical methods of analysis is available in the INP, established on the existing spectrometric and analytical equipment, including the methods of elemental analysis such as neutron activation analysis, X-ray fluorescence analysis, inductively-coupled plasma mass spectrometric analysis and the complex of instrumental and radiochemical methods of analysis of radionuclide and isotopic composition.

The INP has designed and developed the special hardware-and-methodological system providing the forensics examination of various nuclear and radioactive materials and products. The wide range of available equipment and procedures is applied for study of the materials/products received for examination.

The INP is licensed for handling of ionizing radiation sources, radioactive substances and waste, and for providing the services in nuclear energy application, including determination of radionuclides in the materials, environment objects; it operates necessary technical equipment for the wide range of analytical research in applied nuclear physics, including the specialized laboratories and the qualified staff of former “weapon” specialists with experience in similar work. The INP applies the quality management system in accordance with the international standards ISO 9001:2000, confirmed by relevant certificates. The Center of Complex Ecological Research in the INP is accredited to meet the requirements of Standard ISO/IEC 17025 - 2007 “General requirements for competence of testing and calibration laboratories”. The quality of analyses is confirmed by successful participation in many international inter-laboratory comparisons and professional tests organized by IAEA.

Lately, the international cooperation of INP is dynamically developing in nuclear forensics. Many workshops, trainings and conferences have been held in Kazakhstan. We can note the scientific practical conference “Development of the analytical plan to support nuclear forensics” (Almaty, 2015), which was supported by DOE with participation of the specialists from several US National Laboratories.

The representatives of the INP have participated in several meetings of the International Technical Working Group. The Inter-laboratory comparison study of nuclear materials from the Lawrence Livermore National Laboratory, US DOE has been completed. The INP participated and continue to participate in various exercises “Csodaszarvas: Mystic Deer”, “Galaxy Serpent”, CMX-5, CMX-6. Now the partner project of the International Science and Technology Center “Advancement of material technical and regulation-methodological framework for Nuclear and Radiologic Materials Forensics in the Republic of Kazakhstan” is being implemented jointly with LLNL

ROLE OF INTERNATIONAL RECOMMENDATIONS IN DEVELOPMENT AND MAINTAINING STABLE CAPABILITIES OF NUCLEAR FORENSICS

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1. INTRODUCTION

International nuclear forensics documents can play a significant role in helping countries in developing as well as in maintaining stable national nuclear forensics capabilities. These documents can accumulate whole experience, gained by different countries in solving problems that arise in both: in setting analytical tasks and in analyzing NRM samples or samples contaminated with trace amounts of NRM.

International recommendations for the development and maintenance of stable nuclear forensic capabilities may have two directions:

- Proposals for the organization and improvement of the national system for identification of NRM, detected outside regulatory control;
- Recommendations for performing analyses of samples in the framework of forensic examination of physical evidence.

Proposals for the organization and improvement of the national system should be developed by a team of specialists in different fields and from different countries. The team of authors should include representatives of law enforcement agencies: experts in the field of legislation, as well as practitioners conducting criminal investigations, and both kinds of analysts: experts in the field of nuclear forensic examinations as well as experts in traditional forensic techniques. Moreover, if the document under development concerns practical recommendations on interaction with courts, than countries with different judicial systems and with different rules and traditions of law enforcement agencies should be represented in the team. If the recommendations contain proposals for structural changes in existing national services and organizations, these recommendations should be discussed with representatives of such services and organizations from different countries. These proposals should have clear purposes and contain only carefully verified definitions, basic concepts and approaches. These definitions, concepts and approaches must comply with the definitions, basic concepts and approaches developed and adopted in other areas of forensic science, and should not contradict the culture of the forensic community.

It is highly appreciated that state decision makers take part in the development of these recommendations. Their experience makes it possible to evaluate the applicability of the proposed recommendations, estimate their viability and, if necessary, adjust the recommendations.

Concretization of general concepts, such as international cooperation, interdepartmental interaction and others, is necessary. Such concretization allows the persons, studying these recommendations, to understand what aspects of these concepts are being discussed and to recognize the resource, which is necessary for performing these components of the recommendations.

One of the successful examples of the document being developed on the fields of nuclear forensics in the international format is a document on the countries' self-assessment of their own capabilities in this field. Recommendations for performing forensic examination of physical evidence can be useful only if they are developed by analysts who have experience in performing such examinations. Herewith, it is not necessary in these recommendations to provide detailed information about all the possibilities of the methods and on the general rules for processing the measurement results. Such information can be gleaned from textbooks and other special literature.

In such recommendations it is important to focus on the informativeness and features of the analysis, which are due to the physical specificity of the samples, which can be held as evidence in the investigation, as well as due to juridical status of these samples. Examples of such recommendations are documents developed by nuclear forensics international technical working group.

INVITED PRESENTATION I

NUCLEAR FORENSICS SPECIAL TOPICS: NUCLEAR FORENSICS INTERNATIONAL TECHNICAL WORKING GROUP (ITWG)

THE NUCLEAR FORENSICS INTERNATIONAL TECHNICAL WORKING GROUP (ITWG): A UNIQUE FORUM OF PRACTITIONERS CONTRIBUTING TO GLOBAL NUCLEAR SECURITY

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1. INTRODUCTION

The Nuclear Forensics International Technical Working Group (ITWG) is an informal, unaffiliated association of nuclear forensics practitioners that identifies, develops, and promotes best practices in the field of nuclear forensics. It was established in 1995 amidst heightened concerns over the threat posed by nuclear smuggling and continues to help forensics practitioners investigate nuclear security events. To advance its mission, ITWG carries out a variety of unique activities including the conduct of exercises designed to inform best practices and the production of guidelines documents on nuclear forensics techniques. ITWG works actively with other international nuclear forensics efforts like the Global Initiative to Combat Nuclear Terrorism (GICNT) and the International Atomic Energy Agency (IAEA) to promote forensics as a nuclear security tool, and its activities both inform and complement work done by the GICNT and IAEA.

The ITWG conducts much of its work through Task Groups. There are presently five task groups: Evidence & Testimony, Exercises, Guidelines, National Nuclear Forensic Libraries, and Training & Outreach. Additionally, the ITWG meets annually, with the first part of the annual meeting being devoted to the ITWG Nuclear Forensics Laboratories (INFL), where the presentations and discussions are largely technical and aimed at the laboratory practitioner as well as professional development. The second part involves individual sessions of the task groups as well as plenary sessions where the presentations are of more general interest. The most recent meeting of the ITWG, i.e. ITWG-23, was held in June 2018 at Switzerland's Federal Training Center in Schwartzenberg, with the SPIEZ laboratory serving as host.

The ITWG task groups focus on particular scientific and technical aspects of nuclear forensics.

- In the **Evidence & Testimony Task Group** questions related to the collection, preservation and handling of evidence from a radiological crime scene are discussed, bringing together the needs and priorities of law enforcement and measurement experts.

- The **Exercises Task Group** organizes and performs collaborative material exercises that are not intended as proficiency testing but rather as joint learning exercise.
- The **Guidelines Task Group** develops consensus technical and scientific guidelines covering all aspects of a nuclear forensic investigation (e.g. evidence collection, gamma spectrometry, mass spectrometry, signatures of uranium fuel pellets, graded decision framework).
- The **National Nuclear Forensic Libraries Task Group** addresses technical questions related to establishing, populating and using libraries in support of nuclear forensic interpretation.
- **Training & Outreach** activities are addressed in the fifth task group, where the communication within ITWG (restricted website), the presentation to the public and interested parties (open website) and sharing of experience and capacity building are addressed.

The ITWG serves as a bridge to law enforcement and other disciplines of forensics science and nuclear security, e.g. safeguards and environmental monitoring. Experts from more than fifty countries have participated in ITWG activities over the past twenty years. Participation in the ITWG is open to qualified experts affiliated with a competent national or international authority recognized by the ITWG. By coming together in an informal network, ITWG participants can fulfil the role of advancing best practices in nuclear forensics. An example of the work of the ITWG is the conduct of collaborative laboratory-based material exercises. To date, ITWG has conducted five such exercises (a sixth is currently underway) that involve laboratories in 25 countries and the European Commission. (See Table 1.) Results have helped the ITWG participants to identify best practices, promising analytical techniques as well as laboratory methods in need of additional development.

TABLE 1. LIST OF LABORATORIES THAT HAVE PARTICIPATED IN ITWG COLLABORATIVE MATERIAL EXERCISES

Country	**Laboratory Name**
Australia	Australian Nuclear Science and Technology Organisation
Austria	Austrian Research Center at Seibersdorf
Brazil	Comissao Nacional de Energia Nuclear
Canada	Defence Research and Development Canada
China	China Institute of Atomic Energy
Czech Republic	Nuclear Research Institute
European Commission	Joint Research Center in Karlsruhe
France	Commissariat à l’Energie Atomique et aux Energies Alternatives
Germany	Institut für Radiochemie, München
Hungary	Institute of Isotopes, Hungarian Academy of Sciences
Israel	Soreq NRC Radiation Protection Division
Japan	Japan Atomic Energy Agency
Kazakhstan	Center of Complex Environmental Research, Institute of Physics
Korea	Korea Atomic Energy Research Institute
Lithuania	Institute of Physics in Vilnius
Moldova	Laboratory of Radiology and Radiation Control
Netherlands	Center for Environmental Safety and Security
Poland	Institute of Nuclear Chemistry and Technology

Romania	Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering
Russia	Laboratory for Microparticle Analysis
Singapore	DSO National Laboratory
South Africa	NECSA-NOMS, Nuclear Forensics Lab
Sweden	FOI CBRN Defence and Security
Turkey	Cekmece Nuclear Research and Training Center
United Kingdom	Atomic Weapons Establishment
United States	Lawrence Livermore National Laboratory

ITWG produces guidelines on nuclear forensic methods and techniques and a quarterly newsletter. (See list of ITWG Guidelines in Table 2.) Both are available on its website (www.nf-itwg.org). The newsletter includes updates on ITWG and other activities in the field of nuclear forensics, perspectives from different laboratories around the world, and a calendar of community events.

TABLE 2. LIST OF ITWG GUIDELINES

Name of ITWG Guideline
Guideline on Alpha Spectrometry
Guideline on Evidence Collection in a Radiological or Nuclear Contaminated Crime Scene
Guideline on High-resolution Gamma Spectrometry – General Overview
Guideline on In-field Applications of High-resolution Gamma Spectrometry
Guideline on Laboratory Applications of High-resolution Gamma Spectrometry
Guideline on Powder X-ray Diffraction (XRD)
Guideline on Secondary Ion Mass Spectrometry (SIMS)
Guideline on Thermal Ionization Mass Spectrometry (TIMS)
Guideline on Age Dating
Guideline on Characteristic Parameters of UO2 Fuel Pellets
Guideline on Elemental Assay – Pu Titration
Guideline on Elemental Assay – U Titration
Guideline on Importance of Uncertainty in Nuclear Forensics Measurements

The presentation will highlight contributions the ITWG has been making to nuclear forensics for over twenty years. While the ITWG is an informal gathering of experts, it contributed significantly to advancing nuclear forensic science. This materialized in contributions to several IAEA nuclear security guidance documents, in scientific developments (signatures and methods), in publications on scientific and conceptual issues, and in dedicated workshops that have reached experts from more than fifty countries. Specific technical presentations on ITWG's material characterization and NNFL exercises will be offered separately at the IAEA *Technical Meeting on Nuclear Forensics: Beyond the Science* in April 2019.

TECHNICAL SESSION IV
NUCLEAR FORENSICS HUMAN RESOURCE DEVELOPMENT: RESIDENTIAL ASSIGNMENT

INTRODUCTION OF THE IAEA RESIDENTIAL ASSIGNMENT PROGRAM FOR NUCLEAR FORENSICS HOSTED BY MTA EK IN HUNGARY

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1. INTRODUCTION

Following long-standing activities and cooperation with the IAEA in the field of nuclear forensics, the Hungarian Academy of Sciences Centre for Energy Research (MTA EK) was nominated to a Collaborating Centre for nuclear forensics of the IAEA in 2016. The main tasks of the Collaboration Centre are to provide technical assistance for IAEA Member States, to participate in scientific programs in the field of nuclear forensics, and to host different IAEA training programs, like the 1-week long Practical Introduction Training Course or 2.5 month long Residential Assignment Program on nuclear forensics.

The Residential Assignment Program is the most advanced nuclear forensics training program of the IAEA. The objective of the program in Hungary is to provide a scientist in-residence with a comprehensive overview and understanding of the scope and application of nuclear forensic examination. It includes practical learning objectives associated with the commencement of a nuclear forensics examination, training in the techniques and methods used within the nuclear forensics laboratory as well as in evidence handling techniques. A model case exercise is used as part of the laboratory study to emphasize the key learning objectives. The main aim of the program is to follow a nuclear forensics examination in the real time-frame (2 months) considering the international guidelines and standards from the IAEA and Nuclear Forensics International Technical Working Group (ITWG) and using real nuclear samples, as well as all the analytical techniques which are offered by the guidelines and available at MTA EK. A key part of the program is a team exercise based on hypothetical scenarios and follow the examination from crime scene investigation and evidence collection, through material characterization at the laboratories until data interpretation, origin assessment and answering the questions of the investigator. The program is also extended with specific scientific interest of the participants.

At the beginning of the program, each participant was provided with individual scenarios. One of the hypothetical stories is taking place at the border of Country A and Country B. During the investigation of the car by the mobile expert support team (MEST), ^{60}Co contamination, ^{137}Cs-containing white powder in a plastic bag and uranium-containing object were found.

After receiving the request of law enforcement for nuclear forensics examination and relevant questions, an analytical Plan was prepared following guidelines, techniques available and considering the questions of the investigator.

Samples were analysed under controlled conditions using different techniques as physical characterization in a glove box, high resolution gamma ray spectrometry, scanning electron microscopy (SEM), X-ray diffraction and mass spectrometry.

The 24-hour measurements concluded that the seized sample contains nuclear material, low-enriched (LEU) in ^{235}U (~2.44% ^{235}U). During further examination (1-week and 2-months), the following data were obtained:

Production date of the LEU sample was estimated as 18/12/1991.

The value obtained for the ^{236}U isotope content (0.4712 wt% ^{236}U) confirmed that RSP-1 is composed of reprocessed material. The SEM analysis revealed irregular pentagonal shape of grains and also intragranular small pores along its surface, which are characteristic to ^{2}UO pellets. The EDS analysis confirmed that RSP-1 contains mainly uranium, oxide, carbon and nitrogen. The results were also confirmed by the XRD analysis. The Nuclear Forensics Laboratory had an access to the Nuclear Database that contains information about the reactor type, supplier, geometric dimensions and uranium isotopic composition. The sample RSP-1 was identified as fuel pellet from Soviet reactor type: RBMK-1000. There are two potential origins for the sample "Ulba Metallurgical Plant" Joint-Stock Company ("UMP" JSC), Kazakhstan or "Mashinostroitelny zavod" (ELEMASH) (MZ), Russia.

The relatively increased Zn, Al, Ni, Cr and Fe concentration levels imply that both origins are possible as both manufacturers use similar dry chemistry methods for fabrication of fuel pellets.

Despite some small resemblances with the other three open cases in country A and country B (e.g. age or isotopic composition), the physical dimensions and isotopic composition differentiate the sample RSP-1 from the others, thus there is no possible common origin for them.

As a specific extension of the program, during the gamma-spectrometric training, it was noticed that for a reprocessed sample the MGAU v4.2 software is overestimating the abundance of ^{235}U. One of the assumptions was that the MGAU v4.2 does not take into consideration the contribution from ^{232}U isotope.

Future measurements were required in order to prove that for reprocessed samples, MGAU v4.2 does not give accurate results. The experiment consisted in measuring more reprocessed samples to gain an understanding regarding the algorithm and how it is possible to update it in order to obtain precise results.

Due to the difficulty of finding a pure ^{232}U containing material, by simply placing a ^{232}Th containing material near "normal" samples, one can fake the reprocessing characteristic.

In order to increase the confidence in the experiment, measurements will also take place in Romania at Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering and also at the Joint Research Centre (JRC) in Karlsruhe.

IAEA RESIDENTIAL ASSIGNMENT FOR HUMAN CAPACITY BUILDING: EXPERIENCES OF AN ARGENTINIAN MASS SPECTROMETRIST AT LAWRENCE LIVERMORE NATIONAL LABORATORY USA

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1. INTRODUCTION

The International Atomic Energy Agency (IAEA) Division of Nuclear Security has partnered with the U.S. Department of Energy's National Nuclear Security Administration (DOE/NNSA) through the Office of Nuclear Smuggling Detection and Deterrence (NSDD) and Lawrence Livermore National Laboratory (LLNL) to organize an International Residential Laboratory Assignment for Human Capacity Building in Nuclear Forensic Measurements with the Argentinean government through the Sub-Secretariat of Nuclear Energy and the National Atomic Energy Commission (CNEA).

Argentina has almost seventy years of experience in nuclear technology research and development of nuclear energy for peaceful purposes, both nationally and in the region. More specifically, CNEA's Mass Spectrometry (EM) Laboratory has been building expertise and gaining confidence in the uranium isotopic analysis of different nuclear samples through all these years. With proper analytical techniques and training in nuclear forensic methodologies, it will be capable to answer the questions from law enforcement authorities in the event of a nuclear security incident.

This IAEA Residential Assignment places a technically qualified nuclear scientist at a leading nuclear forensic laboratory for a period of sixty-three working days. The goal of this IAEA program is to enhance the skills and confidence of the resident scientist performing analytical measurements in support of a comprehensive nuclear forensic examination. These skills seek to improve the knowledge and expertise available for nuclear forensic analysis at the home organization. In this context, Marta Bavio, a mass spectrometrist from CNEA was selected for this most recent Residential Assignment under the stewardship of the LLNL Nuclear Forensics Team. The IAEA residential assignment has been successfully implemented in leading nuclear forensic laboratories in Europe however, this is the first time the IAEA Residential Assignment is being hosted at a U.S. National Laboratory. By hosting this residential assignment, LLNL is supporting not only the IAEA, but also its emerging nuclear forensics collaboration with Argentina through NSDD. LLNL has been the primary laboratory for this collaboration and LLNL/NSDD remain highly committed to further advancing its nuclear forensics engagement with Argentina.

The research topic for this assignment was focused on isotopic and elemental concentration measurements of a commonly-used, widely available, certified reference material (CRM) 125A, using Multi-Collector Inductively Coupled Plasma (MC-ICPMS), and single collector (low and high) resolution ICPMS (Q-ICPMS / HR-ICPMS). The associated sample preparation processes, calibrations, and mass spectrometry techniques were exercised with LLNL scientists. Results obtained allowed for the determination of Thorium-Uranium (Th-U) and Protactinium-Uranium (Pa-U) model ages by radiochronometry.

As it is best to first test the laboratory's capabilities on a well characterized sample, CRM 125A was chosen as the "forensic sample". CRM125A a uranium oxide (UO_2) pellet that is certified for isotopic composition and Th-U radiochronometry, as well as being a potential type of sample that could be interdicted by law enforcement. To characterize CRM 125A, many weeks of laboratory chemistry were required, including digestions, chemical separations and purifications, and isotopic tracer (spike) calibrations. For Th-U and Pa-U radiochronometry, we followed the methods described in Treinen et al., 2018. For trace element determination, we followed LLNL's trace element sample analysis methods.

Age dating results for Th-U and Pa-U chronometers show that we are within the stated uncertainty for CRM 125A. The certificate age of CRM 125A is August 18th, 1994 ± 116 days (2-σ). Th-U age determinations were made for three aliquots of CRM 125A between April-May 1994 (±53 days, 2-σ) and Pa-U ages of May-June 1994 (±52 days, 2-σ). These results are consistent with the certified Th-U age as well as historical age-dating results of CRM 125A at LLNL. To calculating the model age of a nuclear material, there are two primary assumptions: (1) the daughter isotope was completely purified from the parent isotope, and (2) the sample has not lost or gained either parent or daughter isotopes, except by radioactive decay (i.e., the sample is effectively a closed system).

These results required the careful determination of the sample's uranium concentration by isotope dilution mass spectrometry (UID), uranium isotopic composition (UIC), and thorium and protactinium by isotopic dilution mass spectrometry (ThID / PaID). All results were obtained by MC-ICPMS with mass fractionation and decay corrections, when corresponding.

The assignment's duration was sufficient to cover all the proposed program goals with additional time to investigate other topics, including complementary nuclear forensics analytical techniques, additional sample matrices including uranium ore concentrates, and data reduction techniques including uncertainties propagation.

From the detailed mass spectrometry approach to the wider, complex and multidisciplinary nuclear forensic point of view, the scientist experienced the difficulty on putting together all the key parts (materials, reagents, dedicated working spaces, analytical instruments) and most of all, the human effort and knowledge that are needed to build-up a confident nuclear forensic capability.

ACKNOWLEDGEMENTS

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. LLNL-ABS-760431.

IAEA HUMAN RESOURCE DEVELOPMENT PROGRAM

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Nuclear or other radioactive material could be used in criminal or intentional unauthorized acts, creating a threat to international security; the most concerning nuclear security issue in the world. The IAEA assists Member States to implement and to maintain a national nuclear security regime for improving nuclear security, managing radioactive sources and combatting nuclear terrorism. All States should be aware of the role of nuclear forensics in supporting nuclear security. Nuclear forensics can assist in investigations of nuclear security events as well as help to identify and remedy vulnerabilities in a State's nuclear security infrastructure. A nuclear forensic capability as a preventive measure is effective because it supports both the identification of deficiencies in material security and the prosecution of criminal offences related to this material. Nuclear forensics is the examination of nuclear or other radioactive material, or evidence that is contaminated with radionuclides, in the context of legal proceedings under international or national law related to nuclear security. The analysis of nuclear or other radioactive material seeks to identify what the materials are, how, when and where the materials were made, and what their intended uses were [1].

The IAEA assists the Member States to develop, sustain and advance indigenous technical nuclear forensics capabilities. Therefore, the IAEA provides the Nuclear Forensics Human Resource Development (HRD) program for member States. Nuclear forensics HRD program is a very well structure including four levels. Starting with the introduction to Nuclear forensics, a training course with the purpose of familiarizing participants with the role of nuclear forensics in the context of a national response plan to prevent and respond to incidents involving nuclear and other radioactive material out of regulatory control, as well as with the requirements for, and the conduct of, a nuclear forensic examination.

Following the IAEA nuclear forensics practical introduction course concentrates on providing applied instruction on analytical measurements relevant to nuclear forensic examinations including gamma spectrometry, scanning electron microscopy and alpha spectrometry. The objective is to increase awareness of analytical measurements supporting a national response plan, to introduce current scientific methods for nuclear forensic analysis, and to allow the participants to learn from internationally recognized experts about analytical measurements important to the success of a nuclear forensic examination. By design, this course utilizes the capabilities residing at the Australian Nuclear Science and Technology Organization as well as other regional capabilities to demonstrate current methods for laboratory analysis and encourages scientist-to-scientist exchange between participants

The IAEA Nuclear Forensic Methodologies, the third level course, focuses on providing technical information and a hands-on learning environment for practitioners on the measurement of nuclear and other radioactive samples for forensic analysis in a manner consistent with the Implementing Guide entitled Nuclear Forensics in Support of Investigations. More specifically, the course will utilize an internationally recognized nuclear forensics laboratory setting to enhance awareness of how nuclear forensic measurements can support a national response plan, and will provide participants with an introduction to current scientific methods for nuclear forensic analysis and interpretation, as well as the opportunity to learn from leading experts about measurements essential to the early phases of a nuclear forensic examination.

The highest level is the IAEA Residential Assignment Program for Human Capacity Building in Nuclear Forensics Analytical Measurement. The objective is to provide a scientist-in-residence with a comprehensive overview and understanding of the scope and application of nuclear forensic examination at a leading nuclear forensics laboratory in the region. The assignment includes practical learning objective associated with the commencement of a nuclear forensics examination, training in the techniques and methods used within the nuclear forensics laboratory as well as in evidence handling techniques. A model case exercise is used as a part of the laboratory study to emphasize the key learning objectives. The main aim of the program is to follow a real nuclear forensics investigation in the real time-frame (2.5 months) following the international guidelines and standards from IAEA and ITWG.

In 2013, the Thailand Nuclear Forensics Laboratory officially was established at the Office of Atoms for Peace. The purpose is to enhance the national capability to fight against illicit trafficking of radioactive and nuclear material in Thailand and across the region. In the beginning, the instrument and facilities were supported by the Royal Thai Government, the European Commission, and the IAEA. Currently, Thailand is ongoing to enhance nuclear forensics capabilities. Thailand's nuclear forensics laboratory staff was well trained through the IAEA HRD program. The benefits of the IAEA HRD program are not only increasing knowledge and expertise, but also building up the nuclear forensics network and friendship among participants. Moreover, raising awareness and experience sharing among participant is a key factor to sustain nuclear forensics capabilities to fight against the illicit trafficking on nuclear and other radioactive materials out of regulatory control. Obviously, important lessons have learned from the IAEA HRD program which to bring back home to improve nuclear forensics capability within the country.

The benefits from the IAEA HRD program not only increasing knowledge and expertise but also building up the nuclear forensics network and friendship among participants. Moreover, raising awareness and experience sharing among participant is a key factor to sustain nuclear forensics capabilities to fight against the illicit trafficking on nuclear and other radioactive materials out of regulatory control.

INVITED PRESENTATION IV

NUCLEAR FORENSICS RESEARCH AND DEVELOPMENT: CURRENT STATUS AND FUTURE NEEDS

CAPACITY BUILDING IN NUCLEAR FORENSICS THROUGH INTERNATIONAL COOPERATION

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Abstract

The paper provides an overview of the capacity building activities the European Commission's Joint Research Centre performed in the area of nuclear forensics. The paper will describe the historical evolution of these activities, the partner institutions and countries involved, the main achievements and the current projects in combination with an outlook.

1. INTRODUCTION

The new discipline of nuclear forensic science (often referred to as nuclear forensics) was created of sheer necessity in the first half of the 1990's as a reaction to the multiple cases of illicit trafficking of nuclear and other radioactive material. Initially, only few laboratories were in a position to characterize such material and to provide nuclear forensic conclusions which point at the origin and the intended use of the material. JRC Karlsruhe (at the time named: Institute for Transuranium Elements) was one of the pioneers in this area, because many nuclear smuggling incidents were detected in central Europe and in Germany, in particular.

Research and development activities started in order to advance this new discipline, aiming at improving measurement methods and at identifying new "signatures". Since the phenomenon of illicit trafficking was obviously a border crossing challenge, a joint effort by the international community was required to counter this threat. Capacity building projects were a major component of this international effort. The character of these projects, however, evolved significantly throughout the years. In the late 1990's these activities consisted essentially of bilateral projects aiming at knowledge transfer and the provision of equipment. Geographically, they were focused on the CIS countries (Commonwealth of Independent States, i.e. countries of the former Soviet Union). Nuclear forensic activities were a subset of a broader effort to strengthen the non-proliferation regime in these countries. The scope of these projects was not limited to the scientific aspects (materials characterization, measurement methods) but included also conceptual issues related to interagency coordination. This resulted in the development of the Handbook on Response to Illicit Trafficking of Nuclear Materials (RITNUM), a pre-cursor of the ITWG's Model Action Plan.

Over time, the spirit of the projects changed from a support character to a rather cooperative character. Moreover, we moved from bilateral projects to a larger multi-country project (involving Russian Federation, Ukraine, Azerbaijan, Georgia and Moldova) in order to better address the border crossing nature of the threat. Joint trainings and workshops proved to be a useful platform to foster the direct exchange of experience among experts and to encourage regional cooperation.

With the CBRN Centres of Excellence (COE), the European Union established a new scheme for mitigating chemical, biological, radiological and nuclear threats and risks from outside the EU. Establishing and enhancing Nuclear Forensic capabilities in South East Asia was the pilot project for the CBRN COE. Hence, a new geographical area was addressed, involving ten countries. The project as well as the follow-on project was implemented in partnership with the US DOE NNSA. This enabled the efficient use of resources, the development of a joint syllabus for training courses and seminars and ensured coherence in the communication of nuclear forensic approaches and strategies.

In addition to the COE, the European Union makes use also of other funding schemes. The Science and Technology Center in Ukraine (STCU) is – among many other activities – also supporting nuclear forensics related projects. Currently, three such projects are being implemented at regional level with Georgia, Ukraine, Azerbaijan and Moldova. These projects are co-funded by the EU and the US and both partners jointly supervise the implementation and contribute to project activities. The latter indicates again a significant evolution in the character of nuclear forensic projects: project partners take increased responsibility for the development and implementation of project elements.

In parallel to the capacity building activities outside the EU, the JRC has been working closely with EU Member States in order to improve nuclear forensic capabilities at national level and to support networking and regional cooperation. A series of projects have been implemented over the past years on the basis of the EU CBRN Action Plan; including trainings, workshops and exercises. With the European Nuclear Security Training Centre (EUSECTRA) a unique platform for hands-on training and experts meetings was established at the JRC.

In addition, the JRC also supports the IAEA in their capacity building activities by contributing to national and regional training courses and, most importantly, by hosting every other Nuclear Forensic Methodologies Course, the IAEA's flagship training in nuclear forensics.

Capacity building in nuclear forensics remains a key component in international cooperation in the nuclear security area. These efforts have evolved over time; they have led to efficient partnerships and resulted in operational and effective nuclear forensic capabilities.

TECHNICAL SESSION V
NUCLEAR FORENSICS RESEARCH AND DEVELOPMENT: NATIONAL RESEARCH AND DEVELOPMENT EFFORTS

APPLYING OAK RIDGE NATIONAL LABORATORY NUCLEAR FORENSICS SCIENCE R&D TO ADDRESS THE NUCLEAR SECURITY THREAT

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1. INTRODUCTION

Oak Ridge National Laboratory (ORNL) continues to make broad contributions to pre- and post-detonation nuclear forensic science by building on the organization's rich history in nuclear operations and research and utilizing the laboratory's extensive basic science and research and development (R&D) capabilities. ORNL continues to establish new capabilities to support nuclear forensic science growth and has developed new scientific programs to address the nuclear security threat. ORNL's core capabilities include leveraging neutron science for nuclear forensics research, specialized material handling facilities for highly radioactive to trace materials, and a comprehensive suite of radiochemical counting instruments and state-of-the-art elemental mass spectrometry.

2. ORNL NUCLEAR FORENSICS R&D

ORNL nuclear forensics focus areas include traditional environmental sampling, reference materials characterization, and samplers, sensors and test beds for unmanned aerial vehicles.

In terms of environmental sampling, turnaround time for processing and analyzing IAEA swipe samples requiring high resolution mass spectrometry has been significantly reduced through the development of automated chromatography capable of separating low level uranium (U) and plutonium (Pu) at trace levels [1-3]. Using this technique, samples are processed in an unattended manner allowing for 24-hour operations and provision of clean-room level blank values for U and Pu without cleanroom infrastructure. The system would potentially be very useful in a hypothetical surge situation for the IAEA Network of Analytical Laboratories. Additionally, the system may be modified to collect americium or thorium from samples which would be necessary for age dating Pu or U materials, respectively.

ORNL also screens IAEA swipes for radionuclides using of neutron activation analysis (NAA) at the High Flux Isotope Reactor (HFIR). This technique is currently under evaluation for trace element quantification in uranium ore concentrate (UOC).

Other forensics focus areas include the characterization of reference materials for nuclear forensic purposes [4], and automated separations and detection of trace elements using high-pressure ion chromatography (HPIC) coupled to mass spectrometric analysis in fuel cycle and post-detonation materials [5-6].

Through the development of a patented "Global Communication and Control" system [7] and deployment approach developed in-house, determination of plume trajectory in near-real time for fielded systems has significantly enhanced the ability to transect plumes with mobile platforms, e.g., unmanned aerial systems (UAS), equipped with sensors and collectors. This technology has been field verified in multiple staged surrogate material release studies across the chemical, biological, radiological, nuclear and explosive weapons (CBRNE) regime. Additionally, this technology allows for rapid repositioning of sampling systems to improve the probability of plume transect.

Multiple modular sensor/sampler suites have been developed for both ground and UAS platforms. Each module is tailored for the material of interest and the operational scenario targeted. For some materials, a sensor provides a queue for samplers such that they are powered on during periods when the plume is projected to intersect the system. This method significantly reduces collection of background species that lower signal to noise unnecessarily.

3. ORNL FACILITIES

In addition to development of sampling methods to enhance the probability of detecting key materials, ORNL has leveraged multiple nuclear processing facilities to test leading edge signal collection and data analytics technologies. One such facility is the Radiochemical Engineering Development Center (REDC) that currently has a mission to produce and separate plutonium-238 for NASA. Such facilities allow for testing of newly developed collector/detector systems against an operating nuclear facility. ORNL also has a robust UAS program that has several established test beds including a unique netted enclosure for testing new platforms and sensor packages.

ORNL has also made key advancements and investments in training on-the-ground personnel in forensics methods and investing in world-class facilities such as the Ultra-Trace Forensics Science Center (UFSC). The UFSC provides basic research expertise and support to various high-impact national security and basic science missions that rely on ultra-trace analysis and high-precision measurements.

4. CONCLUSION

ORNL has significant experience in engaging international entities on matters associated with enhancing indigenous nuclear forensics capabilities. ORNL is leveraging these experiences and technical nuclear forensics capabilities to identify novel ways to respond to incidents involving nuclear and other radioactive materials out of regulatory control. This presentation will highlight ORNL's current nuclear forensic science research and development, and future opportunities to link these nuclear forensics approaches with investigative requirements and successful prosecution of nuclear security events.

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CURRENT STATUS AND FUTURE PROSPECTS ON NUCLEAR FORENSICS TECHNOLOGY DEVELOPMENT IN ISCN-JAEA

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Abstract

In the paper, current status and future prospects on nuclear forensics technology development in ISCN-JAEA are discussed.

1. INTRODUCTION

In accordance with Japan's national statement at the Washington, D.C. (United States of America) Nuclear Security Summit (2010), development of technology related to measurement and detection of nuclear material and nuclear forensics has been initiated in Integrated Support Center for Nuclear Nonproliferation and Nuclear Security (ISCN) of Japan Atomic Energy Agency (JAEA) based on international cooperation for the contribution to the identification of origin and history of nuclear and other radioactive materials out of regulatory control (MORC) or materials used in terrorist attacks. Japan has made increased contributions to the international community by establishing these technologies with more precise and accurate capabilities in detection and forensics and sharing the fruits of these new technologies with the international community. In this paper, current status and future prospects on nuclear forensics technology development in ISCN-JAEA are discussed.

ISCN has engaged in R&D activities of nuclear forensics technology for strengthening nuclear security. ISCN implements joint researches with the U.S. Department of Energy including uranium age dating measurements, characterization of nuclear fuel for forensics purposes, establishment of a proto-type nuclear forensics library and morphological characterization for nuclear material particles. Analytical methods for measurement of isotopic abundance and impurity in nuclear material have also been developed and those technical capabilities have been validated through the joint research with the U.S. national laboratories and EC Joint Research Center, and participation in Collaborative Material Exercise organized by Nuclear Forensics International Technical Working Group (ITWG). In past three years, ISCN has also engaged in development of advanced technologies for more rapid and precise nuclear forensics analysis. It includes new uranium age dating methods, data analysis methodology for library based on multivariate analysis and image analysis methodology for particle characterization.

As the future plan of the nuclear forensics technology R&Ds, ISCN has just initiated the development of nuclear forensics technologies for responding post-dispersion event since this fiscal year and will launch innovative nuclear forensics technologies in next year. The technologies for post-dispersion event have two topics; supporting technology for detection and recovery of radioactive samples from event scene, and measurement and signature analysis methodology for post-dispersion samples. As the innovative technology, machine learning algorithm for data analysis on nuclear forensics library, ultra-thin sample processing methodology for transmission electron microscope (TEM) analysis and applicability of autoradiography for nuclear forensics purpose will be studied. These innovative technologies can contribute to the improvements of rapid analysis and reliability of nuclear forensics analytical results.

FROM THE EXPERIENCE OF NUCLEAR FORENSICS RESEARCHES AND EXAMINATIONS PERFORMED BY "LABORATORY FOR MICROPARTICLE ANALYSIS"

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Nuclear forensic research occurs at the stage of initiating and investigating a criminal case on the fact of detection of nuclear and other radioactive materials (NMR) outside regulatory control. The results of such research form the basis of decisions taken by law enforcement and other government agencies. Therefore, as a rule, they have legal and organizational consequences.

In the framework of the first stage of nuclear forensic research, including research on the crime scene, an analysis of the submitted materials is carried out. This analysis is designed to help answer two questions:

- Is this NRM incident a criminal case (it depends on the specific of national legislation)?
- Whether the detained material presents a danger to the public and the environment, as well as to persons participating in the investigation and in the removing of the incident consequences?

To answer these questions, the kind of the detained or dispersed material (categorization of NRM) and its activity are usually determined. If the incident is investigated in the frameworks of criminal case, more detailed samples analyses are necessary.

The nuclear forensics community pays great attention to the improvement of country readiness to nuclear forensic research. For these purposes different proposals are elaborated and recommended in some publications. Among others, it is recommended to perform research in three stages: 24 hours, one week and two months. Moreover, some publications recommend the binding certain research methods and determination of materials characteristics to defined stages.

Laboratory's real-world experience in solving both: real-life forensic tasks as well as nuclear forensic exercise tasks shows that recommendations to divide the examination into specific time stages: 24 hour, one week, and two months is not useful for nuclear forensic examinations. Rather, this approach is more applicable for training purposes.

Of course, the first stage of the investigation, the stage prior to the initiation of a criminal case, has its own specifics. It requires obtaining the results of samples analysis as soon as possible (depending on the legislation of the country, it may be, for example 24 hours, 48 hours or 72 hours). However, even at the first stage, experts should not limit their task by answering only two questions, concerning incident qualification and safety. The questions posed by the investigator should, if possible, cover the entire task of investigation and should not be limited by frameworks of recommended stages. Such approach makes it possible to draw up an analytical plan and correct it in the course of the investigation more effectively.

Besides, this approach implies the use of the most informative analytical methods at early period of the investigation. An example of the use of highly informative methods at the very beginning of the investigation is the analysis of CMX-5 samples, using secondary ion mass spectrometry (SIMS) and inductively coupled plasma mass spectrometry (ICP-MS) methods during the first 24 hours of exercise. Such research was performed by the Laboratory for Microparticle Analysis.

Fragments of two fuel pellets A and B were the objects of the research. The pellets were manufactured by mixing three different materials. One of the purposes of the exercise was to compare the characteristics of two samples and their manufacturing techniques.

Analysis of the isotopic composition of uranium in samples A and B was performed by ICP-MS method using a Thermo ELEMENT 2 dual-focusing mass spectrometer. The preparations for analysis were prepared from several sample aliquots. Size of aliquots depended on the homogeneity of samples. All preparations of sample A (200 μg subsample aliquots were used) contained uranium with uranium-235 concentration of 1%. In turn, the preparations of sample B, prepared from 200 μg subsamples aliquots, contained uranium with an average concentration of uranium-235 in the range from 0.78 to 1.3%.

Already four hours after the beginning of the examination, the use of the ICP-MS method allows to reveal that sample B is a mixed sample and that the degree of heterogeneity of the materials of samples A and B is different. Such analysis can be performed within the first 24 hours after receiving the samples. The obtained results clearly show the high informativeness of this technique.

For a more detailed characterization of the pellets materials components, analysis of individual microparticles was carried out using the SIMS method. Within 12 hours from the beginning of the examination, the isotopic composition of uranium in the individual microparticles of both samples was measured. The result of the analysis showed the presence of at least two different materials in each pellet. Moreover, concentrations of uranium-235 were determined for most abounded component as well as for component with lowest meaning of this concentration. For both samples, these concentrations were equal to 0.3% and 4.3%.

Submitted and tested approach which implies the use of the most informative analytical methods at early period of the investigation. It is also proposed not to use the separation at the time stage of the questions raised by the investigator.

INVITED PRESENATION V

NUCLEAR FORENSICS SPECIAL TOPICS: NUFOR2019

A NEW CONFERENCE FOR NUCLEAR FORENSICS

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Abstract

The paper highlights a new nuclear forensics conference, NUFOR 2019 that aims to promote nuclear forensics to increase awareness and interest to improve recruitment and retention of staff into industry and students into academia to follow careers in support of nuclear forensics.

1. INTRODUCTION

Despite some outstanding work around the world to promote awareness of nuclear forensics it is still not widely known or understood in broader academic and industrial circles and is often not viewed as a discipline in itself. The result of this is a difficulty in recruiting high calibre early-career scientists into the nuclear industry and into fields that support nuclear forensics. Furthermore, there is an ongoing challenge with finding high-calibre students to fulfil Masters, PhD and post-doctoral research positions sponsored by nuclear forensics programmes.

The UK has developed a new bi-annual conference known as NUFOR 2019, which will be hosted at the University of Bristol on 10 to 11 July 2019. The aim of the conference is to develop increased awareness and interest in nuclear forensics and to build a sustainable pipeline for developing future experts and specialists. The conference aims to allow scientists and practitioners highlight their work in nuclear forensics and to showcase their work to students, researchers, academics and early-career staff working in the nuclear industry.

TECHNICAL SESSION VI

NUCLEAR FORENSICS RESEARCH AND DEVELOPMENT: DESTRUCTIVE ANALYSIS

GETTING THE WORLD ON THE SAME NUCLEAR FORENSICS RADIOCHRONOMETRY BASELINE

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Abstract

The paper describes the early results of international collaboration in radiochronometry, which that demonstrate promise for establishing consensus model ages of quality control nuclear materials.

1. INTRODUCTION

Radiochronometry, or the science of age dating radioactive materials, is a fundamental research area addressing the “when was a material produced or purified” question within the field of nuclear forensics. The measurement of an age of a radioactive material outside of regulatory control provides support to nuclear forensic investigations; however, the science of radiochronometry is technically challenging and requires advanced radiochemical and mass spectrometry capabilities that few laboratories in the international community have.

One major challenge for the future of radiochronometry is establishing that reproducible ages for nuclear materials e.g. reference materials can be measured by laboratories around the world. Without this, it is difficult to confirm a global radiochronometry capability that deters proliferation. Supported by the United States Department of Energy Nuclear Smuggling Detection and Deterrence Office, Los Alamos National Laboratory and Lawrence Livermore National Laboratory have jointly partnered with international collaborators in Australia, Canada, China, the European Union, France, Israel, Japan, and South Korea to research ^{230}Th/^{234}U and ^{231}Pa/^{235}U radiochronometry measurements and establish a global baseline capability.

Through these collaborations, we have compared different radiochemical purification techniques as well as different brands and types of mass spectrometers. In the case of protactinium, we have also compared different spike preparation methods. Here we compare the results of these methods and report ^{230}Th/^{234}U and ^{231}Pa/^{235}U model age results of internationally available certified reference materials. Despite challenges in terms of reference material availability we demonstrate that early results from international collaboration show promise for establishing consensus model ages of quality control nuclear materials. This is especially important for the ^{231}Pa/^{235}U radiochronometer because there are no commercially available reference materials with certified ^{231}Pa/^{235}U model ages.

DETERMINATION OF ^{231}PA/^{235}U MODEL PRODUCTION DATE OF URANIUM MATERIALS

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Abstract

The paper presents the measurement of the ^{231}Pa/^{235}U model production date for four uranium certified reference materials. Direct addition of ^{237}N pin secular equilibrium with its ^{233}Pa progeny was used instead of milking of ^{237}Np. The sample preparation consists of a fast, one-step procedure. The developed ICP-MS method is more precise than alpha spectrometry and is applicable for freshly produced low-enriched uranium materials.

1. INTRODUCTION

Fissile materials are firmly controlled by the nuclear safeguards. However, if such material gets out of the regulatory control, a comprehensive investigation should be performed to identify the planned use, source and last legal owner [1, 2]. Nuclear forensic analyses use several characteristics, like U or Pu isotopes, physical dimensions, chemical form and impurities, isotope ratios of S, Sr, Nd, and Pb, to provide suggestions on the history of the material [1, 2]. One of the nuclear forensic signatures is the elapsed time between the last chemical or physical purification of the material and measurement, often referred to as the age of the sample. It can be measured for radioactive, and thus also for nuclear materials [3, 4].

The age can be calculated as follows:

$$t = \frac{1}{\lambda_{parent} - \lambda_{daughter}} \ln\left(1 - \frac{N_{daughter}}{N_{parent}} \cdot \frac{\lambda_{daughter} - \lambda_{parent}}{\lambda_{parent}}\right) \tag{1}$$

The daughter-to-parent ratio (*Ndaughter/Nparent*, here ^{231}Pa/^{23}5U) is the chronometer, while the elapsed time (t) is called the (model) age of the material. A major drawback for the Pa measurements is the absence of long-lived Pa spike isotopes (beside the analyte ^{231}Pa). The frequently used short-lived ^{233}Pa spike ($T1/2$ = 26.98 days) is usually milked from ^{237}Np and calibrated against a rock standard (e.g. Table Mountain Latite [4] or measured with gamma spectrometry). Milking of ^{233}Pa from the parent ^{237}Np is lab-intensive and it cannot be carried out before enough ^{233}Pa is produced from the decay of ^{237}Np, which can take weeks to reach the needed amount. As Pa is prone to adsorption, loss of the ^{233}Pa spike can occur. An alternative option is to use gamma spectrometry before and after the separation to measure the recovery of ^{233}Pa [1]. The ^{231}Pa analysis can be performed by alpha spectrometry or inductively coupled plasma mass spectrometry (ICP-MS). It should be noted that as ^{231}Pa and ^{233}Pa decay with a different mode (alpha and beta decay), thus they cannot be measured together by radiometric methods. Thus, mass spectrometry is a viable alternative. With mass spectrometry the measurement of the short-lived ^{233}Pa is difficult, as measurable amount (i.e. relative high activity) is needed for the precise analysis.

The purpose of the present study was to develop a direct, but precise and accurate method for the sample preparation and precise determination of the ^{231}Pa/^{235}U ratio by ICP-MS from uranium materials. The ^{237}Np solution in secular equilibrium with its ^{233}Pa daughter was added directly to the sample solutions before the chemical separation. The direct spiking does not necessitate the regular milking of ^{233}Pa after the ingrowth from ^{237}Np, so the Pa spike is continuously accessible. The developed method was applied for four U certified reference materials (CRMs) [5].

2. 231PA/235U MODEL PRODUCTION DATE RESULTS

The ^{231}Pa/^{235}U mass ratios for the measured samples together with the ^{231}Pa/^{235}U model ages and production dates are summarized in Table 1.

TABLE 1

Sample	^{231}Pa/^{235}U mass ratio	Standard uncertainty	^{231}Pa/^{235}U model age (years)	Exp. Uncertainty (years, k=2)	Measured ^{231}Pa/^{235}U model production date
CRM 125-A	2.278×10^{-8}	4.2×10^{-10}	23.54	0.88	26 December 1994
IRMM1000	5.926×10^{-9}	1.2×10^{-10}	6.12	0.24	27 May 2012
U100	5.619×10^{-8}	7.5×10^{-10}	58.1	1.6	03 June 1960
U630	2.815×10^{-8}	4.0×10^{-10}	29.09	0.83	07 June 1989

The measured values agree well with the reported values [4]. For three materials with CRM125-A, IRMM-1000and ^{630}U certified model production dates by the ^{230}Th/^{234}U chronometer are given: the measured ^{231}Pa/^{235}U model ages are in agreement with the certified values [5]. For U100 the measured ^{231}Pa/^{235}U production dates are in good agreement with the purification date of 8 January, 1959.

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STABLE ISOTOPE RATIOS AS TRACERS OF ORIGIN AND TRANSFORMATION OF URANIUM OXIDES IN THE NUCLEAR FUEL CYCLE: OXYGEN AND MOLYBDENUM

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Abstract

The paper reviews the use of stable isotope ratios to trace the origin and transformation of uranium oxides in the fuel cycle, through the examination of the O and Mo isotopes. The rationale for using these isotopes is given first, then the analytical methods are described. The potential of these nuclear forensic tools is presented through applications to synthetic samples obtained in the laboratory in various conditions mimicking the industrial ones and to samples from the real world.

1. INTRODUCTION

Nuclear forensic methods rely in part on the isotopic characterization of samples in order to derive the intended use of the material, as well as when and how it has been produced. An increasing number of tracers, called nuclear forensic signatures, are being proposed [1]. Most of them being not as simple to use as the $^{235}U/^{238}U$ ratios, it became important to understand how these signatures are created, persist and are modified throughout the nuclear fuel cycle and how they can be used to retrieve information.

2. STABLE ISOTOPE FRACTIONATION

Boosted by the Manhattan project [2], separation of stable isotopes by chemical reactions gave birth to stable isotope geochemistry because Earth processes were as efficient as man-made reactions. All is about measuring small deviations from isotope abundances originally set by nucleosynthesis. These deviations, aka fractionation, follow in most cases thermodynamic or kinetic laws and separation scales with the difference in the masses of the isotopes, which is called mass-dependent fractionation. In some cases separation does not scale with the difference in the masses, leading to a new field of investigation named mass-independent fractionation [3]. The first studies focused on the isotopes of light elements (H, C, O, S, N) [4] measured via gas-source Isotope-Ratio Mass Spectrometry. Recent developments of new high-sensitivity analytical techniques based on inductively coupled plasma mass spectrometry (ICP-MS) or thermal ionization mass spectrometry (TIMS) following wet chemistry render possible determination of fractionation among isotopes of heavy elements such as Cr, Fe, Mo, known as the non-traditional isotopes [5].

3. OXYGEN AND MOLYBDENUM STABLE ISOTOPES IN URANIUM OXIDES

Oxygen, a major element in uranium ores and ore concentrates, shows large variations in O/U ratios among the various compounds involved in the fuel cycle. Changes in the number of oxygen atoms per atom of U go with changes in the O-U bond strength, which in turn fractionate the 18O-16O isotopes. Distinctive oxygen isotope fractionation was documented in relation with important manufacturing processes [6, 7]: U leaching from uraninite and precipitation into uranates or peroxides, calcining into ^{3O8}U, reduction to ^{2}UO, leading to contrasted O-isotope ratios for the various uranium compounds produced along the nuclear cycle.

Molybdenum (Mo) is a trace element in uranium (U) ores. Because Mo and U have similar chemical properties, Mo is an impurity difficult to separate during the U extraction and purification processes. However, its concentration is required to be lower than some specification limits because (i) volatile Mo fluorides would hamper proper ^{235}U enrichment and (ii) Mo would decrease the yield of nuclear reactions. Only recently, Mo isotope fractionation was documented in relation with the chemical reactions used in the U extraction and purification processes [8-10], notably leaching, solvent extraction, uranium precipitation.

Oxygen and molybdenum isotope ratios record most of the manufacturing processes producing uranium oxides as well as their conditions (amount and types of leaching, precipitation, solvent extraction; calcining temperature, etc.), leading to a variety of signatures that might seem meaningless to untrained users. Quantitative models are established to account for the associated isotope fractionations. They allow to calculate characteristics of unknown reagents or products or retrieve the employed conditions. These models constitute an essential addition to databases compiling isotope ratios measured on uranium oxides of known origins. Understanding the fractionation processes and using models is important because databases cannot be comprehensive and could miss material used at small scale by nuclear proliferators.

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TECHNICAL SESSION VII

NUCLEAR FORENSICS INITATION AND SUSTAINABILITY: NATIONAL CONSIDERATIONS II

DEVELOPMENT OF INTERAGENCY COOPERATION FOR NUCLEAR FORENSICS EXAMINATIONS IN MOLDOVA

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Methods of forensic examination can play an important role for crimes investigation, involving nuclear or other radioactive (R/N) materials or evidence contaminated with radionuclides [1]. Although the crimes, involving R/N materials, are quite rare, the possible severe consequences and high public resonance of these crimes enforce us to be ready to their comprehensive investigation.

Five crimes involving R/N materials were registered in Republic of Moldova for last eight years. However, it is probable that such crimes could increase in number due to risks including the extensions of authorized activities with R/N materials (energy, medicine, scientific researches, etc.), regional conflicts that increase the risk of losing control over R/N materials and taking possession of them by criminal organizations, and IT development that facilitate access to information about R/N materials.

For these reasons, it is important for our country to ensure the permanent availability of law enforcement authorities to solve the forensic tasks and the relevant legal issues.

The analysis of the incidents that occurred in the Republic of Moldova and other countries, as well as the scenarios and results of the exercises conducted by the Nuclear Forensics International Technical Working Group (ITWG): CMX-4, CMX-5 and CMX-6, demonstrated that forensic examinations can require significant analytical resources. In particular, the analysis of CMX-5 materials [2] confirms the useful applying of almost twenty analytical methods for the characterization of "retained" materials.

Obviously, for countries that have not large-scale nuclear activities, and perhaps for all countries, the creation of a single analytical laboratory, containing all analytical methods mentioned in [2], is inexpedient. And for solving similar to CMX-5 tasks, using a variety of methods [2], more preferable is to mobilize national resources from different departments and organizations.

Evaluation of country-wide forensics capability can be done in accordance with the approach developed by the working group the GICNT Nuclear Forensics Working Group [3, 4]. It is obvious that each country will take for assessment of national capabilities those elements of the self-assessment mechanism proposed in [3], which will comply with national legislation, established rules and the adopted procedure.

The results of Republic of Moldova's participation in the CMX-4 and CMX-5 exercises demonstrated that the country has the capability of performing forensic examinations of the R/N materials, using many basic analytical methods, if resources of different departments will be combined.

The following methods were used for the study of samples in the frames of these exercises:

a) Electron microscopy and X-ray analysis (Technical University of Moldova);
b) X-ray fluorescence analysis (Forensic and Legal Expertise Center of General Police Inspectorate);
c) Density, geometric measurements (Ministry of Agriculture, Regional Development and the Environment);
d) Micro-hardness measurement (Academy of Sciences of Moldova);
e) Gamma-spectroscopy (National Agency for Regulating Nuclear and Radiological Activities);
f) Diffractometry (State University of Moldova).

Some of the involved methods were developed to perform traditional forensic examinations of non-nuclear materials. Most others are designed to solve scientific and technological problems that are not related to the study of nuclear materials. Variety of organizations have being involved in the analyses process requires establishing the rules and the order for relationship of different organizations and relationship of experts and specialists from different ministries and departments.

It should be noted also that the investigation of crimes involving R/N materials may require the complex forensic examination of the same evidence (nuclear and other radioactive (R/N) material or evidence contaminated with radionuclides) by using both: nuclear as well as traditional (fingerprints, shoes, tires, DNA, etc.) forensic methods. This causes the necessity of development a mechanism of cooperation between traditional forensic and nuclear forensic experts.

The Republic of Moldova accumulates the experience of interdepartmental cooperation for comprehensive forensic expertise. Training courses on “Applying Existing Capabilities in Nuclear Forensic Investigation” held in October 2018 in Chisinau for police officers, border police and customs service, National Agency for the Regulation of Nuclear and Radiological Activities and other departments.

The ongoing and planned activities will mobilize efforts to establish a mechanism of cooperation between forensic experts and representatives of different departments to successfully investigate crimes involving R/N materials.

Applying existing capabilities in the forensic investigation and establishing a mechanism for cooperation between forensic experts and representatives of different departments are required to successfully investigate the crimes involving R/N materials.

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CURRENT STATUS ON NUCLEAR FORENSICS AND MYANMAR

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Abstract

The paper intends to introduce the current status on establishment of the nuclear forensics capability building in Myanmar.

1. INTRODUCTION

Myanmar thinks that in order for the utilization of nuclear energy to be peaceful and secure, disarmament and nuclear non-proliferation must be achieved on the global scale. Currently, there are number of radioactive sources used peacefully in various sectors such as agricultural, industrial, research and education and health sectors. Most of them are used in medicine for diagnostic and radiotherapy. Public companies also have been using radioisotopes. According to the existing information, there are 564 radioactive sources in Myanmar, including 4 high activity sources categorized as Category -1 sources which are used in hospitals. The radioactive sources in Myanmar is shown in the following table (Table 1).

TABLE 1: RADIOACTIVE SOURCES IN MYANMAR

Sr. No	**Type of Works**	**Radioactive Sources**
1	Health(Radiotherapy, Diagnosis)	Co-60, X-ray, Cs137, Linear Accelerator, Ir-192, I-131, I-125
2	Research and Teaching	Ni-63, Co-60, Am-241/Be, Am-241, Tr-204, Sr-90, Po-210, Cs-137
3	Analytical Techniques	Cs-137, C-14, Ni-63
4	Fixed Nuclear Gauges	Cs-137, Am-241, Kr-85
5	Industrial Radiography	Co-60, Cs137, Ir-192
6	NDT	Ir-192, Co-60, Cs-137
7	Well Logging	Cs-137, Th- 232, Co-60, Am 241-Be, H-3, Ba-133, Ra -226

So far, the Division of Atomic Energy (DAE) as a regulatory body keeps and maintains a register of sources according to the enacted Atomic Energy law. Myanmar mainly uses for Regulatory Information System (RAIS version 3.3) including specific area as radionuclide, activity, category, location, use and worker's history.

As the application of radioactive sources is increasing daily, the need to design and implement the safety measures and security measures is growing with respect to the safety and security of radioactive sources such as guidelines and regulations to control accidents, incidents and misuse of sources.

A possible accident that could occur in a country with lack of technology infrastructure like a fire breaking out in the hospital or industry using radioactive sources and consequently, could lead to a loss of control of radioactive sources and sources potentially being damaged, lost or hidden as well as sources becoming unshielded or radioactive materials being dispersed. Myanmar also imports radioactive sources and materials and inadequate import or export controls with respect to Class 7 and inadequate capability to respond to a radioactive materials incident or emergency. If these materials are not managed safely and securely, accidents can occurred that cause permanent injury to people who handled them. It is also important to protect against sabotage and unauthorized removal of nuclear and other radioactive material, associate facilities and associated activities. Therefore, Myanmar needs to be strengthen the national capabilities for nuclear security and nuclear forensics concerning the nuclear and other radioactive materials out of regulatory control.

In Myanmar, there is a crime laboratory equipped with DNA and Automated Finger Print Identification System (AFPIS) in Forensic Technical branch at Criminal Investigation Department (CID) under Ministry of Home Affairs. Myanmar needs to establish a laboratory skilled in nuclear forensic analysis that combines the capabilities of the crime laboratory and the nuclear forensics laboratory. At the present, Radiation Detection and Measurement Laboratory under DAE is responsible to check and identify suspect metals and all detected event are notified initially to the IAEA Incident and Trafficking Database (ITDB). In addition, the inspectors from DAE also disseminate security culture for radioactive sources to pave way for future use of nuclear security practices among private and government sectors.

DAE is cooperating with the relevant organizations such as polices, stakeholders, law enforcement customs, as the National Nuclear Security Working Group. Myanmar is trying to initiate the establishment of the nuclear forensics capability building. Currently, DAE is working to understand challenges and best practices for organizing nuclear and other radioactive materials and information and associated expertise within state before and incident occurs, including the establishment of formalized intra- and international information exchange mechanisms.

Although Myanmar has not faced an incident of material out of regulator control, Myanmar is developing their nuclear forensics capabilities and needs availability of specialized techniques, translation of technical documents into the national language, and capacity development opportunities. Additionally, public awareness campaigns, engagement in national and international events, and exchange of knowledge with relevant stakeholders would help broaden the familiarity of nuclear forensics in the country and help develop and sustain national nuclear forensics capabilities.

REGULATORY AUTHORITY ACTIVITIES IN SUPPORT TO NUCLEAR FORENSICS

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1. INTRODUCTION

Nuclear forensics is the process of comparing sample characteristics with existing information about the types of material the origin and methods of production of nuclear and other radioactive material or previous cases associated with similar material. Thus, nuclear forensics regarded as a new area of integrated science research that allows not only the identification of radioactive material (withdrawn from illicit trafficking or resulting from a nuclear accident), but also to trace the entire chain of related events - from source origin until to detection. Nuclear forensics is the examination of nuclear and other radioactive materials using analytical techniques to determine the origin and history of this material in the context of law enforcement investigations or the assessment of nuclear security vulnerabilities. In this activity, consolidation and assistance of all organizations that can be involved in nuclear forensics are necessary. Considering the scope of activities and responsibilities of the regulatory body, maintaining a register of all radioactive sources and nuclear materials, controlling the movement of such materials, authorizing activities related to their use, issuing export and import statements, as well as state supervision and control of activities and export-import operations are included in the responsibilities of the regulatory body. Thus the regulatory body makes an indispensable contribution for the purposes of nuclear forensics.

2. PRACTICAL ACTIVITIES

In accordance with the current local legislation, all activities related to the use of nuclear and radioactive materials, including the activities of research organizations involved in conducting nuclear forensics examinations, is subject to authorization by the regulatory body. The regulatory body also keeps and regularly updates the records on all nuclear and radioactive materials available in the country in authorized use by implementation of their state accounting and control responsibilities. This database is used for the timely detection of the loss of such materials as well as during the investigation helps to provide existing information about the history of this material, its owners and responsible persons. In the frame of IAEA National TC Project AZB/9/006 'Supporting the Preparation of the National Radiological Emergency Plan (NREP)' by employees of SANRAR (Regulatory Body) elaborated the draft of the National Radiological Emergency Plan (NREP), which clearly outlines roles and responsibilities of all organizations involved in preparedness and response phases during nuclear and radiological emergency situations, including situations related to prevention illicit trafficking and finding of unknown (orphan) nuclear or other radioactive materials which is out of regulatory control. As such arrangements involve multiple and complex issues, there are bilateral agreements with other member states on the provision or request of international assistance that may be required for an actual event to conduct forensic examinations. The European Union funded Nuclear Forensics Programme at Science and Technology Center in Ukraine (STCU) 9902 project is aimed to strengthening the non-proliferation regime and counteraction against terrorism threats by improving nuclear forensic capabilities and increasing international co-operation in combating illicit trafficking of NRMs Georgia, Ukraine, Azerbaijan, and Moldova. This project covers the national laboratories, which are recognized by the governments as expert organizations that perform nuclear forensic characterization of NRMs, seized from illicit trafficking. In the frame of the 9902 project, the core technical capabilities of nuclear forensic laboratories in Azerbaijan have been revised and essentially upgraded to allow categorization and basic characterization of intercepted nuclear and radioactive materials. The nuclear forensic laboratory will provide reach-back capabilities for first responders and field experts in Azerbaijan, as well as expert support to law-enforcement authorities and other national organizations and agencies involved into the counteraction to illicit trafficking and nuclear smuggling.

3. FINDINGS OR RESULTS

Decision-making capabilities, established organizational structure and financing mechanisms allow the fulfillment of the main functions of the regulatory authority at present. At the same time, there are challenges related to the legislative base and staffing of regulatory authority with the highly qualified staff in connection with the planning of expansion of activities in the field of peaceful nuclear technologies and for improving their capabilities for successful implementation an appropriate role in support to nuclear forensics activities.

4. CONCLUSION

The decision on development of nuclear technologies for peaceful purposes and planning of the construction of research reactor in the future requires improving the structure and capabilities of the Regulatory Authority, as well as improving the legislative framework for the possibility of comprehensive execution of regulatory functions. The presentation will summarize achieved progress and provide proposals to improvement of existing infrastructure in considerable to extent to the necessary requirements.

Nuclear forensics is the examination of nuclear and other radioactive materials using analytical techniques to determine the origin and history of this material in the context of law enforcement investigations or the assessment of nuclear security vulnerabilities. Consolidation and assistance of all organizations that can be involved in nuclear forensics are important issues to achieve to the common goal.

JAEA'S INITIAL EFFORTS ON BUILDUP OF NUCLEAR FORENSICS CAPABILITY IN ASIAN COUNTRIES

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Abstract

In the paper, the results of the nuclear forensics questionnaire provided for Asian countries are introduced and the experience of the regional training course on nuclear forensics organized by ISCN is reported.

1. INTRODUCTION

In 2010, the Japanese Government issued the national statement at Nuclear Security Summit (Washington D.C., USA) to develop technologies related to nuclear forensics, and to share them with the international community. In response to this statement, Integrated Support Center for Nuclear Nonproliferation and Nuclear Security (ISCN) of Japan Atomic Energy Agency (JAEA) has carried out R&Ds on nuclear forensics technical capabilities since Japanese Fiscal Year of 2011. In parallel with nuclear forensics technology R&Ds, ISCN has also contributed the capacity building of nuclear forensics such as providing training courses for Asian countries and supporting Japanese government for building domestic nuclear forensics capabilities.

One of the important mission of ISCN is to contribute to nuclear nonproliferation and nuclear security both in domestic and international arenas through its activities such as human resource development assistance. In particular, ISCN has provided training courses for capacity building assistance in Asian countries regarding nuclear security and nuclear nonproliferation. ISCN will organize a regional training course on nuclear forensics in January 2019. The contents of planned training course has been developed based on the questionnaire about nuclear forensics capability building provided for Asian countries in 2017, which was one of contribution in Forum for Nuclear Cooperation in Asia (FNCA). This questionnaire was provided to FNCA member countries covering the wide area of the Asian region, and the purpose of the questionnaire was to share the information among those countries about the current status of national capability for nuclear forensics and to identify common challenges or needs on capability building in Asia. The questions were pared based on the national core capabilities to perform nuclear forensics activity referred in IAEA Nuclear Security Series No.2/No.2-G [1].

Based on the results of questionnaire, the keywords of common challenges on nuclear forensics national capability building among those member countries are: national framework, chain of custody, nuclear forensics laboratory including application of already available resources and interpretation/findings including nuclear forensics library. The regional training course on nuclear forensics is developing to focus on these common challenges among Asian countries identified by the questionnaire.

Outline of contents and topics for the training course are to be as below.

- Overview of nuclear forensics (scope and application, national response plan, core capability)
- MORC crime scene (crime scene management and investigations, categorization, seizure and transportation)
- Nuclear forensics laboratory (requirements, signatures, methodology and equipment, analytical planning and quality assurance)
- Nuclear forensics interpretation (nuclear forensics library, interpretation including subject matter expert, reporting and confidence)

The present training course will provide tabletop exercises regarding laboratory and interpretation that enables participants to obtain more practical knowledge on the topics and share experiences of each country. A hands-on training course for nuclear forensics measurement in laboratory is also planned as the next step of nuclear forensics capacity building assistance for Asian countries.

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POSTER PRESENTATIONS

TESTING CAPABILITIES AT IPEN FOR URANIUM DETERMINATION BY ALPHA SPECTROMETRY

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1. INTRODUCTION

The implementation of a Nuclear Forensics Laboratory in Peru begins with the identification of its existing facilities, examining the capacity that could be used in response to sudden nuclear threats or illicit activities. To do so, uranium radioisotopes ^{238}U, ^{234}U and ^{235}U present in enriched and depleted uranium could be analyzed using a homemade Alpha Spectrometer built in the RACSO Nuclear Center in Peru. The low-cost prototype consist of an alpha detector built with silicon PIN photodiode S3590-19 (Hamamaatsu Photonics K.K.) with a sensitive area of 10 mm x 10 mm and with a maximum depletion thickness of 0.3 mm inside of a vacuum chamber. The software Genie 2000 is used for the counting acquisition. Electrodeposition of uranium oxide from $UO_2(NO_3)_2$ $6H_2O$ solution on 2.5 cm diameter 316 L stainless steel disks previously polished was carried out in a cell with an straight non-rotating platinum wire as an anode and a potentiometer as an external source. Several test were conducted with this arrangement and optimal resolution due to proper electrodeposition was achieved applying 0.2 A for 2 hours for a 20 mmol L^{-1} $UO_2(NO_3)_2$ $6H_2O$ solution at pH 2.5. The uranium oxide layer was characterized by X-Ray Fluorescence using radioactive Cd-109 source in all the electrodeposited samples. It is seen that this latter technique is able to determine a proper characterization of disks in a short time and non-destructive way.

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DEVELOPMENT OF NUCLEAR ANALYTICAL TECHNIQUES LABORATORY AT THE BATAN NATIONAL NUCLEAR ENERGY AGENCY FOR NUCLEAR FORENSIC APPLICATIONS IN INDONESIA

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1. INTRODUCTION

The paper describes the current status of improving and strengthening the human resources capabilities and development in nuclear analytical techniques (NATs) at the National Nuclear Energy Agency of Indonesia (BATAN), such as neutron activation analysis for forensic applications. Since 2006, when the neutron activation analysis working group program was officially started, several activities has been designed and implemented. The three research reactors in Indonesia, GA Siwabessy in Serpong, TRIGA MARK 2000 in Bandung and Kartini reactor in Yogyakarta, have supported the neutron activation analysis research and development for forensics applications. Several development on Neutron Activation Analysis (NAA) facilities in BATAN have been carried out. In BATAN Serpong the development for cadmium epithermal NAA and automation NAA system have been done. While, the development of gamma spectrometry analysis and BATAN k0 softwares have been carried out in BATAN Bandung. Experimental facility such as irradiation pipes, pneumatic transfer tube, and multiple HPGe detectors have enabled the development of neutron activation analysis and make it greater use of NAA in forensic applications.

Nuclear forensics requirements in Indonesia are in the form of providing evidence related to several cases of heavy metal pollution in the environment, poisoning of food or human, and monitoring of environmental radioactivity from industrial activities, geological activities or mining. BATAN has applied the nuclear analytical techniques in characterization trace element or heavy metal concentrations in biological samples, food and health samples, environmental and geological samples. Determination of arsenic and mercury in human hair samples for evidence investigation of contamination in some areas were carried out using NAA. The information obtained from analysis results provide the level of poisoning from industrial activities and occupational exposure. Mercury poisoning from the occupational exposures were identified due to the long term working period of car painting. While the industrial contamination of heavy metal arsenic and mercury were also identified in some cases. For the food and health samples, NAA was applied to characterization of supplement spirulina and food samples (seaweed, fish, fruits, vegetables, foodstuffs etc.) to investigate the concentration of micronutrient as well as the toxic elements. Environmental and geological samples such volcanic ash, zircon sand, airborne particulate matter, soil, sediments, and coal fly ash were characterized for environmental risk assessment.

Beside the development and the application, to ensure the validity of the method, since 2006, the BATAN Bandung laboratory have implemented the ISO/IEC 17025 for the NATs applications in characterization of several matrices of samples. BATAN Bandung has initiated to organize inter-laboratory studies within NAA group in Indonesia during 2006-2015. In order to evaluate the analytical capabilities of the technique, these NAA laboratories have also participated in several inter-comparison tests organized by Indonesian Institute of Science (LIPI), Asia Pacific Food Analysis Network (APFAN), International Atomic Energy Agency (IAEA), and Wageningen Evaluating Program for Analytical Laboratories (WEPAL). These inter-comparison mainly in trace elements analysis in environmental and food samples analysis.

The research collaboration under regional cooperation agreement, technical cooperation, research contract and regional collaborations give significant contribution to the improvement and strengthening of human resources capability. Several other activities related human capability such as trainings, workshops, fellowships, scientific visits and expert missions are conducted regularly. Annually the national training of NAA have been conducted under cooperation with the Center of Education and Training of BATAN transferring the basic knowledge of NAA, procedure of analysis as well as its application and data utilization. Additionally, the certification of personnel competency as NAA operator and supervisor also have been carried out to ensure the human resources competency, with cooperation with each NAA laboratory, and Center of Nuclear Standardization in BATAN. The human resources improvements ensure the sustainability of nuclear analytical techniques research. These activities covering the development of capability and facility as well as the human resources improvements are highlighted to demonstrate that NATs research capability and experience make the NATs laboratory in BATAN is available for high-precision trace element analysis for forensics applications.

ON SITE RADIOMETRIC CATEGORIZATION OF NUCLEAR MATERIAL BY GAMMA SPECTROMETRY. FIRST RESULTS

Field exercise designed for training of law enforcement agents.

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1. INTRODUCTION

Since entry into force of the Amendment to the Convention on the Physical Protection of Nuclear Material (CPPNM) [1] and in concordance with UN 1540 resolution [2], each State has the responsibility for the establishment, implementation and maintenance of a physical protection regime of nuclear material. In order to establish control of the nuclear material (even during transport), the State may provide the tools and specific knowledge to the law enforcement agents for detecting, characterizing and controlling the presence of nuclear material out of the regulatory control as soon as possible.

The paper is focused on how to improve the information that law enforcement agents obtain on site using their equipment for the detection and characterization of nuclear material. Almost all countries have special teams in the law enforcement corps as first responders against CBRN attacks. These forces always have as a part of their technical equipment a gamma spectrometry portable device for detection and measuring any dose rate and/or the presence of contamination. One typical scenario for the law enforcement agents (i.e., customs control, security control, inspection of any industry or facility) is where they have to detect the presence of nuclear material using this type of gamma spectrometry devices, which raises several issues. First, is it possible to detect nuclear material using gamma spectrometry devices? Although U, Pu and Th are alpha emitters, law enforcement agents also need to know that they have gamma emission as well and due to alpha decay and the presence of emission of gamma daughter isotopes is possible to detect. Second, in case of U nuclear material, is it possible to distinguish between mineral U, processed U, depleted U and or material enriched in ^{235}U?

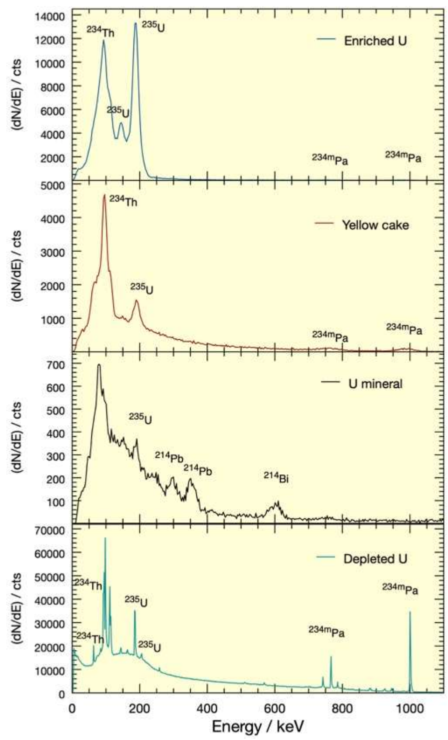
Based on aforementioned issues, this work presents the first results obtained in CIEMAT by the close collaboration with the Spanish law enforcement corps. The centre of CIEMAT in Madrid is a nuclear facility since 1950's, ab initio as the headquarters of the JEN (Nuclear Energy Board) where the main activities carried out were related to the development of the nuclear fuel close cycle in Spain. Until 1970's the uranium extraction process from the minerals of different Spanish mines was done. The process of purification of the mineral consisted of partitioning it from the rest of the components of the matrix by physical and chemical methods, obtaining concentrates of U [3] [4]. In addition, in the former JEN, nuclear fuel manufacturing processes (pyro and hydrometallurgical extraction process) were also carried out, including the enrichment stage for use in nuclear reactors, and the fuel cycle was closed with a reprocessing plant that stopped working at 1973. This background allows to have different small amounts of U nuclear material that can be used for radiochemical measurements using gamma spectrometry portable devices.

In the paper, the portable equipment considered are those used by the law enforcement corps aforementioned, as they are: contamination monitors (AN/PDR-77, SCG2 and UDR 14) and scintillator detectors NaI(Tl) and CZT. Using these last ones it is possible to obtain a particular gamma spectra of the U nuclear material selected (see Fig

1.). In Figure 1 is summarized 4 different gamma spectra obtained from mineral U, processed U, depleted U and enriched U nuclear material.

A comparative study of the spectra (Fig. 1) allows categorizing each one as a function of its U isotopes ratio. This knowledge is a key tool for law enforcement agents, due to increase the detection of nuclear material and furthermore decrease the response time due to the categorization of the nuclear material.

FIGURE 1. GAMMA SPECTRA OF NUCLEAR MATERIAL OBTAINED WITH PORTABLE SCANNING



Nevertheless, and considering this information specific field exercise for law enforcement that include workshop and training must be done in order to increase the capabilities on national nuclear forensic.

A description of the field exercise done at CIEMAT and the conclusions obtained will be presented.

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VALIDATION OF AGE DATING METHOD FOR A NUCLEAR MATERIAL

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1. INTRODUCTION

Depending of its use, a nuclear material will undergo different chemical/physical transformation (purification, enrichment …). In the frame of the struggle against illicit trafficking of nuclear material, unknown samples can be seized, and have to be characterized in order to determine their origin, possible use, and date of production.

2. PRINCIPLES OF AGE-DATING

The age determination gives information on the time elapsed since the last chemical purification undergone by a nuclear material. This date of purification (also called "model age") is obtained by measuring between a daughter nuclide and its parent. The production date is estimated following this equation (1):

(1)

$$t = \frac{1}{(\lambda_p - \lambda_d)} \times ln\left(1 + \frac{N_d}{N_p} \times \frac{(\lambda_p - \lambda_d)}{\lambda_p}\right)$$

where λp and λd are the decay constants of parent and daughter product, Nd/Np is the atom ratio of daughter over parent and t the time elapsed since the last purification of the material.

The precision of such determination will depend on two main parameters: the purity of the material, and the accuracy of the isotopic ratio (Nd/Np) measurement. The quantification of either the parent or the daughter nuclide is performed by isotopic dilution mass spectrometry. For this, a well-known quantity of a tracer (artificial isotope of the element of interest which is not present in the sample) is added to the sample. The accuracy of the measurements is highly dependent on the accuracy of such tracer.

For uranium age dating, two radiochronometers are commonly used: ^{230}Th/^{234}U and ^{231}Pa/^{235}U. The tracers used for isotopic dilution are ^{233}U for U isotopes, ^{229}Th for Th and ^{233}Pa for Pa.

3. EXAMPLE OF PA-233 TRACER CALIBRATION

^{233}Pa tracer is a decay product of ^{237}Np. It is obtained by milking a solution of ^{237}Np. As it has a relatively short half-life (T1/2=26.975 days), its concentration is decreasing rapidly once separated from its parent. One of the major difficulties of the method is then to calibrate the ^{233}Pa concentration of the freshly prepared solution. Unfortunately, no ^{231}Pa reference materials are currently available.

^{233}Pa is often calibrated with ^{231}Pa extracted from rocks at secular equilibrium [1, 2]. This technique has some limitations: rocks solubilisation has to be total, the process is time consuming regarding the half-life of ^{233}Pa, ^{235}U concentration of the rock solution must be precisely measured. These limitations as well as the performances of this method will be presented for ultra-trace quantities of ^{233}Pa (below pg).

To overcome this, a solution of ^{231}Pa is currently being calibrated at CEA. Measurements are being performed on a 6 months basis by preparing a mixed solution of ^{231}Pa, freshly prepared ^{233}Pa and certified ^{238}U. ^{231}Pa/^{233}Pa is measured just after ^{233}Pa milking. After 6 months, most of the ^{233}Pa has decayed to ^{233}U. The quantity of ^{233}U is then measured by isotopic dilution with ^{238}U and ^{233}Pa concentration is then derived as well as ^{231}Pa concentration.

ACKNOWLEDGEMENTS

Authors would like to thank Z. Varga from JRC-Karlsruhe for providing ^{231}Pa initial solution.

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NUCLEAR FORENSICS HUMAN RESOURCE DEVELOPMENT IN THE CZECH REPUBLIC – A NEW Ph.D. PROGRAMME IN NUCLEAR SAFETY, SECURITY AND FORENSICS

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Abstract

The paper reviews a new doctoral study program in Nuclear Safety, Security and Forensics, backed by new experimental background, which is under development at the Czech Technical University (CTU) in Prague. The programme will be launched in October 2020.

1. INTRODUCTION

Due to the increasing threat of terrorist groups acquiring nuclear materials, solid precautions need to be made to intercept illicit transfers of radioactive and nuclear materials as well as to efficiently protect existing nuclear installations from theft or sabotage. At the same time, focus of governments and international organizations shifted on strengthening overall safety of nuclear installations.

Within this framework, nuclear safety, security and forensics are the most vital and crucial aspects associated to nuclear technology. Nuclear safety comprises radiation protection, emergency preparedness and prevention of accidents and mitigation of accidents' consequences. Nuclear security consists of physical protection of nuclear installations, nuclear materials and other sources of nuclear radiation against unauthorized use, as well as cyber security and information security. Apart from illegal treatment, non-nuclear and nuclear radioactive materials can be released into the environment via the emissions from industrial installations, due to accidents but also due to military or terrorist actions. Understanding and applying nuclear forensic methods helps to detect a nuclear related crime. The origin, nature and isotopic composition of trapped or assembled nuclear materials can be revealed, with the aim of unveiling their transportation routes or their intended use.

Nuclear safety and radiation protection related courses are present in several university programmes in the Czech Republic and worldwide. However, neither emergency preparedness nor nuclear security including physical protection, cyber security or information security, are covered by any university study program in the Czech Republic. The situation in nuclear forensic is similar, if not worse. Despite that studies of forensic sciences and forensic (analytical) chemistry are provided by several universities in the Czech Republic, none of these studies includes a nuclear forensic component. On the other hand, even though several nuclear analytical courses are taught in the Czech Republic, most of them at the Czech Technical University in Prague, the link to nuclear forensics is missing.

2. NEW PHD STUDY PROGRAMME AND ITS STRUCTURE

The new Ph.D. study program in Nuclear Safety, Security and Forensics was conceived to fill the above identified gaps by dealing with security of nuclear installations, nuclear materials and sources of ionizing radiation, underpinning the relations between them. Interconnection between safety, security, emergency preparedness, and nuclear-based methods of investigation included in nuclear forensics, makes this program unique; not only in the Czech Republic but also within Central Europe. Participation of foreign students in this program is expected, based on existing academic international relations. Synergic effects among safety, security and forensics distinguish the proposed program from those that are currently available.

The structure of the studies will reflect both the broad spread of the fields covered and the expected different background of the students. The four main fields contributing to the programme will be:

- Safety and security of nuclear installations
- Radiation protection in emergency situations
- Nuclear forensic analysis
- Nuclear cybersecurity

Several elective courses will be offered in each of these fields. The students will be expected to specialize into one of these fields by choosing a minimum of two relevant elective courses from this offer. For the field of nuclear forensic analysis, the courses under development are:

- Nuclear forensic analysis
- Instrumental and radiochemical methods for nuclear forensic analysis
- Nuclear and radioanalytical chemistry

accompanied by two courses extending their knowledge of general nuclear chemistry –"Advanced nuclear chemistry" and "Experimental nuclear chemistry". The unifying role in the new study programme will be played by an obligatory course "Introduction into the nuclear safety, security and forensic" that will provide all students with a broad view across the entire field.

3. EXPERIMENTAL BACKGROUND, RESEARCH AND COLLABORATION

As mandatory for all doctoral study programmes, Ph.D. studies in the new programme will be closely combined with scientific research work. The students' research projects will be conducted both at the CTU in Prague and in the collaborating institutions. In the field of nuclear forensics, the main Czech partner for carrying and supervising the Ph.D. students' research will be the Research Centre Řež that has been formed around the large research infrastructure SUSEN. Internationally, contacts exist with the Nuclear Safeguards and Forensics unit of the Joint Research Centre in Karlsruhe, additional contacts are sought.

As a part of the support for establishment of the study programme, set-up and furbishing of the following four new laboratories has been supported:

- Nuclear materials and ionizing radiation sources detection laboratory
- Nuclear installations physical protection laboratory
- Nuclear installations and ionizing radiation sources cybersecurity laboratory
- Nuclear and dual-use materials forensic analysis laboratory.

The joint Nuclear materials and ionizing radiation sources detection and Nuclear and dual-use materials forensic analysis laboratory will be equipped, among others, by high-resolution gamma-ray spectrometers with low-background shielding, alpha spectrometers, beta- and neutron-counters, neutron generator, analytical high performance liquid chromatography (HPLC) system for dual-use materials, or semi-hot box. In addition to this new and to the existing equipment of the participating departments, the students and researchers will have access to the new multi-isotope Accelerator Mass Spectrometer that is under construction in a parallel project.

4. STATUS, TIMEFRAME AND CONCLUSIONS

The project has been running for almost two years now. By the end of this year, request for accreditation of the programme should be submitted to the National Accreditation Bureau for Higher Education of the Czech Republic. Also by the end of this year, the experimental laboratories should be fully furnished. Since the first students should enroll into the programme since the academic year 2020/2021, nine months will be left to fine-tune the materials for theoretical courses and to make the laboratories fully operational.

To conclude, by the end of September 2020 a new doctoral study programme Nuclear Safety, Security and Forensics will start its regular operation.

ACKNOWLEDGEMENTS

The establishment of the new Ph.D. programme Nuclear Safety, Security and Forensics has been supported by grants No. CZ.02.2.69/0.0/0.0/16_018/0002367 and CZ.02.1.01/0.0/0.0/16_017/0002370 awarded by the Czech Ministry of Education, Youth and Sports.

THE RELIABILITY OF AND CONFIDENCE IN NUCLEAR FORENSICS – FUNDAMENTAL ROLE OF NUCLEAR ANALYTICAL METHODS, WITH EMPHASIS ON QUANTITATIVE GAMMA-SPECTROMETRY USING ANGLE SOFTWARE

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Abstract

Fundamental role of nuclear analytical methods in nuclear forensics is emphasized, particularly that of spectroscopic ones. ANGLE software for advanced quantitative gamma spectrometry is briefly presented and its potential for applicability in nuclear forensics is elaborated. Example of ANGLE applicability to nuclear forensic signatures will be discussed in more detail.

1. INTRODUCTION

Nuclear analytical methods (NAMs) represent a fundamental source of evidence in nuclear forensics, providing information, which cannot be obtained otherwise, especially not with the degree of reliability the NAMs can deliver. The reliability, on its turn, is fundamental to confidence and, ultimately, trust in nuclear forensics (NF). Among NAMs, spectroscopic methods are the most prominent and exploited, especially gamma spectroscopy [1].

Rapid and reliable radioactivity assessment (in both qualitative and quantitative terms) of various objects/samples is an essential requirement in a nuclear forensics task (NF signatures being a typical example). Time is often precious, as well as the quality of the information – in order to make proper decisions and manage the situation. In the present paper ANGLE software for advanced quantitative gamma-spectrometry is briefly outlined and its applicability to NF is discussed (www.angle4.com). It is further proposed to develop a specific methodology which could adequately address the above requirement.

In its various forms ANGLE has been in use for 25 years now in hundreds of gamma-spectrometry based analytical laboratories worldwide (Fig. 1), including many dealing with various aspects of nuclear security – thus not only NF, but also with threat assessment, interdiction and response, accountancy/control of nuclear and other radioactive materials, fuel cycle, transport security, radiation protection, etc.

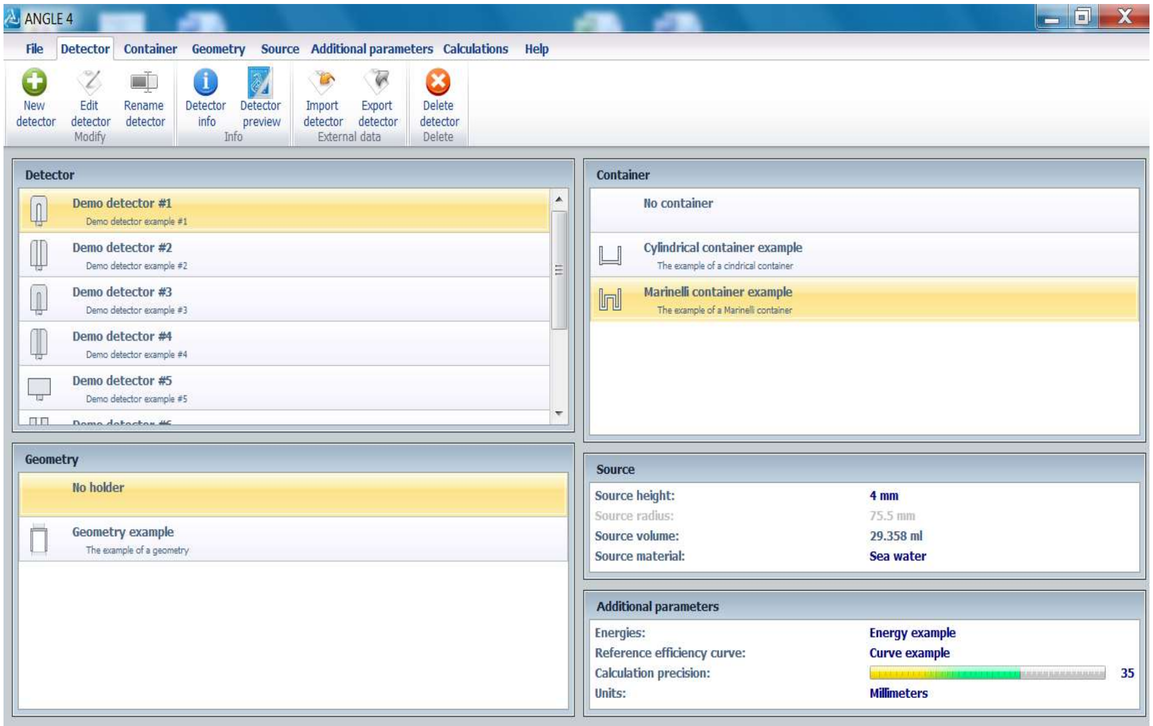
ANGLE purpose is to allow for the accurate determination (in laboratory or in situ conditions) of the activities of gamma spectroscopic samples for which no “replicate” standard exists, in terms of geometry and matrix [2,3]. It utilizes a semi-empirical “efficiency transfer” (ET) approach, which merges advantages of both absolute (e.g. Monte Carlo) and relative (traceable-source-based) methods to determine sample activity – while reducing practical limitations of the latter methods and minimizing potential for systematic errors in the former.

FIGURE 1. SOME OF ANGLE USERS WORLDWIDE

The physical model behind is the concept of the effective solid angle – a parameter calculated upon the input data on geometrical, physical and chemical (composition) characteristics of (1) the source (including its container vessel), (2) the detector (including crystal housing and end-cap) and (3) counting arrangement (incl. intercepting layers between the latter two). ANGLE main screen is shown in Fig. 2. Theoretical background and numerous examples of successful application can be found at ANGLE web site.

ANGLE is characterized by (1) a wide range of applicability, (2) high accuracy, (3) ease-of-use, (4) short computation times, (5) flexibility in respect with input parameters and output data, including easy communication with another software and (6) suitability for teaching/training purposes. The ANGLE architecture also offers (7) potential for accommodating other efficiency calculation methods of different types. In addition, its current breadth of applicability (8) can readily be extended to further/particular user's needs and/or fields of interest – thus, it can be thought of as an “open-ended” computer code. A key aspect and difference from other approaches, which greatly enhances practicality, is that (9) no “factory characterization” of the detector response is required. In fact (10) any detector may be used as some basic knowledge of its construction is available. Apparently, most of this reflects favorably in NF applications.

FIGURE 2. ANGLE MAIN SCREEN: A COMPREHENSIVE AND SELF-EXPLANATORY INPUT FOR GAMMA EFFICIENCY CALCULATIONS



The program can be applied not only in NF, but in practically all situations encountered in gamma-laboratory/in situ practice, e.g. for environmental monitoring, radioactivity control, waste management, fuel analysis, and scientific research applications. Point, disc, cylindrical or Marinelli samples, small or large, of any matrix composition, measured on coaxial, planar or well-type detectors are supported by the software. Practically any type of semiconductor or scintillation detector can be handled – again to an advantage in NF.

ANGLE applicability in NF is thus apparent and straightforward – its simplicity, flexibility and fast performance supports the quantitative analyses of large numbers of samples in time constraining conditions, regardless of type, origin, size, shape, matrix composition etc. In real life, this translates into rapid checks for radionuclides in various objects – which is critical for reliability and proper conclusions, turning eventually into confidence and trust in NF.

ANGLE it is already in use in numerous establishments related to nuclear security one way or another – technical support and monitoring institutions, NF laboratories, emergency teams, regulatory organs, expertize and advisory bodies, as well as educational and training centres – paving the way to the above application. Having said that, appropriate standardization/verification/validation of the method should be an integral part of the development.

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ACTIVITIES OF THE NATIONAL NUCLEAR FORENSICS LIBRARIES TASK GROUP OF THE NUCLEAR FORENSICS INTERNATIONAL TECHNICAL WORKING GROUP

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1. INTRODUCTION

The ability to interpret nuclear forensic examination data and answer investigative questions regarding material production history and provenance has long been recognized as a key capability to support investigations of nuclear or radioactive materials outside of regulatory control (MORC). The national nuclear forensic library (NNFL) concept provides a framework for countries to identify and coordinate the data resources and expertise necessary to assess the characteristics of MORC and determine if it is consistent or not with materials used, produced, or stored within their country.

Within the Nuclear Forensics International Technical Working Group (ITWG), the NNFL Task Group was created to help illustrate the importance of NNFLs to MORC investigations, and organize practical exercises that demonstrate technical aspects of NNFLs. The NNFL Task Group has executed three exercises, titled "Galaxy Serpent 1, 2, and 3," each designed around a unique type of nuclear or radioactive material and test participants ability to organize data and execute the comparative analyses needed to answer investigative questions. To date, the exercises have focused on spent nuclear fuel, radioactive sources, and uranium ore concentrates, which are very different materials, each requiring a unique NNFL approach. One of the most important outcomes of these exercises is building a better understanding that there is not a one-size-fits-all approach to a establishing an NNFL, and the resources and expertise needed for successfully implementing an NNFL are dependent on material type, available material characteristic data, comparative analysis tools, and a wide range of subject matter expertise. Approximately 30 teams have participated in each exercise, and feedback has been overwhelmingly positive, both in terms of illustrating concepts, and demonstrating the importance of NNFLs to nuclear forensics stakeholders within participating countries.

We are currently planning for the Galaxy Serpent 4 exercise, scheduled to start in late 2019. Based on comments from previous participants, this new exercise will emphasize the query and response process between investigators and NNFL experts. Specifically, there will be a focus on how investigators should formulate queries to the NNFL, and how the NNFL should respond to queries using forensic estimative language consistent with assessments of other types of technical forensic evidence.

Through the activities of the NNFL Task Group, the ITWG is pleased to serve the broader international nuclear forensic community by building a better understanding of the importance of NNFLs to nuclear forensic investigations.

DEVELOPMENT OF A STANDARD OPERATING PROCEDURE OF NUCLEAR FORENSICS TO STRENGTHEN THE CAPABILITY ON PREVENTION AND DETERRENCE OF NUCLEAR TERRORISM

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1. INTRODUCTION

Thailand is the main transport and logistics hubs in ASEAN countries. There are thirty-two provinces connecting the borders, which tend to encounter with illegal activity. Additionally, the Incident and Trafficking Database (ITDB) has reported that the unauthorized act of nuclear and radioactive materials remain to occur. Nuclear forensics is a majority measure for prevention and deterrence of nuclear terrorism. Consequently, a standard operating procedure (SOP) needs to develop to define the role and responsibility of the competent authority follows the national legal framework. The SOP can support the incident response goal and nuclear smuggling investigation. Office of Atoms for Peace (OAP) plays a role in developing and implementing the SOP by collaboration with the competent authority.

2. CREATING STANDARD OPERATING PROCEDURE

The process for SOP development comprises three main steps. First, study the role and responsibility of the competent authority. Second, consider the related law and regulation which are National Intelligence Act (1985), National Police Act (2004), Public Disaster Prevention and Mitigation Act (2007), Internal Security Operations Command Act (2008), Forensic Service Act (2016), Nuclear Energy for Peace Act (2016), National Security Council Act (2016), and Criminal Procedure Code 133. Finally, the SOP has developed by discussing with the nuclear forensics networks in 2017. The role and responsibility of the competent authority regarding the law and regulations from each procedure can describe as follows:

(a) On-scene assessment
After being informed of a nuclear accident, the first responder notifies the local police for crime scene investigation. Later, OAP performs the radiological risk assessment. If the situation is not illegal, the OAP will take over follows the Radiation Emergency Preparedness and Response Plan. In case of the circumstance is violated the laws, the inquiry officer (IO) will be in charge. In the situation of a disaster, follow the National Disaster Prevention and Mitigation Plan. Suppose it is not the disaster, the OAP will take action to survey the radiation, and recover the materials until the radiation level is safe.

(b) Evidence collection
The IO assigns the forensics experts, which are Office of Police Forensic Science (OPFS) and Central Institute of Forensic Science (CIFS) to collect the evidence. The OPFS and CIFS are responsible for gathering evidence in the designated area. After that, the OAP will recheck the radiation level and decontamination at the crime scene before releasing the scene.

(c) Investigation procedure
The IO collects all evidence from forensic experts and then releases the scene. The samples will be distributed to the designated forensics laboratories to follow the chain of custody.

(d) Forensics analysis

The physical evidence is examined in terms of traditional forensic by OPFS and CIFS. The example of forensic analysis is a fingerprint, tool mark, DNA, shoe and tire impressions, explosive residue, firearm ballistics, paints, metallic features, documents, trace evidence, and forensic medicine. The contaminated evidence involves a radioactive material (RM), and nuclear material (NM) have to investigate the radionuclide, including the signatures by OAP.

(e) Finding support criminal prosecution
The IO gathers the analysis reports from OPFS, CIFS, and OAP. The inquiry reports need finalization and proposing to the prosecutor as well as present in the court. In case the prosecution requires the additional inquiries, the investigating officer has to assign the laboratories to re-examination the evidence together collect the completing document before submitting to the prosecutor.

The flow chart of the standard operating procedure for nuclear forensics illustrated in Fig. 1

Fig 1 .The standard operating procedure of nuclear forensics.

3. IMPLEMENTATION THE SOP WITH THE COMPETENT AUTHORITY

The exercise program is established for the competent authority and comply with the SOP. The scenario applies to the circumstance of national threat assessment. Later, the SOP is evaluated and improved to meet the requirement of the state implementation.

4. SUSTAINABLE OF THE NUCLEAR FORENSICS NETWORKS

The SOP is an important process to maintain the nuclear forensics networks in long-term. After having the SOP, it is necessary to comply with the relevant organizations. A simulation exercise needs to perform for practicing at least once a year to raise the awareness of the competent authority in the aspect of combat nuclear terrorism.

ACKNOWLEDGEMENTS

The authors are especially grateful to Police Captain Dr. Parinya Seelanan, Forensic Scientist of CSI Sub-Division, Office of Police Forensic Science, Royal Thai Police, who has been supportive of the comprehensive information as part of crime scene investigation and forensic law enforcement.

CORRECTION FOR GAMMA-SPECTROSCOPY ON SWIPE SAMPLE TO MINIMIZE THE EFFECT OF ITS THICKNESS

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Abstract

The paper expresses the technique, applied to gamma-spectroscopy on swipe sample to reduce the effect of the sample thickness.

1. INTRODUCTION

Environmental samples such as swipe sample are usually used to verify nuclear activities. So, swipe sample from nuclear facilities and the environment is expected to contain nuclear material. Its initial information is important to set the target nuclide for destructive analysis and ensure the accuracy and reliability of the analysis. The screening technique using gamma-spectroscopy is able to roughly determine the radioactivity concentration of the gamma-emitting nuclides contained in the swipe sample (10 cm x 10 cm). But the swipe sample is usually folded to be fitted onto a detector size. In this case, it is necessary to correct the acquired data to increase the accuracy, since the detection efficiency may vary according to the distance between the sample and the detector because the folded sample has its own thickness.

2. METHODS/SAMPLE PREPARATION

It is difficult to produce a standard sample of swipe sample, because the radioactive material is hardly distributed on the fabric sample homogeneously. An alternative standard sample which is similar to swipe sample is produced from Korea Research Institute of Standards and Science, an accredited organization to make standard material such as National Institute of Standards and Technology, USA. The sample was used to calibrate the energy and efficiency of a High Purity Germanium (HPGe) detector. And a set of sample container was fabricated and each container has a distance between 1mm to 5 mm from the detector, as shown in the Fig. 1. Errors were examined on each distance between the standard sample and the detector to evaluate a correction factor.

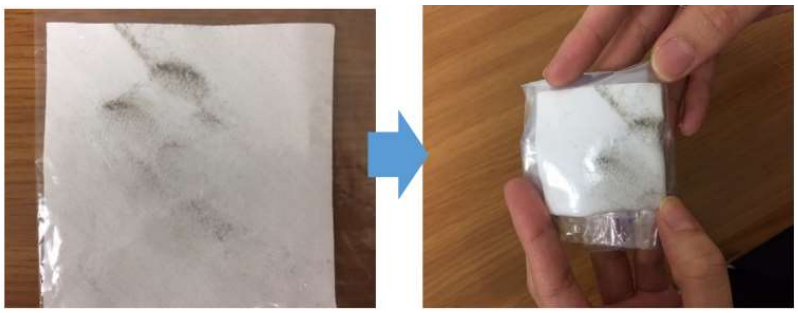
FIGURE 1. AN EXAMPLE SET OF THE SAMPLE HOLDER

A swipe sample which has information of radioactivity was used to verify the correction factor. The sample was

folded twice to be fit onto the detector surface, and the quartered sample of four layers is prepared as shown in Fig.

2. The four-layered sample is thicker than the plane sample, and the top layer would have much error with less detection efficiency than the bottom one. The correction factor would reduce the deviation between layers.

FIGURE 2. SWIPE SAMPLE PREPARATION



3. RESULTS

TABLE 1. ERRORS FROM DISTANCES USING THE STANDARD SAMPLE

Distance	0mm	1mm	2mm	3mm	4mm	5mm
Averaged Errors (%)	2.16	6.05	10.51	13.18	18.34	22.28

Errors with the standard sample were measured under 3600sec (dead time 1.2%). The error gets higher as the sample gets further from the detector. Before the verification test, it is assumed that the detection efficiency of the central point would be optimal to minimize the deviation which is induced from the thickness of the four-layered sample.

TABLE 2. SWIPE SAMPLE TEST

Nuclide	Known Activity (Bq)	Measured Activity (Bq)	Error (%)	Corrected Activity (Bq)	Corrected Error (%)
Cs-137	0.88	0.701	20.3	0.779	11.4
U-235	0.26	0.210	18.1	0.233	9.0
Eu-154	1.52	1.198	21.11	1.093	12.3

It is needed to verify the correction factor with a swipe sample. Our folded sample was 4mm thick and the central point of the sample should have a distance of 2mm from the detector. From error 10.51% of 2mm distance, correction factor 0.9 was evaluated. The swipe sample was measured under 100,000 sec (dead time 0.04%). As a consequence, the error was significantly reduced and the measured activity approached the true value.

4. CONCLUSION

Our study has solved the problem to minimize the error which is induced from the thickness of the sample in a very simple way. This technique may be applicable to screen various samples which contain nuclear material and radioactive material. Furthermore, it is worth trying gamma-spectroscopy on swipe sample to quantify radionuclides, because isotope ratio of radionuclide is very essential to verify nuclear activities for nuclear security and safeguards. An exquisite technique in the view of energy and the absolute detection efficiency should be dealt in the additional experiments.

CHARACTERIZATION OF URANIUM AND THORIUM PARTICLE FOR NUCLEAR FORENSICS ASPECT USING MICROANALYSIS TECHNIQUE

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1. INTRODUCTION

Scanning electron microscopy (SEM) analysis is an advantageous and well-known technique for the microstructural characterization of solid samples. Together with energy dispersive x-ray spectrometry (EDS), these technologies can determine elements composition in a resolution of a few nanometers scale. Monazite ore is a phosphate mineral consists of cerium (Ce) as major element, therefore it contains up to 20 wt% of uranium and thorium. In this study, monazite (Ce, La, Y, Th) PO4 samples containing uranium and thorium 0.3 wt% and 8.0 wt%, respectively, were characterized using SEM/EDS. The X-ray diffraction (XRD) determined crystal structure of material and its molecular composition. Backscattered electron (BSE) image together with energy dispersive technique determined small particles of uranium and thorium particles distributed in monazite.

The aim of this work was to evaluate the ability of the BSE image analysis together with x-ray microanalysis to identify the uranium and thorium particle in monazite ore. The benefits from this study are setup the microanalysis procedure for supporting nuclear forensics investigation and build up the national nuclear forensics' capability.

2. EXPERIMENT

The monazite samples in this study are by-product from tin processing. Samples were crushed and sieved through 325 meshes. Then samples were dried in the oven at 120 C for 2 hours after that dried samples were kept in desiccator to avoid the moisture during XRD and SEM/EDS observation. Two monazite samples (M475 and F476) were studied. X-ray diffraction patterns were obtained by the means of a Bruker D2 PHASER diffractometer using Cu K 2 radiation (= 1.54184 Å). XRD patterns were recorded at room temperature in the 10 ≤ 2 ≤ 100 range, with a step size (2) of 0.02 and interval of 0.002. Scanning electron microscope observation, the samples were applied onto of a 12.5 mm SEM sample stub holder. The sample holder coated by the double special carbon tape. The sample powder was gently scatter over special carbon tape until sufficient powder adhered to the carbon tape. The microstructure of monazite samples was studied by a TESCAN VEGA3 type of scanning electron microscope equipped with a 50 max Silicon Drift Detector Oxford type of energy dispersive X-ray spectrometry. BSE image technique was used to identify the high atomic mass elements under 20 and 30 kV accelerating voltages with working distance of 15 mm. The uranium and thorium were identified by EDS using Aztec software.

3. RESULTS AND DISCUSSION

Crystal structure size and shape and XRD observation indicated M475 and F476 are monazite: (Ce, La, Y, Th) PO4. Scanning electron images of M475 and F476 observed under BSE and secondary electrons (SE) mode at 500 x magnifications and 30 kV accelerating voltage were shown in Fig.1. Images revealed crushed particles, particle size distributed from 1 - 30 micrometer.

X-ray dispersive energy spectroscopy Basically, BSE image observation together with X-ray microanalysis has a great advantage to identify high atomic mass elements, such as U and Th. Thorium and uranium particles were detected in M475 and F476 as shown in Fig.2. The white arrows indicated the clear shiny particle at 30 kV, and are hard to observe shiny particle at 20 kV. It is concluded that 30 kV is the best accelerate voltage for revealing Th or U particles. X-ray energy at L of Th and U is 12.968 and 13.614, respectively. The brightness of the image related to the total mass irradiated. High accelerating potentials may be expected to improve resolution, however there are often of questionable utility. The use of several accelerating potentials is strongly indicated. [1]. In addition, BSE yield depend up on the atomic number in contrast of SE [2]. As results, it implied the sufficient accelerate energy of X-ray microanalysis is about 3's of X-ray energy of element. X-ray microanalysis results of M475 and F476 were shown in Fig. 3, revealed 49.9 wt% of thorium and 8.7 wt% of uranium in M475. F476 contained Th and U about 14.3 and 1.5 wt%, respectively. However, the results were observed at a very small area, it is better to observe other positions in a sample to increase the accuracy and reliable result.

FIGURE 1. PARTICLE SIZE IN SE AND BSE MODE (A) M475 AND (B) F476

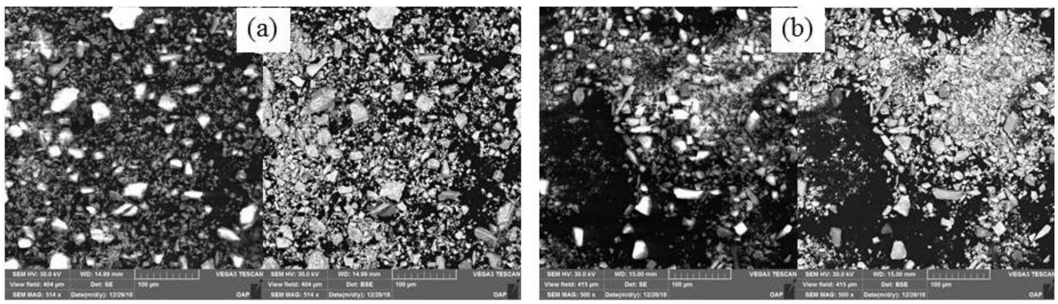


FIGURE 2. COMPARISON BSE IMAGES OBSERVED AT 30 KV AND 20 KV: (A) M475 AND (B) F476. ARROWS IN IMAGES HIGHLIGHTED SHINY PARTICLES.

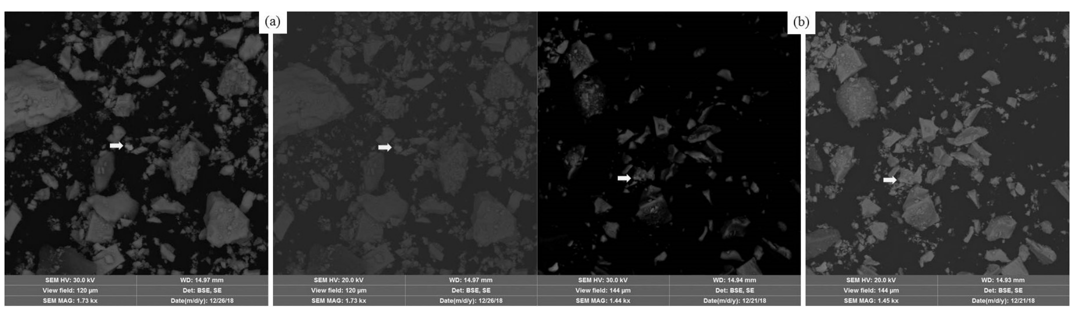
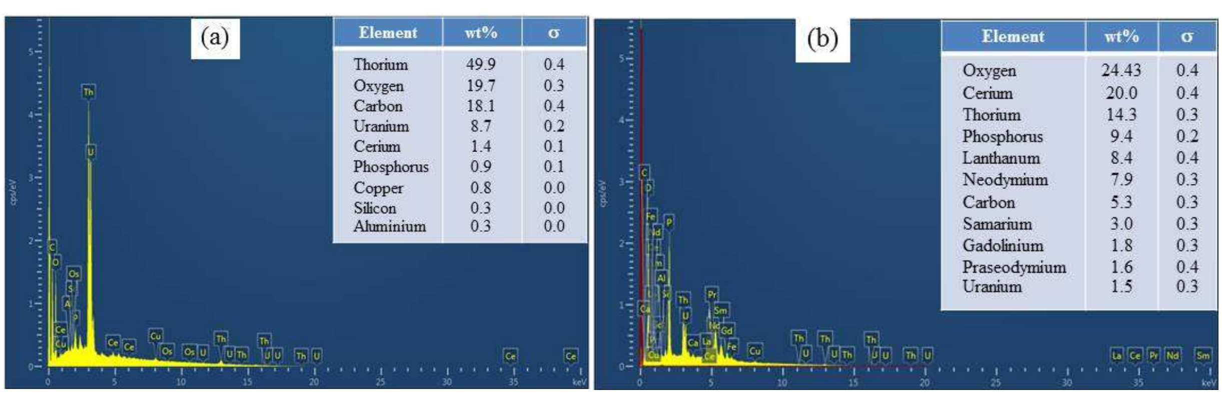


FIGURE 3. X-RAY MICROANALYSIS SPECTRUM AND ELEMENTS DISTRIBUTION: (A) M475 AND (B) F476



4. CONCLUSIONS

An analytical method for determination of U and Th particles in monazite is developed for the nuclear forensics investigation aspect. Backscattered secondary images together with X-ray energy dispersive techniques have a great advantage to identify small particles of uranium and thorium distributed in monazite. BSE images observed at 30 acceleration voltages, much shinier of U and Th particles are visible in monazite samples when using an acceleration voltage of 20 kV. U and Th particles are the signature of seizure nuclear materials. The method has potential application in the field of nuclear forensics, where morphology and nuclear materials found can be used for the assessment of unknown samples origin.

ACKNOWLEDGEMENTS

The SEM/EDX instrument was support by EU project no.29 “Centre of Excellence for Nuclear Forensics in Southeast Asia Region”.

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TECHNICAL SESSION VIII

NUCLEAR FORENSICS HUMAN RESOURCE DEVELOPMENT: TRAINING

ESTABLISHING A TRAINING CURRICULUM FOR THE APPLICATION OF ALPHA SPECTROMETRY TO NUCLEAR FORENSIC EXAMINATIONS

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1. INTRODUCTION

As part of an ongoing collaboration between the United States and Armenia focused on building nuclear forensics capacity, a new curriculum was developed and tested for incorporating alpha spectrometry into nuclear forensics examinations. Alpha spectrometry is attractive for many reasons, including that it is capable of characterizing many high-risk nuclear materials, instrumentation is robust and relatively easy to operate, and results are useful as evidence for prosecuting criminal activity and provide investigative leads regarding material provenance. A certain level of expertise is required to adopt alpha spectrometry, including radiochemical separations, source preparation, instrument calibrations, and data reduction and evaluation. This new training curriculum covers these topics, and uses hands-on laboratory work to provide trainees with the basic skills necessary to perform relevant nuclear forensics measurements.

Trainees begin the course with necessary safety and security briefings, and lectures to introduce the fundamentals of alpha spectrometry. To ensure applicability, the course is designed around using alpha spectrometry to answer specific investigative questions regarding a uranium material hypothetically found outside of regulatory control, including what is the enrichment of the uranium and what is the radiochronometric model age of the uranium. Over the six-day course, trainees perform the radiochemistry to purify uranium and thorium from the sample under examination, prepare electrodeposited sources, and determine ^{234}U, ^{235}U, ^{238}U, and ^{230}Th by alpha spectrometry. Trainees then reduce data to determine the ^{235}U enrichment in the sample, and the model age based on the ^{230}Th / ^{234}U radiochronometer.

This new curriculum was successfully tested in October 2018, when five scientists from Armenia were trained at Los Alamos National Laboratory. The new alpha spectrometry measurement methods are now being incorporated into Armenia's nuclear forensic examination program, and add capability for characterizing nuclear forensic samples. While many countries look to more advanced mass spectrometry methods for these measurements, the cost of instruments, infrastructure, and expertise development are prohibitive. However, successfully implementing alpha spectrometry is an important foundation for ultimately adopting more sophisticated methods, many of which rely on the same fundamental knowledge of radiochemical separations and data evaluation.

THE 5TH INTERNATIONAL TRAINING COURSE ON NUCLEAR FORENSIC METHODOLOGIES

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Abstract

The paper describes the outcome of the fifth International Training Course on Nuclear Forensics Methodologies, summarizing the successes and recommending aspects of improvement ahead of the next offering of the course, currently scheduled to occur at EC-JRC in 2019.

1. INTRODUCTION

The IAEA defines nuclear forensics as "…the examination of nuclear or other radioactive material, or of evidence that is contaminated with radionuclides, in the context of legal proceedings under international or national laws related to nuclear security." While access to advanced nuclear forensic analysis is available globally through technical collaborations facilitated by the Nuclear Forensics International Technical Working Group, every country should retain some basic capabilities for categorizing suspect nuclear and radioactive materials outside of regulatory control. To further that goal, the International Atomic Energy Agency (IAEA), in cooperation with the United States Department of Energy (DOE) and the European Commission's Joint Research Centre (EC-JRC), has developed a training course on nuclear forensic methodologies for practitioners.

The IAEA International Training Course on Nuclear Forensics Methodologies, or simply the 'Methodologies' course, has been offered by the IAEA a total of five times since 2012, previously hosted at Pacific Northwest National Laboratory (PNNL) in Richland, Washington, USA, in 2012, 2013, 2015 and 2018 and at the EC-JRC, in Karlsruhe, Germany in 2016. Over that period of time, more than 110 representatives from over fifty partner countries have participated in this two-week intensive training course.

From 23 April to 4 May 2018 Pacific Northwest National Laboratory hosted twenty-two participants from ten countries (China, Estonia, Georgia, Moldova, Morocco, Romania, Singapore, Tajikistan, Thailand and the United Arab Emirates), for the fifth offering of the IAEA Methodologies. The training course covers a comprehensive summary of key scientific methodologies used to support a nuclear forensic investigation. The majority of the course, which included a mix of traditional classroom instruction, demonstrations and hands-on instruction, was held at DOE's Hazardous Materials Management and Emergency Response Training and Educational Center (HAMMER). In addition, participants spent several days in analytical laboratories on the PNNL campus. Throughout the two-week training, participants were asked to periodically demonstrate lessons learned by role playing as border guards, forensic examiners, or nuclear science experts, and respond to a mock nuclear forensic examination in support of a nuclear security investigation. These scenario based exercises encompass every aspect of a nuclear forensic investigation, from the detection of material out of regulatory control (MORC) at border crossing and the demonstration of a radiological crime scene, to the receipt, handling, inventory and processing of traditional and nuclear forensic evidence, to the evaluation of radioanalytical results in order to answer questions posed by law enforcement. The course was taught by world-leading nuclear forensics experts from the EC-JRC, the Swedish Defense Research Agency (FOI, the United Kingdom Atomic Weapons Establishment (AWE) the US Department of State (DOS) and the Federal Bureau of Investigation (FBI), the Washington State Crime Lab, as well as numerous experts from the Department of Energy's National Laboratories including Lawrence Livermore (LLNL), Los Alamos (LANL), and PNNL [1], and the IAEA.

Nuclear forensics is a valuable tool for combatting nuclear smuggling and ensuring that nuclear material is used for only peaceful purposes. When illicit nuclear trafficking occurs, experts can use nuclear forensics to help identify the point that control of that material was lost, and then work with responsible officials to ensure the event is not repeated. This presentation describes the outcome of the fifth International Training Course on Nuclear Forensics Methodologies, summarizing the successes and recommending aspects of improvement ahead of the next offering of the course, currently scheduled to occur at EC-JRC in 2019.

ACKNOWLEDGEMENTS

Acknowledgements to the 2018 instructors: D. Smith and J. Davydov(IAEA); D. Dale, M. Iyer (NNSA); P. Thompson (AWE); M. Wallenius (EC-JRC); H. Ramebäck (FOI); J. Phillips (Washington State Crime Lab, USA); J. Blankenship (FBI); M. Curry (DOS);.W. Geist, E. Rose, P. Karpius (LANL); K. Treinen, N. Marks, K. Samperton (LLNL); J. Schwantes, S. Morley, S. Tedrow, M. Athon, R. Pierson, E. Buck, L. Sweet, M. Liezers, E. Krogstad, C. Brown, S. Spurgeon, N. Henderson, A. Nixon, T. Morales, S. Cooley, B. Pierson, L. Montez, R. Clark, D. Reilly, J. Corbey, K. Mchugh, A. Eng, S. Shen, I. Leavy, M. Nims, M. Maynard, E. Ashbaker, A. Cannell, N. Unak, (PNNL).

TOWARD CHARACTERIZING THE NUCLEAR FORENSICS TRAINING TOOLBOX

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Abstract

The paper will discuss an array of TTX-based nuclear forensics training tools that are being used and developed, with a more thorough explanation of the Tabletop Cooperative Simulation Exercises (TCSE). Discussion will suggest guidelines and resources for preparing an exercise appropriate to training goals within a systematic approach. This work is intended to bolster international efforts to deliver nuclear forensics training offerings that are well characterized within best practices.

1. INTRODUCTION

Core guidance from the IAEA is found in Nuclear Security Series 31-G, and states that "capacity building for nuclear security refers to a systematic approach to the use of education, training, exercises, awareness raising, workforce management, knowledge management and knowledge networks to develop and continuously improve the governmental, organizational and individual competences and capabilities necessary for establishing, implementing and sustaining an effective nuclear security regime." Capacity building activities for nuclear security in general, and nuclear forensics in particular, can be engaged at a range of different levels, depending on the needs and existing capacity of the partner.

As often discussed in training and education literature and guidance, tabletop exercises (TTX) have great value as an adaptable training resource that promotes active learning. They have emerged as a common capacity building activity, especially in security areas where professionals must be prepared to deal with low probability and high consequence events - i.e., those for which realistic practice is difficult to attain. There are many ways to approach TTX development; available offerings thus vary widely in their level of customization, complexity, level of interactivity, duration and audience size, amongst other things. In accordance with this variation, TTX offerings go by a variety of names, including inter alia simulations, role play, scenario-based policy discussion and serious games.

The paper examines Tabletop Cooperative Simulation Exercises (TCSEs), a type of TTX built on the foundation of advanced practitioners' nuclear detection knowledge and experience. The TCSE aims to promote the harmonization and exchange of good practices amongst experts. The exercises simulate work situations and environment at the table top level, and can be designed to focus on interactions between organizations with different but linked nuclear and other strategic security functions within one state, or from different states. This exercise methodology thus involves teaming individuals with similar job roles and tasks, and challenging them to work within a realistic and regionally appropriate scenario environment with inject elements ranging from routine to high consequence. Exercise design promotes high participant engagement, both with the exercise and with each other, resulting in the exchange of ideas and established practices within and across different fields involved in the practice of nuclear security. The TCSE exercise is a methodologically sound training design through which regional practitioners can exchange good practices and network with their colleagues in an atmosphere attuned to the behavioral and cultural factors that affect nuclear security capacity building. Past iterations include SimEX (2015) and IASE (2016), which emphasized export control; COSINUS I (2016, Southeast Asia) and II (2018, Central Asia) which focused on nuclear security. In 2017, a TCSE was adapted for the first time to nuclear forensics: NUFORSE 2017. For this exercise as for other TCSEs, feedback received from participants during evaluation of past exercises indicates that TSCEs might be different, and their impact higher, than more standardized discussion-based offerings. The pace and difficulty of work, the intensity of interaction, and the realism of situations are amongst the characteristics which participants point to as both unique and valuable.

This abstract elaborates the TCSE exercise concept and highlights the ways in which exercise components increase retention of core concepts and increase the understanding of nuclear forensics knowledge networks. Importantly, discussion will also contextualize the TCSE within the array of TTX-based nuclear forensics training tools that are being used and developed, suggesting guidelines and resources for preparing an exercise appropriate to training goals within a systematic approach. This work is intended to bolster international efforts to deliver training and education offerings that are well characterized within international best practice, and to elevate the dialogue between training providers regarding the training tools available for nuclear forensics capacity building.

TECHNICAL SESSION IX
NUCLEAR FORENSICS RESEARCH AND DEVELOPMENT: NON-DESTRUCTIVE ANALYSIS

DETERMINATION OF URANIUM ENRICHMENT BY GAMMA SPECTROMETRY

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Abstract

The paper is focused on non-destructive gamma spectrometric techniques for the measurement of the ^{235}U enrichment.

1. INTRODUCTION

The Republic of Turkey is improving its nuclear forensics capabilities in line with its progress in the development of civilian nuclear power. The Turkish Atomic Energy Authority (TAEK) is the sole officially assigned government organization in Turkey to assess nuclear forensics cases and analyse any samples collected during these incidents. TAEK is working on enhancing its existing nuclear forensics analysis infrastructure and regulatory framework including analytical methods and regular procedures. These improvements include establishment of necessary infrastructure associated with analytical best practices, and encouraging collaboration with other national partners.

Gamma spectrometry is the first step in nuclear forensics analyses. It is a comparatively easy method due to its fastness and reliability requiring none to minimal sample preparation. It is also preferred because of its non-destructive nature which allows further detailed analyses on the samples. This study is focused on non-destructive gamma spectrometric techniques for the measurement of the ^{235}U enrichment and different enrichment analysis methods by gamma spectrometry is discussed in detail.

There are several methods to determine uranium enrichment in nuclear materials. When the spectrum of uranium is worked on, it can be recognize that there are potentially three regions that might be considered for measuring both ^{235}U and ^{238}U. These regions are from 50 to 65 keV, 80 to 120 keV, and from 120 to 1001 keV. The first one is very low, both in energy and in intensity. Thus, it is not generally applicable. With applying good correction factors, it can be possible to determine activities of uranium isotopes by efficiency relations of standard materials. In the second region, there are several gamma-rays and x-rays that are superimposed. To separate these peaks and to calculate intensities of each peak, it must be developed a fitting algorithm. Thus, it will be possible to determine an approximate efficiency curve or to apply Multigroup analysis method. The third region spans a large energy range. In this region, the gamma ray peaks can be fitted to determine the relative efficiency curves. The oldest and the most widely method employed use the 185.7 keV full energy peak. This method requires calibration of the instrumentation with standards. Some authors have preferred to use another U-235 characteristic peak, instead of the 185.7 keV especially for measuring uranium concentration in ores.

CHARACTERIZATION OF PURE-BETA EMITTERS BY NON-DESTRUCTIVE TECHNIQUES: APPLICATIONS IN NUCLEAR FORENSICS

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Abstract

The paper describes the development of a non-destructive method for the characterization of beta minus radioactive sources, which do not emit any detectable gamma lines. An experimental set-up based on plastic scintillation detection system has been built for this purpose. This set-up was tested on standard $^{90}Sr/^{90}Y$ radioactive source and then applied for the characterization of a similar radioactive sources found outside the regulatory control.

I. INTRODUCTION

According to the Incident and Trafficking Database (ITDB) of the International Atomic Energy Agency (IAEA), most of the reported cases contained information on radioactive sources which had a potential use in medical or industrial applications [1]. The large amount of radioactive sources seized outside the regulatory control can be explained by their modest physical protection (ex. in hospitals, factories, etc.). There were 752 incidents reported in the Black Sea region itself, between 1993 and 2017, more than a half of which involved radioactive sources. According to the RSG-1.09 IAEA standards, 50% of these cases involved sources that can give rise to considerable doses if not properly controlled. [2]

When a radioactive material is seized out of regulatory control, after opening the criminal case, investigative authority can require information concerning the seized materials. In this context, techniques for handling and analyzing this kind of materials must be available.

II. PURE-BETA EMITTERS

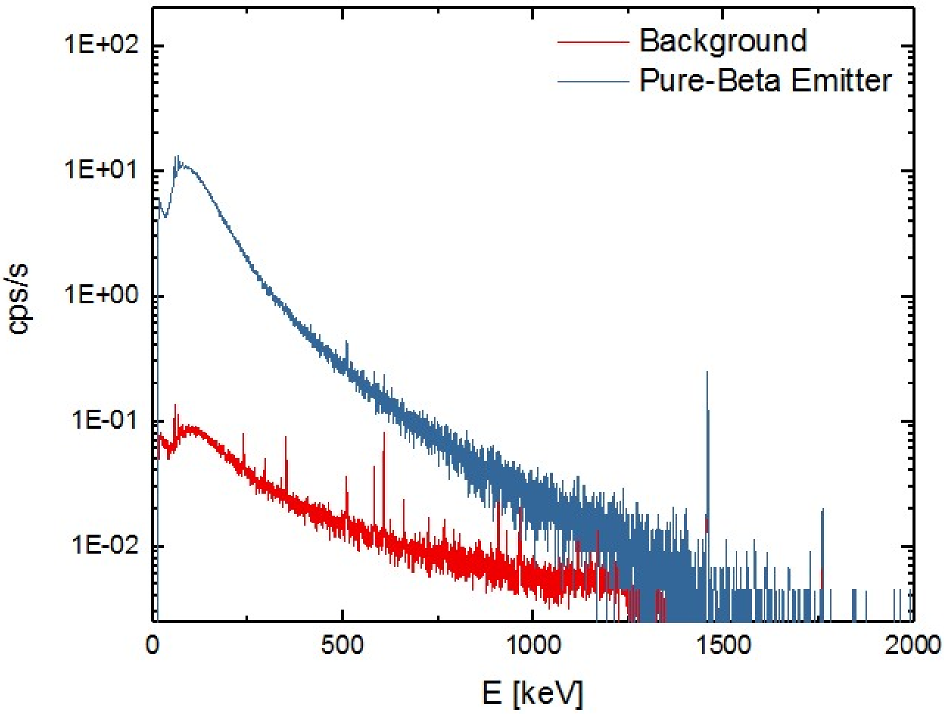
Most commonly encountered outside the regulatory control pure-beta sources, used in industry and medicine, are $^{90}Y/^{90}Sr$, ^{63}Ni, ^{32}P, and ^{106}Ru. Examples of the beneficial purposes of these sources are industrial gauges measurements, some of them can be used in teletherapy sources, radioisotope thermoelectric generators or even as brachytherapy implant in order to treat cancer. However, due to reasons such as the inadequate dismantling of facilities or hospitals that use such sources, some of them might escape outside the regulatory control and pose threat to public health.

The main challenge in analyzing pure-beta emitters consists in the fact that this type of sources have continuous spectra meaning that the beta particles are not emitted with discrete energies and do not emit any characteristic gamma lines (Fig.1).

Until now, the characterization of pure-beta emitters was based on destructive methods required for beta spectrometry. The new developed method consisted in calibrating the thick plastic scintillator detector based on experimental setup using reference sample and afterwards performing measurements on the unknown pure-beta minus emitter samples.

The lesson-learned during the successful analysis of a real sample found outside the regulatory control in Romania (within criminal investigation) involving pure-beta emitters will be presented as an example of an application of the developed method.

FIGURE 1. SPECTRUM OF A PURE-BETA EMITTER (BLUE) AND THE BACKGROUND (RED)



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IMPLEMENTATION NUCLEAR FORENSIC IN SECURITY OF EVIDENCE GOODS IN THE CONDITION OF THE CASES

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1. INTRODUCTION

Indonesia, an archipelago consisting of 5 large islands and thousands of small islands, has a robust industrial base that includes nuclear and radioactive materials. The islands are connected by sea and airspace with more than 280 airports, enabling the transfer of nuclear material from one place to another both through airports and harbors. This may also possibly allows the smuggling of nuclear materials from outside to Indonesia. Nuclear forensics is a series of investigations on nuclear/radioactive materials to find evidence of criminal activities such as illicit trafficking, smuggling, nuclear waste disposal, dirty bomb as well as nuclear incidents such as nuclear emergency, transportation and nuclear satellite re-entry explosion. It also includes orphan sources, which are the discovery of nuclear/radioactive materials in unintended locations.

The nuclear forensic objective is to find evidence in the form of nuclear/radioactive material and secure it. Then, through the testing of nuclear material by using analytic techniques, it can be determined the origin and history of the aforementioned substance. These are done in the context of law enforcement or nuclear security assessment. Safeguarding evidence in the crime scene is very important due to potential hazard of radiation and contamination from nuclear/radioactive materials to community and environment. This also carried out so that the evidence remains intact (preventing of loss/damage) and eliminating the possibility of intervention from other parties, as well as reducing the potentially harmful consequences of radiation exposure to the public and our officers, limiting the dispersion of contamination involving radiation sources or radioactive materials.

Within Indonesian nuclear forensics teams are divided into three groups, namely the Field Team, the Laboratory Team, and the Nuclear Library Team. The Field Team is tasked to ensure safety and security of the crime scenes along with searching and securing evidence. The Laboratory Team is responsible for developing the analysis and identification of nuclear/radioactive materials and determining the characteristics of the evidence through laboratory analysis. The Nuclear Library Team has the task of developing nuclear material characteristics database in collaboration with the nuclear library of developed countries and determining the source of evidence by adjusting the characteristics of the evidence exists in the data base.

The steps in safeguarding evidence begin with reports from the First Responder, namely interested parties to uncover cases, search for nuclear materials/radioactive sources, and resorting for perpetrators/owners. The First Responder can be individuals or institutions such as the Police in abandoned source cases, dirty bombs, and traffic incidents. Customs/Quarantine at the airport/harbors in the case of smuggling, illicit trade of people contaminated, Indonesian Maritime Security Agency in the case of smuggling/radioactive materials disposal, Indonesian National Board for Disaster Management in nuclear accident/emergency, and National Nuclear Regulatory Agency in case of missing radioactive materials.

Reports from the First Responder will be followed up by the Field Team who will sweep the crime scene. The Field team is equipped with radiation measuring and other safety equipment such as chain barriers, radiation signs etc. They will measure exposure and contamination around the scene and then make a boundary perimeter (in term of safety and security). Additionally, they will make access to the entrance/exit, determine control points (checkpoints), install radiation signs, and control personnel/officers inward and outward of the barrier. Then, the Field team will search the evidence using radiation instrument by sweeping the crime scene suspected to contain evidence. The discovered evidence is documented and then secured by sealing, before being sent to the Forensic Laboratory Team to be identified

The identification results of the forensic laboratory will then be analysed by the Nuclear Library Team to find out the origin of the material as evidence for the law enforcement and police in finding the perpetrators and solving cases.

Several things still need to be considered in terms of developing forensic nuclear division in our country are:

1. Updating of Standard Operating Procedure (SOP)
2. Completeness of the radiation detection instrument and laboratory analysis equipment
3. Increased knowledge and expertise from human resources
   Human resources involved in the nuclear forensic team must have expertise and knowledge that is specific to each of its fields, so even the knowledge and expertise must be increased by means of education or skills courses.
4. Increased cooperation with various institutions both from within and outside the country
   To accelerate the transfer of knowledge and technology, it is necessary to collaborate with various institutions both from within and outside the country, with this collaboration it is hoped that it can complement and evaluate nuclear forensic activities in each country.
5. Commitments from the government in terms of funding
   To carry out forensic nuclear activities in an ideal manner, it is necessary to have a commitment and participation from the government in funding, and assistance from other countries so that they can provide benefits and can complement each other.

NUCLEAR FORENSICS IN IFIN-HH: A BRIDGE BETWEEN FUNDAMENTAL RESEARCH AND NUCLEAR SECURITY

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Abstract

During the last years a coherent program started in IFIN-HH with the aim of establishing the first dedicated nuclear forensics laboratory in Romania. The steps taken in the implementation of this program are presented, with some results obtained our R&D activity.

1. INTRODUCTION

With a contribution of over 10% of the national scientific output, IFIN-HH is one of the most important public R&D organizations in Romania and hosts a variety of experimental facilities of national and European interest, including 3 Tandem accelerators, 2 Cyclotrons, the Multipurpose Irradiation Facility Centre, and the Radioactive Waste Treatment Plant. During the last years, a program started in IFIN-HH with the aim of developing the first dedicated Nuclear Forensics Laboratory in Romania.

The steps taken in the implementation of the nuclear forensics program were: to put to use the existing infrastructure, to identify the need for new equipment and acquire it, to develop of the human resources in this new field of activity and to establish collaborations with national authorities and international partnerships.

We started to develop and test new methods for nuclear forensics using our existing facilities by using the PIXE (Proton Induced X-ray Emission) / PIGE (Proton Induced Gamma-ray Emission) reactions at the 3 MV Tandetron for measuring the concentrations of trace elements in uranium samples [1]. This is a fast, nondestructive type of measurement that proved useful for measuring concentrations down to hundreds-tens of ppm with reasonable good accuracy; for a higher accuracy we developed the procedures for inductively coupled plasma mass spectrometry (ICP-MS) measurements in the case of uranium oxides [2]. We successfully tested all these methods in the practical nuclear forensics exercises CMX-5. As a result, we decided to acquire a new ICP-MS equipment to be dedicated to nuclear forensics measurements. The same philosophy, to develop a fast method for a first response and use a second one, more time-consuming but more accurate for a later response, was applied in the case of identifying the signature of reprocessed uranium. This is also an excellent example of the new technical possibilities offered by doing nuclear forensics studies in a performant fundamental physics research laboratory. A 4π array of 25 gamma-ray detectors with BGO shields called RoSPHERE is used at the 9 MV Tandem to study the structure of atomic nuclei. If a Uranium sample is placed in the center of the array and we require to have two photons detected simultaneously, all the natural background lines are suppressed and the detection of 208Tl decay from the sample becomes straightforward. Beside really rapid and accurate gamma spectrometry, RoSPHERE allows to assess the presence of ^{236}U, thus indicates quickly if the sample was reprocessed after irradiation.

From the experience acquired due to participation to international practical exercises and to technical meetings in the field, we identified the need for new equipment and new techniques. In this respect we already improved our CBRN vehicle with a gamma spectrometer and we installed XRF equipment and new HPGe planar detectors. In order to strengthen our capacity to characterize the microstructure of the samples we decided to acquire new XRD and SEM equipment. Also, a 3D-laser-scanner will be used to acquire in digital form the complete description of a sample's geometry before any destructive measurements to be performed. A database was developed as a prototype in the frame of a Galaxy Serpent international exercise; our current goal is to include in it the measured signatures and all available information for samples existing in IFIN-HH. A special attention was dedicated to improve our skills and attract new, young researchers. Some members of our team were trained in JRC, IAEA, laboratories from USA and Hungary etc. and we also improved our knowledge on microstructural characterization using SEM and XRD. We already had successful PhD and MSc thesis defense in this field and two PhD students are currently working on topics related to nuclear forensics. At the beginning of our activity in the nuclear forensics domain the only successful collaboration we had, was with the Romanian regulatory body, CNCAN. But we quickly identified the need to discuss with all the national authorities involved in preventing and responding to a nuclear security event in order to present the specifics of our work as a base for a future, better collaboration. As such, we had fruitful discussions representatives from the Inspectorate for Emergency Situations, General Inspectorate of the Border Police, Ministry of External Affairs, National Police, Romanian Intelligence Service and Public Ministry - Directorate for Investigating Organized Crime and Terrorism.

At international level, IFIN-HH is actively involved in the activities of the ITWG and GICNT. We collaborated with Stockholm International Peace Research Institute on a regional project and organized the conference “Nuclear Security in the Black Sea region” in April 2018 for the assessment and final approval of the project’s report. Also, Memoranda of Understanding were signed with the nuclear forensics laboratories of Republic of Moldova and Hungary. Moreover, the Practical Arrangements dedicated to nuclear forensics were signed between IFIN-HH and IAEA, and an Amendment to the existing Collaboration Agreement with the JRC of the EC is currently being finalized.

TECHNICAL SESSION X
NUCLEAR FORENSICS RESEARCH AND DEVELOPMENT: NATIONAL NUCLEAR FORENSICS LIBRARY

JOINT SAMPLE ANALYSIS ON URANIUM ORE CONCENTRATES AND ITS APPLICATION ON THE IMPLEMENTATION OF A NATIONAL NUCLEAR FORENSIC LIBRARY IN KAZAKHSTAN

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1. INTRODUCTION

Through various workshops and guidance documents, the international nuclear forensics community has been promoting the development and implementation of National Nuclear Forensics Libraries (NNFL) in support of investigations relating to nuclear and other radioactive materials found out of regulatory control. An NNFL is a national system of expertise and information that may be utilized to identify nuclear or radioactive material found out of regulatory control.

The Office of Nuclear Smuggling Detection and Deterrence (NNSA/NSDD/NA-213) has been supporting the international community through the development and delivery of NNFL workshops that focus on the technical and practical aspects of developing and implementing an NNFL.

Under the auspices of the 2006 Joint Communiqué on counter trafficking of nuclear and radioactive material, NSDD is cooperating with the Government of the Republic of Kazakhstan and the Institute of Nuclear Physics (INP) on strengthening Kazakhstan's nuclear forensics capabilities. As part of the ongoing nuclear forensics collaboration between NSDD and the Republic of Kazakhstan, several government organizations, including INP and associated stakeholders expressed interest in establishing an NNFL. In this context, NNSA/NSDD supported the recent NNFL Workshop at the Kazakhstan Institute of Nuclear Physics (INP) in September of 2018. The event was very successful with representatives from all stakeholder organizations (i.e. the National Security Committee, the Committee for Atomic and Energy Control and Oversight, the Institute of Nuclear Physics, Kazatomprom, and Institute of Atomic Energy) actively participating in the workshop, and the Kazakhstan government expressing its full support in partnering with NSDD on nuclear forensics capacity building activities, including the design and implementation of an NNFL.

As the largest single producer of uranium in the world, Kazakhstan has a targeted interest in understanding the measurable characteristics associated with the uranium ore concentrate (UOC) it produces. The planned Kazakhstan NNFL will include data resources and expertise on the wide range of nuclear and radioactive materials present in Kazakhstan. UOC is signature-rich and is therefore a good material to target for inclusion in an NNFL. The first data resource for the Kazakhstan NNFL will therefore be UOC.

In support of the implementation of an NNFL in Kazakhstan, and to advance the technical and analytical skills relevant to nuclear forensic analyses, NSDD has engaged in a new joint sample analysis with INP though Lawrence Livermore National Laboratory (LLNL) and the International Science and Technology Center (ISTC). A set of six commercially available UOC samples of known origin was sent from LLNL to INP for a full nuclear forensic examination.

Through this joint sample analysis, LLNL and its partner organizations in Kazakhstan will continue to collaborate and advance technical and analytical skills relevant to nuclear forensic analyses. This work will include establishing best practices for obtaining, interpreting and reporting data.

This UOC sample set will be fully characterized through a range of analytical techniques to include morphology, chemical form (i.e. $^{3}U^{8}O$, ^{4}UO, ADU etc.), activity, uranium isotopic composition and assay, as well as major, minor, and trace elemental analyses. Through this analysis, participating laboratories will enhance their experience working with UOCs, as well as our understanding of the signatures associated with this type of material.

Based on the knowledge gained during the NNFL workshop and previous nuclear forensics engagements, LLNL/NSDD have partnered with INP and its associated stakeholder organizations on the implementation of an NNFL exercise in Kazakhstan using the chemical and physical characteristics (i.e. signatures) of the uranium ore and UOC samples investigated in this joint sample analysis. The different participating organizations will receive information on the provenance of all the UOC samples, except for one sample that will serve as an "unknown". As part of the exercise, the "unknown" sample can be queried against the five "known" samples in the (preliminary) NNFL dataset. Analysts will have the opportunity to perform comparative analysis and determine whether the "unknown" sample has a similar provenance and process history to any of the "known" samples.

As part of the planned work, the Kazakhstan NNFL will include databases and statistical tools to assist the nuclear forensics examiner in performing a comparative analysis of nuclear materials. The NNFL databases will store physical, chemical, elemental and isotopic characteristics inherent to UOCs obtained by the different analytical techniques applied to the samples. Typically, NNFLs include large data resources and often include relational databases and multivariate statistical tools. For initial development, and for the purpose of this first NNFL joint exercise, however, the data will be captured in a simpler flat database that can be easily used by non-database experts.

The development and exercising of the UOC component of the NNFL will be an important early step in the assembly of a comprehensive library capturing important nuclear and radioactive materials in Kazakhstan. Although it is possible to create an NNFL by incorporating all material types in a single data resource, many countries, including the U.S., have taken a federated approach whereby different material types are captured in several data resources that can be accessed by the library. By adopting a federated approach to the NNFL, Kazakhstan will be able to include additional materials, expertise, and data resources in the NNFL as they become available.

ACKNOWLEDGEMENTS

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. LLNL-ABS-761288.

APPROACHES FOR DEVELOPING AND SUSTAINING THE SEALED RADIOACTIVE SOURCE AND MATERIAL COMPONENT OF A NATIONAL NUCLEAR FORENSICS LIBRARY

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1. INTRODUCTION

To support the investigation of an illicit trafficking event or in circumstances where a sealed radioactive source or radioactive material is found outside of regulatory control, nuclear forensic signatures can be collected. Comparison of the data collected to known data sets, or a National Nuclear Forensics Library (NNFL) can be leveraged to assist with the identification of the source and material, and may provide potential leads to the investigative authority. Comparison of the data collected to data sets of known provenance – that is, data within a NNFL – can assist in identifying the origin of the material and can provide leads of potential value to the investigation into the point at which regulatory control was lost. Development of an NNFL for the application of sealed radioactive sources may include, but not limited to, the incorporation of reference information, including administrative and accountancy and control information from a State's regulatory authority including import, export, and transportation; material manufactures, material analysis reports and historical documentation archives.[1]

Unlike the provision to establish the regulatory body in the IAEA Code of Conduct on the Safety and Security of Radioactive Sources [2], the responsible organization(s) for nuclear forensics and the development and deployment of NNFL is at the discretion of individual States. This paper will discuss two approaches a State could consider for the development of the sealed radioactive source and radioactive materials component of a NNFL, highlighting the leveraging and accessing of existing information.

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INTERNATIONAL QUERIES OF THE U.S. NATIONAL NUCLEAR FORENSICS LIBRARY

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As part of a gift basket at the 2016 Nuclear Security Summit, the United States offered the international community the ability to query the United States' National Nuclear Forensics Library (NNFL). The formal process for such inquiries is detailed to further illuminate the streamlined procedure available through diplomatic channels. Further, the process used by the US Government to pass the query to the US NNFL will be described as will the query process and the formal response back to the international community. Lastly, a case study is highlighted to demonstrate the potential benefits of querying the United States' NNFL when questions regarding material provenance arise or when materials are found out of regulatory control.

FORENSIC EXAMINATION OF NUCLEAR MATERIALS AND RADIOACTIVE SUBSTANCES

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Abstract

The paper presents main points of organization and performing forensic examination of nuclear materials and radioactive substances, which should be taken into consideration when organizing national system for identification of nuclear and other radioactive materials found out of regulatory control.

1. INTRODUCTION

The process of identification of nuclear materials and radioactive substances (NRM) should be organized in accordance with the requirements of national legislation, including collection of material evidence, the sequence of operations with them and the presentation of an expert conclusion. It should also use generally accepted standards when performing its individual actions. The results of the identification should be executed in such a way that they could be presented to the court.

The experience of the performed investigations shows that the interests of the investigation may require an analysis of different kind of samples.

The methods of preparation of these samples for analysis, methods of analysis, and, accordingly, a possible list of the involved analytical laboratories is determined by the specific of real objects to be analysed within the framework of the examination.

The collection of material evidence in a criminal case is carried out by the investigator in the course of performing investigative actions such as inspection of the crime scene, search and others. The task of nuclear material experts and specialists during the inspection of the crime scene or during a search is to assist the investigator in carrying out the investigative action: determining the real possibility and conditions of work at the scene or with a concrete suspect, or drawing the investigator's attention to circumstances, objects, or traces that can carry information about the crime.

During the forensic examination, the task of experts and specialists is to provide the most comprehensive answers to the questions of the investigation.

If the state carries out a large amount of work on the development of nuclear technologies and on the control of nuclear activities, then it already possesses all the necessary specialists for performing forensic examinations of nuclear materials. Participation of these specialists in exercises with particular scenarios is sufficient for mastering specific forensic examination by them. Exercise scenarios should be as close as possible to the actual investigation scenarios of the relevant kinds of crimes.

The crimes with an NRM can have very different scenarios and conditions, therefore methods and approaches to analysis of NRM for support crime investigations can vary widely. Accordingly, the tasks of identifying the NRM can be solved in different ways for investigation of various incidents. Nevertheless it can be noted some of the most common details and trends inherent to the organization of the process and to the performance of identification.

At the first stage of the study of detainees or detected samples of NRM or their traces, material evidence is analysed by non-destructive methods. First of all, inscriptions and other sign characteristics of the NRM are studied and their informativeness is determined. After that, the analyses of the detained samples of NRM or of material evidence contaminated by its traces are performed by radiometric methods as well as by other methods that do not alter the properties and characteristics of the detained samples.

Based on the results of studies of samples by non-destructive methods, analysis of information from databases and other sources, a list of material characteristics, which should be established in the result of samples analysis, and materials to be requested for comparative analysis are determined. The comparative analysis of the detained material and materials from the archive with close characteristics is performed in the same laboratory (same laboratories) by the same methods.

The result of a comparative analysis is a comparison of the properties and characteristics of the detained material or trace amounts of material with the properties and characteristics of materials with known parameters: the manufacturer, precursors or raw materials from which the material is made, the date of manufacture, etc. If the properties and characteristics of the detained material coincides with properties and characteristics of one of the archive materials, a preliminary conclusion about the identification of the detained material is made. In case of coincidence of measured properties and/or characteristics of the detained material and several materials from the archive, the unambiguous identification of the detained material or its traces is impossible. If it becomes clear in the result of a comparative analysis that there is no material in material archive with properties and characteristics, which are the same with properties and characteristics of detained material, following examination is reduced to analyzing the information available in the databases and to modeling the properties and characteristics of materials. In both cases: determination of material, which could be original for detained one, as well as recognition of absence such material among materials produced, used or stored in the state, expert evaluates these outlets in terms of their significance.

A RECENT IAEA PUBLICATION "DEVELOPMENT OF A NATIONAL NUCLEAR FORENSICS LIBRARY: A NATIONAL SYSTEM FOR THE IDENTIFICATION OF NUCLEAR OR OTHER RADIOACTIVE MATERIALS OUT OF REGULATORY CONTROL"

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1. INTRODUCTION

The extended abstract provides an overview of the IAEA non-serial publication Development of a National Nuclear Forensics Library: A National System for the Identification for Nuclear or Other Radioactive Material out of Regulatory Control published in November 2018. The document provides policy makers, law enforcement officials, technical personnel, and competent authorities with information about the concept and benefit of establishing and using a National Nuclear Forensics Library (NNFL) as part of a nuclear security investigation; and, imparts a background for the use of a NNFL to identify the origin and account of nuclear or other radioactive material found out of regulatory control.

In support of measures to prevent, detect and respond to a nuclear security event, nuclear forensics science provides information on the origin and history of nuclear and other radioactive materials out of regulatory control in the context of international legal instruments and national laws related to nuclear security. Important to a nuclear forensics examination is the ability for States to identify nuclear and other radioactive material within the State and determine whether those materials are consistent with domestic holdings. A nuclear forensics examination reflects the demonstrated confidence in conclusions following laboratory analysis and interpretation of findings. A NNFL is one tool that can facilitate interpretation of findings and assist States in the determination whether that material found out of regulatory control is consistent or inconsistent with its domestic holdings. With increased recognition of the role of nuclear forensics as a means to enhance a nuclear security infrastructure, States may choose develop and maintain a Library in order to reinforce already existing mechanisms to identify nuclear and other radioactive material encountered out of regulatory control (MORC).

The non-serial publication, Development of a National Nuclear Forensics Library: A National System for the Identification for Nuclear or Other Radioactive Material out of Regulatory Control [IAEA-TDL-009, 2018] provides Member States with the rationale for the development of a Library and addresses how a State may use a Library in investigations of MORC.

The publication's objectives are:

- To provide policy makers, law enforcement officials, technical personnel, and relevant competent authorities with information about the role and benefit of establishing and using an NNFL as part of a nuclear security investigation;
- To impart context for the use of an NFFL to identify the origin and history of nuclear or other radioactive material found out of regulatory control.

In addition, the publication provides information to understand and organize information on nuclear and other radioactive material within the State, relevant to nuclear forensics, based on nuclear processing steps, radioisotope source types, and radioisotope source applications. The publication also includes approaches to compare data characteristics, or signatures, necessary for utilization of a NNFL in determinations of material origins and process history.

It is important to note that this publication does not include specific information on the establishment of an NNFL; the establishment of a material sample archive; legal, policy, and financial aspects regarding the establishment or use of an NFFL; what, if any, information can be shared with other States; or advice on how to conduct nuclear forensic examinations. For conducting nuclear forensic examinations, guidance is provided in, Nuclear Forensics in Support of Investigations (Nuclear Security Series No. 2-G (Rev.1) [1].

ACKNOWLEDGEMENTS

IAEA consultancies as well as a technical meeting on this publication began in 2010 and continued through to final drafting and publication at the end of 2018. During this time, the Member States provided valuable comments during multiple revisions of the draft. The IAEA is grateful to the Member States for their many contributions that improved this publication.

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GALAXY SERPENT; WEB-BASED TABLE-TOP EXERCISES. USING NATIONAL NUCLEAR FORENSICS LIBRARIES IN SUPPORT OF AN INVESTIGATION

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1. INTRODUCTION

Galaxy Serpent is an ongoing series of virtual, web-based international table-top exercises, where teams of scientists from various countries use provided realistic surrogate nuclear or other radiological (RN) material data to formulate their own National Nuclear Forensics Library (NNFL), and determine if hypothetically seized RN material is or is not consistent with their model NNFL. These table-top exercises are conducted under the auspices of the Nuclear Forensics International Technical Working Group (ITWG), and have involved teams of scientists from over 40 states and international organizations.

Galaxy Serpent aims to mature the concept and utilization of NNFLs by providing an opportunity for participants to identify key technical expertise to create a NNFL and to illustrate the potential benefits offered by such a library in support of an ongoing investigation involving RN material out of regulatory control and generating investigative leads.

The first version of the exercise, GSv1, conducted February 2013 to April 2014, utilized public domain spent fuel compositions as the material of interest. A second version of the exercise, GSv2, conducted June 2015 to November 2016, employed synthetic radioactive sealed source data. A third version of the exercise, GSv3 conducted June 2017 to February 2018, employed surrogate uranium ore concentrate (UOC) data derived from geologic deep-sea basaltic core samples.

The design of the GSv3 dataset and exercise will be will be discussed, along with the results and lessons learned from the exercise. The exercise was conducted in two phases in which teams were provided the surrogate UOC data sets, and subsequently used to answer investigative questions pertaining to three hypothetical barrels of UOC found out of regulatory control. Specifically, teams were asked a) to determine whether the material in any of the three different barrels was of similar origin, and b) to assess whether the UOC in each individual barrel was consistent with classes represented in their model library. During the play of GSv3, teams had to contend with real-world aspects such as incomplete data, and had to consider these decisions impacted their ability to utilize their model library in response to posed investigative questions. Despite different approaches and analytical methodologies, teams reported consistent though not identical analytical conclusions.

The Galaxy Serpent series of exercises has led teams to identify additional technical expertise, develop different material components of a model NNFL, and utilize the library to support a hypothetical investigation and generate investigative leads.

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Rueanngoen, A.	Office of Atoms for Peace, Ministry of Sciences & Technology
Tudrabiab, T.	The Office of Forensic Science of Royal Thai Police

TURKEY

Dikmen, H.	Turkish Atomic Energy Authority

UKRAINE

Gaidar, O.	Prospekt Nauki 47
Pashchenko, V.	Nuclear Security and Safeguards Department, State Nuclear Regulatory Inspectorate of Ukraine

UNITED KINGDOM

Awbery, R.	Atomic Weapons Establishment (AWE)
Graham, G.	Atomic Weapons Establishment
Hobbs, C.L.	Centre for Science and Security Studies (CSSS), King's College London
Simm, J.	Metropolitan Police Service

UNITED REPUBLIC OF TANZANIA

Chuma, F.	Tanzania Atomic Energy Commission
Pantaleo, P.A.	Tanzania Atomic Energy Commission (TAEC)

UNITED STATES OF AMERICA

Black, T.	National Nuclear Security Administration
Blankenship, J	FBI Laboratory
Borgardt, J.	Juniata College
Curry, M.	US Department of State
Dallas, L.	Culmen International, LLC
Decker, D.	Stimson Centre
Denton, J.S.	Nuclear and Radiochemistry Group, Los Alamos National Laboratory
Ford, D.G.	National Security Council
Goodsell, A.	Department of Energy
Kips, R.S.E.	Lawrence Livermore National Laboratory
Lamont, S.	Los Alamos National Laboratory
Mclain, D.	Argonne National Laboratory
Pappas, R.	National Nuclear Security Administration (NNSA)
Podlesak, D.	Los Alamos National Laboratory
Schwantes, J.	Pacific Northwest National Laboratory
Stratz, S.A.	United States Department of State
Treinen, K.	Lawrence Livermore National Laboratory
Warner, B.	7000 East Avenue
Wellington, T-A.	Oak Ridge National Laboratory
Wong, F.	Lawrence Livermore National Laboratory

URUGUAY

Goyen, G.	Uruguayan Air Force
Lazzari, M.	Ministry of National Defense
Leal, D.	Uruguayan Air Force

VIET NAM

Le, T.	Institute of Nuclear Sciences and Technology
Tao, X.K.	Ministry of Science and Technology (MOST)

YEMEN

Al-Mahbashi, H.	Department of Forensic Medicine & Clinical Toxicology, Faculty of Medicine, Sana'a University
Al-Shami, E.	Taiz Street

ZAMBIA

Mwaba, P.	Radiation Protection Authority

FULL CONFERENCE PROGRAMME

Monday, 1 April 2019

08:30 – 10:00	Registration
10:00 – 10:30	**Opening Presentation**: Goals and Objectives of the IAEA Technical Meeting on Nuclear Forensics: Beyond the Science Mr David Kenneth Smith (IAEA)
10:30 – 11:00	**Opening Session**: **IAEA Division of Nuclear Security** **Director** Mr Raja Raja Adnan (IAEA) **Welcome by Chairpersons of the Technical Meeting** Ms Maria Wallenius (European Commission) Mr Frank Wong (United States of America)
11:00 – 12:00	**Progress and Potential: Nuclear Forensics in the Context of Nuclear Security** **Invited Panel Session** Ms Kathleen Heppell-Masys (Canada) Mr Klaus Lützenkirchen (European Commission) Ms Maria Klimova (Russian Federation) Mr Grant Ford (United States of America) moderated by Mr David Kenneth Smith (IAEA)
12:00 – 13:30	Lunch
13:30 – 14:30	**International Perspectives on Nuclear Forensics** **Invited Panel Session** Mr John Buchanan (INTERPOL) Mr Ali El-Jaby (GICNT) Mr Klaus Mayer (ITWG) Ms Tegan Bull (INFCIRC/917) Mr Jerry Davydov (IAEA) moderated by Mr Richard Pappas (United States of America)
14:30 – 15:30	**Nuclear Forensics Practices and Experiences: National and International Perspective I** **Technical Session** Chair: Mr Ali El-Jaby (Canada) Ms Maria Wallenius (European Commission) Mr John Simm United Kingdom) Mr Jon Schwantes (United States of America) Mr Pavel Lobanov (Kazakhstan)
15:30 – 16:00	Coffee/Tea Break
16:00 – 17:00	**Nuclear Forensics Practices and Experiences: Case Studies Technical Session** Chair: Mr Vitaly Fedchenko (Sweden) Ms Emily Alice Kroeger (Germany) Ms Andreea Elena Serban (Romania) Mr Eyal Elish (Israel) Mr Edouard Nzambimana (Burundi)

Tuesday, 2 April 2019

09:00 – 11:00	**Radiological Crime Scene and Nuclear Forensics Scenario** Radiological Crime Scene Video with Commentary Mr Peter Burton (IAEA) Mr Frank Wong (United States of America) Interactive Panel [With Audience Intervention] Mr John Simm (United Kingdom) Ms Ruth Kips (United States of America) Ms Tegan Bull (Australia) Mr John Buchanan (INTERPOL)
10:30 – 11:00	Coffee/Tea Break
11:00 – 11:30	**Nuclear Forensics Special Topics: Nuclear Forensics and Criminal Prosecution Invited Presentation** Chair: Ms Maria Wallenius (European Commission) Mr Andrei Apostol(Romania)
11:30 – 12:00	**Nuclear Forensics and Criminal Prosecution Invited Panel Session** Ms Elena Dinu (Romania) Mr Nikolay Kovalenko (Russian Federation) Mr John Simm (United Kingdom) Ms Maria Lorenzo Sobrado (UNODC) moderated by Mr Andrei Apostol (Romania)
12:00 – 13:30	Lunch
13:30 – 14:30	**Nuclear Forensics Initiation and Sustainability: National Considerations I Technical Session** Chair: Ms Ruth Kips (United States of America) Ms Éva Kovacs-Széles (Hungary) Mr Hudson Angeyo Kalambuka (Kenya) Mr Pavel Lobanov (Kazakhstan) Mr Vladimir Stebelkov (Russian Federation)
14:30 – 15:00	**Nuclear Forensics Special Topics: Nuclear Forensics International Technical Working Group (ITWG)** **Invited Presentation** Chair: Mr David Kenneth Smith(IAEA) Mr Klaus Mayer (European Commission)
15:00 – 15:30	**Nuclear Forensics Human Resource Development: Residential Assignment Technical Session** Chair: Ms Kerri Treinen (United States of America) Mr Ivaylo Ivanov (Bulgaria) Ms Marta Bavio (Argentina) Ms Areerak Rueanngoen (Thailand)
15:30 – 16:00	Coffee/Tea Break
16:00 – 16:45	**Nuclear Forensics Human Resource Development: Residential Assignment Invited Panel Discussion** *Career Perspectives* Ms Éva Kovacs-Széles (Hungary) Ms Maria Larisa Ganea (Romania)

	Joint Research Centre - Karlsruhe Mr Klaus Mayer (European Commission) Mr Andrei Apostol (Romania) *Lawerence Livermore National Laboratory* Ms Kerri Treinen (United States of America) Ms Marta Bavio (Argentina) moderated by Mr Jerry Davydov (IAEA)
16:45 – 17:00	**Nuclear Forensics Special Topics: Perspectives from Russian Federation I** **Invited Presentation** Chair: Mr David Kenneth Smith (IAEA) Vladimir Maltsev (Russian Federation)
17:30 – 19:00	IAEA Hosted Reception for Technical Meeting

Wednesday, 3 April 2019

09:00 – 09:30	**Nuclear Forensics Research and Development: Current Status and Future Needs** **Invited Keynote** Chair: Mr Frank Wong (United States of America) Mr Klaus Mayer (European Commission)
09:30 – 10:15	**Nuclear Forensics Research and Development: National Research and Development Efforts** **Technical Session** Chair: Mr Klaus Mayer (European Commission) Ms Tracey-Ann Wellington (United States of America) Mr Yoshiki Kimura (Japan) Mr Kirill Zhizhin (Russian Federation)
10:15 – 10:30	**Nuclear Forensics Special Topics: NUFOR 2019** **Invited Presentation** Chair: Mr Klaus Mayer (European Commission) Mr Roy Awbery(United Kingdom)
10:30 – 11:00	Coffee/Tea Break
11:00 – 11:30	**Nuclear Forensics Special Topics: Perspectives from the United States of America** **Invited Presentation** Chair: Mr Stephen Lamont (United States of America) Mr Tom Black (United States of America)
11:30 – 12:00	**Nuclear Forensics Research and Development: Destructive Analysis** **Technical Session** Chair: Ms Éva Kovacs-Széles (Hungary) Ms Joanna Denton (United States of America) Mr Zsolt Varga (European Commission) Mr Eric Pili (France)
12:00 – 13:30	Lunch
13:30 – 14:30	**Nuclear Forensics Workforce Development and Sustainability** **Invited Panel Discussion**

	Hiring Managers Ms Tegan Bull (Australia) Ms Ruth Kips (USA) *National Strategies* Mr Ali El-Jaby (Canada) Mr Roy Awbery (United Kingdom) *Career Perspectives* Ms Alison Goodsell (USA) Ms Andreea Elena Serban (Romania) moderated by Mr Christopher Hobbs (United Kingdom)
14:30 – 15:30	**Nuclear Forensics Initiation and Sustainability: National Considerations II** **Technical Session** Chair: Mr Vladimir Steblekov (Russian Federation) Ms Alina Nitrean (Moldova) Ms Mar Mar Oo (Myanmar) Mr Ramin Pashayev (Azerbaijan) Mr Hirofumi Tomikawa (Japan)
15:30 – 16:00	Coffee/Tea Break
16:00 – 17:00	**Nuclear Forensics Poster Session (VIC M01 Exhibition Area)** Co-Chairpersons: Ms Maria Wallenius (European Commission) Mr Frank Wong (United States of America) Ms Amélie Hubert (France) Mr Junghwan Park (Republic of Korea) Ms Harinate Mungpayaban (Thailand) Ms Marta Fernández (Spain) Ms Cynthia Cáceres Rivero (Peru) Mr Slobodan Jovanovic (Montenegro) Ms Diah Dwianna Lestiani (Indonesia) Ms Areerak Rueanngoen (Thailand) Mr Stephen Lamont (United States of America) Mr Jan John (Czech Republic)

Thursday, 4 April 2019

09:00 – 09:30	**Nuclear Forensics Special Topics: Perspectives from the Russian Federation II** **Invited Presentation** Chair: Mr Jerry Davydov (IAEA) Ms Maria Klimova (Russian Federation)
09:30 – 10:15	**Nuclear Forensics Human Resource Development: Training** **Technical Session** Chair: Mr Roy Awbery (United Kingdom) Mr Stephen Lamont (United States of America) Mr Jon Schwantes (United States of America) Ms Liz Dallas (United States of America) Mr Klaus Mayer (European Commission)
10:15 – 10:30	**Nuclear Forensics Special Topics: Perspectives from Tajikistan** **Invited Presentation** Chair: Mr Roy Awbery (United Kingdom)

	Mr Ilkhom Mirsaidov (Takijistan)
10:30 – 11:00	Coffee/Tea Break
11:00 – 12:00	**Nuclear Forensics Research and Development: Non-Destructive Analysis Technical Session** Chair: Ms Jovana Nikolov (Serbia) Mr Hasan Dikmen (Turkey) Ms Maria Larisa Ganea (Romania) Mr Agus Sumaryanto (Indonesia) Ms Raluca Marginean(Romania)
12:00 – 13:30	Lunch
13:30 – 15:00	**Nuclear Forensics Research and Development: National Nuclear Forensics Library Technical Session** Chair: Mr Stephen Lamont(United States of America) Ms Ruth Kips (United States of America) Mr. Derek McLain (United States of America) Mr David Podlesak (United States of America) Mr Vadim Gladyrev (Russian Federation) Mr Jerry Davydov (IAEA) Mr James Borgardt (United States of America)
15:00 – 15:30	**Nuclear Forensics Special Topics: Perspectives from Sweden Invited Presentation** Chair: Mr David Kenneth Smith (IAEA) Mr Lars van Dassen (Sweden)
15:30 – 15:45	Coffee/Tea Break
15:45 – 16:30	**Nuclear Forensics 2025: A Strategic Vision Invited Panel Discussion** Mr Tomás Bieda (Argentina) Mr Bruce Warner (United States of America) Mr Roger Howsley (World Institute for Nuclear Security) moderated by Mr David Kenneth Smith (IAEA)
16:30 – 17:00	**Closing Session**: **IAEA Division of Nuclear Security, Nuclear Security of Materials outside of Regulatory Control** **Section Head** Mr Daming Liu (IAEA) **Closing Remarks by Chairpersons of the Technical Meeting** Mr Frank Wong (United States of America) Ms Maria Wallenius (European Commission)