IAEA NUCLEAR SECURITY SERIES NO. XX

NST014

DRAFT, February 2013

STEP 8: 120-day Member State comment: deadline 28 June 2013

Interface document: NSGC, RASSC, WASSC

NUCLEAR FORENSICS IN SUPPORT OF INVESTIGATIONS

(REVISION OF NUCLEAR SECURITY SERIES NO. 2)

DRAFT IMPLEMENTING GUIDE

INTERNATIONAL ATOMIC ENERGY AGENCY

VIENNA, 20XX

FOREWORD

[TO BE ADDED LATER]

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

Forensic science, referred to as forensics, is the examination of physical, biological, behavioural, and documentary evidence in the context of international or national law. The goal of forensics is to discover linkages among people, places, things, and events. Nuclear forensic science is a sub-discipline of forensic science and is referred to as nuclear forensics. Nuclear forensics is the examination of nuclear or other radioactive materials or of evidence contaminated with radioactive material in the context of international or national law or 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 were their intended uses.

In the mid-1990s there was increased reporting of nuclear and other radioactive material out of regulatory control. This increase in illicit trafficking was recognized as a significant security threat by the international community. To investigate such trafficking incidents involving nuclear and other radioactive materials, national authorities required information on the material, how and when it had been produced, and its subsequent history. These inquiries lead to the inception of nuclear forensics as a key element of a nuclear security infrastructure.

Given the widespread and important use of nuclear and other radioactive materials, all States should be aware of the role of nuclear forensic science in supporting nuclear security. Nuclear forensics, using capabilities maintained by the State, can assist in investigations of nuclear security events as well as help identify and remedy vulnerabilities in a State’s nuclear security infrastructure. Nuclear forensics as a preventive measure is effective because it supports the identification of deficiencies in material security and prosecution of criminal offenses related to this material

In recognition of the benefits of nuclear forensics to the implementation of national nuclear security infrastructures, the IAEA began planning for the publication of a technical document on nuclear forensic support in 2002. The basis for the publication was a document entitled Model Action Plan for Nuclear Forensics and Nuclear Attribution [1], developed by the Nuclear Forensics International Technical Working Group (ITWG[1]), that outlined a generalized approach to the conduct of a nuclear

[1] The ITWG is a multinational, informal association of practitioners of nuclear forensics. Prior to 2010, the ITWG was known as the Nuclear Smuggling International Technical Working Group.

forensic examination. The resulting document was published in 2006 as IAEA Nuclear Security Series No. 2 Nuclear Forensics Support [2].

Since the original publication, there have been further advances in nuclear forensics. Nuclear forensic examinations have been successfully applied to a number of reported cases involving the illicit trafficking of highly enriched uranium and plutonium, as well as other events involving nuclear or other radioactive material out of regulatory control. The same techniques as used in nuclear forensics are used to support nuclear counter-terrorism and compliance with various international legal instruments such as the Convention on the Physical Protection of Nuclear Material.

Nuclear forensics is an emerging discipline. The terms and definitions used in this publication represent current best practice and will be subject to change as practices develop.

This publication supports key recommendations in Nuclear Security Recommendations on Nuclear and Other Radioactive Material out of Regulatory Control [3], issued in 2011 and is complemented by other Nuclear Security Series publications including Combating Illicit Trafficking in Nuclear and other Radioactive Material [4], issued in 2007 as well as Radiological Crime Scene Management [5] Development of a National Nuclear Forensics Library [6] which are currently in preparation.

1.2. OBJECTIVE

The objective of this publication is to describe the role of nuclear forensics in support of investigations of a nuclear security event and provide a context for nuclear forensics within a national nuclear security infrastructure. Additionally, the publication promotes international cooperation by encouraging States to seek or provide assistance, where appropriate, with regard to developing capabilities or during an investigation of a nuclear security event.

1.3. SCOPE

This publication provides national policy makers, decision makers, law enforcement and technical personnel with guidance on the role of nuclear forensics in the context of investigating a spectrum of nuclear security events. Also included are descriptions of nuclear forensic examinations; the role of nuclear forensics in a national nuclear security infrastructure including the investigation of a nuclear security event; and mechanisms for international cooperation and assistance in nuclear forensics. The essential elements of nuclear forensics capacity building including awareness, education, expertise development and training are described. Furthermore, this publication emphasizes that nuclear forensics encompasses more than just instrumentation or analytical measurements. It is a comprehensive plan undertaken by States to determine the origin and history of nuclear or other radioactive material in support of law enforcement or nuclear security investigations. Such investigations may include, but are not limited to, illicit trafficking incidents, or nuclear or other radioactive materials encountered outside of regulatory control.

This publication does not provide detailed guidance on the design, equipping or staffing of a laboratory where nuclear forensic analysis may be conducted; nor does it provide detailed guidance on radiological crime scene management, the conduct or management of an investigation of a nuclear security event, or traditional forensic examinations, although each of these subjects is important to the success of a nuclear forensic examination.

1.4. STRUCTURE

Following the introduction, Section 2 illustrates the nuclear forensics model action plan and highlights issues for all States to consider for the development of a nuclear forensic capability. Section 3 outlines the response activities at the scene of a nuclear security event that are relevant to nuclear forensic examinations and Section 4 explains the importance of developing a forensic examination plan and a nuclear forensic analytical plan. Section 5 presents different approaches for performing forensic examinations on evidence contaminated with radioactive material. Section 6 discusses the requirements of a designated nuclear forensic laboratory and the different types of nuclear forensic analysis. Section 7 provides an overview of the methods and processes involved in nuclear forensic interpretation and Section 8 covers the role of confidence in analytical results and communication of the findings. Section 9 describes international cooperation for nuclear forensics and considerations when requesting nuclear forensic assistance. Section 10 discusses national capacity building activities that should be undertaken in order to develop and maintain nuclear forensic capabilities. Following the main sections are Appendices I, II, III and IV, which provide more detailed information on tools for nuclear forensic categorization, techniques for nuclear forensic characterization, other forensic science disciplines and examples of capacity building activities available internationally, respectively, and Definitions, which have been harmonized with other IAEA and United Nations publications.

2. THE ROLE OF NUCLEAR FORENSICS IN A NATIONAL NUCLEAR SECURITY INFRASTRUCTURE

Nuclear and other radioactive materials are present throughout the nuclear fuel cycle, but they are also widely used in industry, research, medical and biological studies, and other technical and scientific applications [4]. It is a State’s responsibility to implement a nuclear security infrastructure to protect these materials, including measures designed to prevent, detect, and respond to nuclear security events. When nuclear and other radioactive materials are detected outside of regulatory control States should be prepared to appropriately respond, including applying nuclear forensics in support of the investigation. Some examples of nuclear and other radioactive materials are shown in Table 1.

TABLE 1. EXAMPLES OF TYPES OF NUCLEAR AND OTHER RADIOACTIVE MATERIAL [4]

Type of Material	Example materials
Nuclear material	^{233}U, ^{235}U , ^{238}U, ^{239}Pu
Medical radionuclides	^{14}C, ^{67}Ga, ^{99m}Tc, ^{123}I, ^{125}I, ^{131}I, ^{201}Tl
Industrial radionuclides	^{57}Co, ^{60}Co, ^{90}Sr, ^{109}Cd, ^{133}Ba, ^{137}Cs, ^{192}Ir, ^{241}Am, ^{252}Cf
Naturally occurring radioactive materials (NORM)	^{40}K (fertilizer, building materials, ceramics), materials containing natural thorium or uranium and their decay products

The IAEA's Incident and Trafficking Database (ITDB) [7] regularly compiles information, reported voluntarily by States, on the unauthorized possession, theft, loss or other unauthorized activities involving nuclear and other radioactive material. From 1993 through 2012, 2331 incidents[2] have been reported to the ITDB. Of these confirmed incidents, 419 involved unauthorized possession and related criminal activities (sixteen of which involved highly enriched uranium (HEU) or plutonium), 615 involved the theft or loss of nuclear or other radioactive material and a total of 1244 cases involved other unauthorized activities and events.

The level of reporting indicates that, despite the existence of national nuclear security infrastructures, material continues to be diverted out of regulatory control, whether unintentionally, such as loss, or intentionally as a result of criminal acts such as theft or was never under regulatory control. Given this information, there is a need for States to develop the capability to prevent, detect and respond to any event involving nuclear or other radioactive material that has nuclear security implications. Events such as these are referred to as nuclear security events. A nuclear forensics examination may be an important component of the response to a nuclear security event.

2.1. NUCLEAR FORENSICS AS A PREVENTIVE MEASURE

Nuclear forensic findings may determine that material has been removed from a site or sites previously deemed secure. Deficiencies may be identified in material accountancy or nuclear security

[2] An incident may be categorized in more than one group—for example the theft and subsequent attempted sale of a radioactive source. Accordingly, the sum of the incidents in the groups can differ from than the total number of incidents. In 69 cases, the reported information was not sufficient to determine the category of incident.

systems both at the facility and at the State level. As such, lessons learned from the investigation of a nuclear security event may be incorporated to improve nuclear security measures, thereby aiding in the prevention of future nuclear security events.

Knowledge that a State has nuclear forensic capabilities may also function as a deterrent to individuals or groups who may otherwise intend to divert or illicitly traffic nuclear or other radioactive material. The success of nuclear forensics as a deterrent will be dependent on its credible implementation and demonstrated success in supporting investigations and subsequent successful legal proceedings that rely upon this evidence.

2.2. NUCLEAR FORENSICS MODEL ACTION PLAN

The nuclear forensics model action plan (Figure 1), which is further described in Sections 3 through 10, provides generalized guidance on the conduct of a nuclear forensics examination and related activities that will be performed in the context of an investigation of a nuclear security event. The process covers activities undertaken by the authorities requesting nuclear forensic examinations and the laboratories that may be called upon to undertake the analysis and interpretation.

Nuclear forensic examinations are undertaken to respond to key questions posed by the investigative authority, which may relate to the nature, history and origin of nuclear or other radioactive material involved in the nuclear security event under investigation. The questions posed by the investigative authority will be influenced by the nature of the nuclear security event and any related legal proceedings that may arise as a consequence of the investigation.

Nuclear forensic analysis and interpretation may lead to findings regarding the material associated with a nuclear security event. When combined with other aspects of the investigation, including traditional forensic findings, conclusions may be drawn about the associations between the material and people, places, events and production processes. States should recognize that although a nuclear forensic capability may not be used on a regular basis, it may play a significant role in the investigation of a nuclear security event.

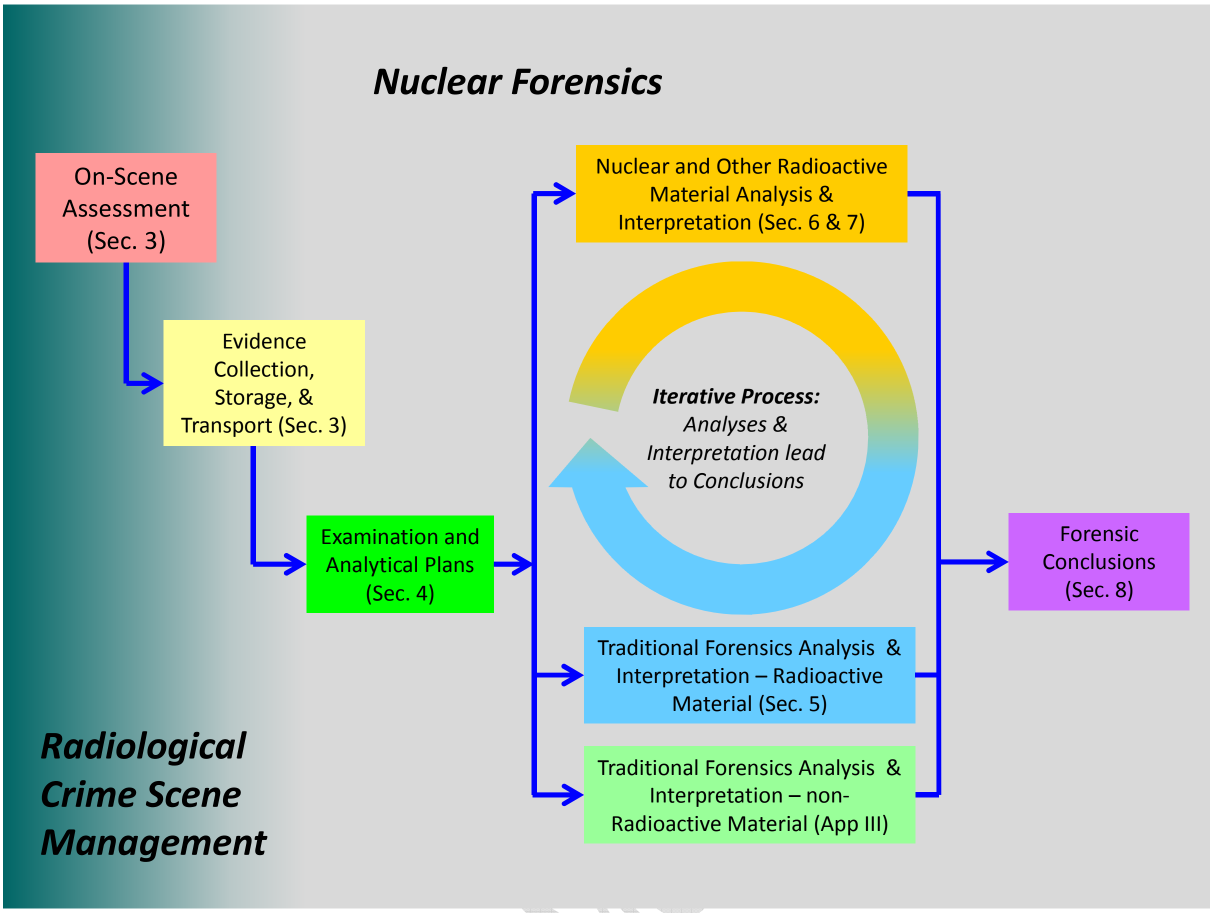

FIG. 1. Illustration of the nuclear forensics model action plan: a process which supports an investigation of a nuclear security event. Background shading differentiates radiological crime scene management and nuclear forensics. Sections in this report related to the model action plan are so indicated.

2.3. NATIONAL FRAMEWORK FOR IMPLEMENTING A NUCLEAR FORENSIC CAPABILITY

All States should have a national response plan for nuclear security events, to allow for an appropriate and coordinated response. As nuclear forensics can play a key role in the investigation into a nuclear security event, the nuclear forensics model action plan (Figure 1) should be incorporated into the national response plan to the extent possible.

States should ensure that roles and responsibilities for nuclear forensics are clearly defined in advance of a nuclear security event and that expertise, instrumentation and procedures are in place. There should also be provisions for the safe and secure storage of seized nuclear and other radioactive material, as well as a means to safely and securely transport the material from the scene to an evidence storage site. Such a storage site may be a laboratory capable of undertaking characterization of collected material or may be an interim evidence storage site, where seized material may be kept until it is sent to a designated nuclear forensic laboratory for analysis.

Development and implementation of a nuclear forensic capability within a State may begin by identifying existing capabilities, including relevant facilities established and expertise used for other purposes, and creating mechanisms for their use in an investigation. Relevant capabilities may exist, for example, at radiation protection institutions; radiochemistry or nuclear physics departments at universities; environmental monitoring laboratories; quality control laboratories of nuclear fuel cycle facilities; as well as at security and defence establishments. Some States may be able to use experience or infrastructure created to help verify compliance with or adherence to international treaties, including the Treaty on the Non-Proliferation of Nuclear Weapons [8] and the Convention on the Physical Protection of Nuclear Material (CPPNM) and the Amendment thereto [not in force].

States may also establish a national nuclear forensics library of data and information under their control to enable a credible assessment of whether material encountered out of regulatory control is or is not consistent with nuclear and other radioactive material produced, used, or stored within the State [6]. For further discussion of national nuclear forensics libraries see Section 7.2.

International cooperation allows States to request, receive, and provide nuclear forensics assistance with respect to developing capabilities or as part of an investigation of a nuclear security event. Specialized analytical tools for characterization of nuclear and other radioactive material may only be available in a few laboratories worldwide and, in fact, may not be required for the investigation of many nuclear security events. States without national capabilities to perform a full characterization of nuclear or other radioactive material or of evidence contaminated with radioactive material may choose to establish bilateral/multilateral agreements or arrangements with laboratories comprising additional nuclear forensic capabilities, in order to facilitate assistance if the need should arise, as discussed in Section 9.2.

2.4. NUCLEAR FORENSICS IN RELATION TO INTERNATIONAL AND NATIONAL LEGAL INSTRUMENTS

The responsibility for nuclear security, and nuclear forensics, rests entirely with each State. Currently there is no one single international legal instrument that fully addresses all aspects of the nuclear security infrastructure. The legal foundation for nuclear security is comprised of a body of international legal instruments that are binding including conventions, treaties, and UN Security Council resolutions, including those in References [9–19], as well as recognized principles developed for the promotion and safe and secure use of nuclear technology. These binding international legal instruments have created obligations that require States Parties, inter alia, to create offences in relation to the defined intentional action involving misuse of nuclear and other radioactive material and to implement mechanisms for requesting, receiving or providing assistance. They also contain provisions related to the return of material in certain defined circumstances and under certain conditions. Bilateral and multilateral legal instruments allow cooperation and sharing of information and capabilities and enhance international security.

Nuclear forensics supports the implementation of:

- The international legal framework for nuclear security and the manner in which the international legal framework governs relationships between States, in particular, cooperation and assistance with the investigation of nuclear security events that have transboundary implications; and
- The national legal framework for nuclear security, in particular in support of a State's legal actions related to a nuclear security event, to include potential criminal prosecution.

States should ensure that a comprehensive legal and regulatory framework is implemented to support and empower competent authorities. The responsibilities include regulation, customs and border protection, transport of material, policing and law enforcement and the prosecution and adjudication of alleged offences involving nuclear or other radioactive material.

An effective national nuclear security infrastructure will implement the international legal framework for nuclear security, and harness potentially admissible evidence, derived from nuclear forensic analysis and interpretation to address nuclear security events. To this end, that States are able to provide and receive international assistance in nuclear forensics is an endorsement of this capability.

3. RESPONSE TO A NUCLEAR SECURITY EVENT TO ENABLE NUCLEAR FORENSIC EXAMINATIONS

In order for nuclear forensic analysis and interpretation to be effective, the response at the scene of a nuclear security event must accommodate the needs of forensic science, including nuclear forensics. In this section, the key elements of the on-scene response to a nuclear security event that enable a comprehensive nuclear forensic examination are highlighted. More detailed guidance in relation to response actions and roles and responsibilities are provided in the IAEA implementing guide on Radiological Crime Scene Management [5].

The official in charge of the scene, sometimes referred to as the incident or on-scene commander, has responsibility for decisions pertaining to public safety, environmental protection, safety of response personnel and the preservation and collection of evidence. In order to understand all of the requirements and to make informed decisions about the investigation, experts from all relevant disciplines should be consulted for the provision of advice and support.

3.1. SECURING THE SCENE

Securing the scene of a nuclear security event involves all those activities undertaken to manage access in to, within, and out of a scene where nuclear or other radioactive material is encountered out of regulatory control. The goals in securing the scene of a nuclear security event are similar to those for securing a conventional crime scene. Additional objectives that are unique to a nuclear security event include:

— Minimization of any radiological hazards associated with the scene for the safety of the responders, the public and the environment;

— Establishing control over the nuclear or other radioactive material;

— Collection of nuclear or other radioactive material as well as evidence contaminated with radioactive material.

3.2. COMMON HAZARDS ASSESSMENT OF THE SCENE

The initial phase of operations at the scene of a nuclear security event should include an assessment of the risks at the scene. This assessment should encompass common hazards that might pose a health and safety risk to the public, personnel conducting operations at the scene and the environment. This common hazards risk assessment is identical to the one that would be performed for any other crime scene, with two possible additions.

First, the known or suspected presence of nuclear or other radioactive material requires the assessment of radiation hazards as part of the common hazards risk assessment and that the relevant radiation protection measures at the scene are decided upon and implemented (e.g. the use of appropriate personal protective equipment (PPE) and dosimetry). Appendix I provides additional description of equipment and instruments for on-scene radiation safety assessments.

Second, any non-radioactive hazards, such as adverse weather, debris and explosives, need to be evaluated. The assessment of such hazards should consider their possible impact on (a) personnel wearing the appropriate PPE while on-scene; (b) the possible spread of nuclear or radioactive material within or beyond the scene; and (c) the ancillary equipment used to support operations at the scene. For instance, loose debris might cause a rip or tear to PPE, thus compromising its integrity and placing the wearer at heightened risk. Similarly, if unexploded ordnance were to detonate, the resulting explosion could spread the nuclear or other radioactive material both within the scene and beyond and cause physical harm to on-scene personnel and essential ancillary equipment. Finally, a heavy rain could wash or dilute evidence, including nuclear or other radioactive material, from the scene, and could hamper the mobility of on-scene and near-scene personnel, and create hazardous working conditions.

3.3. CATEGORIZATION OF NUCLEAR OR OTHER RADIOACTIVE MATERIAL

Categorization is the on-scene non-destructive analysis of the nuclear or other radioactive material involved in a nuclear security event. The primary goals of categorization are to identify radionuclides present and estimate the quantities of those radionuclides. This typically requires training and expertise in the proper use of field-portable non-destructive analysis instrumentation, and in some cases, assistance from laboratory experts to properly interpret data. Examples of commonly used instruments for nuclear forensic categorization are described in Table 2.

TABLE 2. EXAMPLES OF INSTRUMENTS FOR ON-SCENE CATEGORIZATION

Categorization Measurement	Non-destructive analysis instruments
Identify gamma-ray emitting radionuclides present, estimate quantities of radionuclides	Low-resolution gamma-ray spectrometer (e.g., sodium iodide, NaI(Tl) or cadmium zinc telluride, (CZT)) High-resolution gamma-ray spectrometer (e.g., high-purity germanium detector, HPGe)
Identify uranium and plutonium and estimate isotopic compositions and quantities	High-purity germanium (HPGe) low energy gamma-ray and X ray spectrometer with spectral deconvolution codes or other relevant methods

The basic information obtained during categorization is often sufficient to identify the intended use for a recovered material (e.g. an industrial radiography source, nuclear fuel pellets, etc.), and may lead to the determination that no further investigation is warranted. Results from categorization can also provide useful information regarding potential risks of material to first responders, law enforcement personnel, the public, and the environment that supplements the basic radiation protection measurements made during the common hazards assessment. Categorization results are essential for making proper decisions regarding how to proceed with a nuclear forensics examination, including selecting the appropriate nuclear forensics laboratory, determining physical protection requirements, and ensuring material are transported according to applicable regulations. Communicating categorization results to the nuclear forensics laboratory as soon as it is available is helpful, as it allows the laboratory to properly plan for the receipt of material and begin preparing a nuclear forensic analytical plan (Section 4.1).

3.4. COLLECTION OF EVIDENCE

Following a nuclear security event, the types of evidence that may be collected include (a) the nuclear or other radioactive material and (b) evidence associated with traditional forensic disciplines that may or may not be contaminated with radioactive material. During evidence collection activities, responders should comply with the protection measures implemented as a result of the common hazards assessment. Responders should be aware that the on-scene risks could evolve during the deployment and the protection measures may have to be adjusted accordingly. For a scene where radiation fields are present, the time on-scene, the distance from the material and the use of shielding are important factors in reducing the external radiation dose to responders. For scenes where unsealed material is present, especially in a loose form such as powder or liquid, protective measures to minimize incorporation (e.g. inhalation or ingestion) will be an additional important factor in reducing the total radiation dose to responders. [20, 21]

Evidence collection activities should follow national rules for evidence, including scene documentation, chain of custody procedures and sample labelling. In addition, all evidence needs to be contained in a manner that minimizes the potential for the uncontrolled spread of nuclear or other radioactive material from the scene. It is essential that appropriate consideration be given to the relative timing of collection activities for traditional forensic and nuclear forensic samples to avoid compromising any of the evidence. Finally, the evidence needs to be appropriately packaged, labelled and secured while awaiting transport from the scene.

3.5. INTERIM EVIDENCE STORAGE SITE

In many investigations of nuclear security events, it may be necessary to safely and securely store the evidence at an interim location prior to its further transportation to the designated nuclear forensic laboratory (see Section 6.2). This may be necessary to ensure national regulations and laboratory procedures are satisfied, or may simply be needed to facilitate the necessary arrangements with the receiving laboratory, particularly in cases requiring international assistance. This interim evidence storage site should have security measures in place to prevent evidence tampering, while also having the appropriate authorizations/licences/permits necessary to store the quantity of nuclear or other radioactive material present. The storage site should also incorporate features to ensure the appropriate handling of evidence, including maintaining the chain of custody for the evidence at all times.

If material categorization was not performed at the scene, it should be performed at the interim evidence storage site before transportation to the designated nuclear forensic laboratory. Even if material categorization was performed at the scene, it may be useful to confirm the categorization, with additional measurements, e.g. gamma ray spectrometry with a high resolution germanium detector rather than a sodium iodide detector. As noted above, all categorization measurements and methods should be fully documented and communicated to the designated nuclear forensic laboratory.

3.6. TRANSPORT OF EVIDENCE

In transporting evidence to either the interim evidence storage site or the designated nuclear forensic laboratory, considerations must be made for safety, security, preservation of evidence and maintaining the appropriate chain of custody. Arrangements that permit the safe and secure transport of evidence, and address any potential safeguards requirements, need to be made in advance of attempting transport. Assuming the integrity of the original packaging has been maintained, most radioactive samples can be kept in their collection containers for transport; unless the nuclear or other radioactive material is in jeopardy of further dissemination, the radioactive material should not be separated in the field from its packaging. These collection containers have to be packed inside another container that is certified for the transport of such material. Precautions should be taken to avoid potential cross-contamination of the evidence from the transport container. In all cases, the packaging and transportation needs to satisfy legal, safety and security requirements of the State (or States) in which the transport is occurring. The IAEA has produced guidance regarding the safety and security in the transport of radioactive material [22, 23].

3.7. DISPOSITION OF EVIDENCE

Any item of evidence must remain under control, including under relevant chain of custody procedures, until a competent authority declares that the item is no longer required for purposes of the investigation or any subsequent prosecution or other legal proceedings. Once the applicable legal proceedings have determined that an item of evidence is no longer required, then the item may be considered for disposal or for retention for purposes other than use in the legal proceedings.

If disposal of an item of evidence is an option, then the disposal will need to be performed in accordance with established local and national laws and regulations regarding the disposal of waste contaminated with nuclear or other radioactive material.

4. DEVELOPMENT OF THE FORENSIC EXAMINATION PLAN AND THE CORRESPONDING NUCLEAR FORENSIC ANALYTICAL PLAN

For the purposes of investigating a nuclear security event, once the preliminary on-scene assessment has been performed, including categorization of the nuclear or other radioactive material, a forensic examination plan will be prepared by the investigating authority in consultation with the relevant forensic laboratories, including designated nuclear forensic laboratories. This plan describes the requirements of the examinations in support of a potential criminal prosecution or to address nuclear security vulnerabilities. Additionally, development of the forensic examination plan may include provisions for setting aside portions of the evidence. These samples could be requested by the defence if the results of the investigation are used at trial.

One challenge encountered in conducting forensic examinations is establishing the sequence in which these examinations are to be performed. The presence of radioactivity adds to this challenge, since it may constrain the types of examinations that may be undertaken and the locations where the examinations may occur. The proper sequencing of examinations conducted in both traditional forensic disciplines and nuclear forensics is required to ensure that essential data are obtained with expediency and that as much data as possible can be derived from a finite sample. This requires the development of a forensic examination plan.

The forensic examination plan should consider the needs of the investigation, the perceived value of the expected results to the investigation, the known or suspected losses of essential characteristics over time if examinations are delayed, and the national level procedures for the conduct of examinations in traditional forensic disciplines and nuclear forensics. In general, priority should be given to examinations where the results are capable of individualization (association with a single source - person, place, event, or process - for example, DNA and fingerprints) rather than those where the results are likely to provide group or class characteristics (for example, shoe and tire impressions and explosives). However, the availability of other investigative or intelligence information might enhance the value of class characteristic results, especially where exclusion is critical to focusing the investigation.

In support of the forensic examination plan, each of the forensic laboratories will then prepare an analytical plan in consultation with the lead investigative authority. This consultation is important to ensure that key requirements of the examination plan are not overlooked in the preparation of the analytical plans of each of the forensic laboratories.

4.1. DEVELOPMENT OF A NUCLEAR FORENSIC ANALYTICAL PLAN

Once specific requirements are defined in a forensic examination plan, a nuclear forensic analytical plan should be developed to specifically describe what types of analyses will be performed in order to meet the requirements of the investigation. The essential elements of a nuclear forensic analytical plan include material characterization methods, as described in Section 6.3. The nuclear forensic analytical plan should be prepared by the designated nuclear forensic laboratory or laboratories, with input and ultimately concurrence from the investigating authority such that it meets the needs of the forensic examination plan and the investigation. The nuclear forensic analytical plan must be flexible and adaptable, so that as new information is obtained through the investigation or through sample analysis, the requirements for the forensic examination may be revised. The plan can be modified as needed, with appropriate consultation and documentation.

4.1.1. Types of samples and analyses

The types of samples and analyses required to answer the questions posed should be considered when developing a nuclear forensic analytical plan. Table 3 provides some examples of the types of samples that could be collected during an investigation of a nuclear security event, their potential forensic value and the specific examination requirements for such samples. Due to the diverse nature of these types of samples and their specific requirements, it may not be possible to analyse the sample in the same physical location (e.g. room, laboratory, etc.) and this should be accounted for when developing the analytical plan. For example, if trace radionuclide analysis is required, these measurements would not be conducted with or near the same experimental apparatus that performs bulk analysis of nuclear or other radioactive material. Once analyses have been performed, it may be necessary to use additional expertise to interpret analytical results and formulate nuclear forensic findings in response to the forensic examination plan. This expertise may need to be obtained from outside the laboratory that performed the measurements.

TABLE 3. TYPES OF SAMPLES THAT COULD BE ANALYZED TO SUPPORT A FORENSIC EXAMINATION PLAN

Sample type	**Potential forensic value**	**Laboratory considerations**
Bulk nuclear or other radioactive material	Determine violation of possession statutes Identify possible material origins Identify material process history Connect cases where the same material was discovered	Capability and infrastructure for handling and characterizing bulk radioactive and nuclear materials. Expertise in nuclear fuel cycle technology to interpret results
Items contaminated with nuclear or other radioactive material	Identify places where nuclear or other radioactive materials have been handled or processed Identify additional nuclear or other radioactive material that may have been previously handled at a location where a bulk material was found Link suspected people to material	Experience with trace analysis of radioactive materials and understanding of potential limitations of such samples and results (e.g. influence of environmental background). Ability to isolate and analyse small samples. Expertise with traditional forensic analysis and interpretation

Sample type	Potential forensic value	Laboratory considerations
Biological samples (urine, blood, hair, tissue, etc.)	Identify individuals who have handled nuclear or other radioactive material Identify individuals who have had an external radiation dose Connect individuals to events involving nuclear or other radioactive material	Experience with bioassay analyses or blood dosimetry. Health physics or radiobiology expertise to interpret results
Environmental or geologic samples associated with the nuclear or other radioactive material	Determine possible smuggling routes or pathways which the nuclear or other radioactive material travelled	Expertise with environmental analysis (minerals, dust, pollens, etc.) and interpretation of geologic and geochemical data

4.1.2. Laboratory considerations

The laboratory undertaking the nuclear forensic analysis should operate under a quality assurance plan, which includes sample chain of custody, validated analytical procedures, staff with demonstrated competencies, documented procedures, standard reporting forms and records management. The procedures should include statements on the control of contamination or cross-contamination. When developing a nuclear forensic analytical plan, the laboratory should identify procedures that will be followed, the quantity of material needed for each analysis, plus any foreseen deviations from documented procedures. The nuclear forensic analytical plan should also address any required interface with traditional forensic analyses, for example if the nuclear forensic laboratory will assist in the collection of traditional evidence or decontaminate materials prior to examination by a traditional forensics laboratory (see Section 5). Furthermore, the evidentiary value of nuclear forensic findings, even when based on analyses adhering to the relevant protocols and standards, may be severely compromised by straying outside the parameters and requested examinations set out in the forensic examination plan. Therefore, law enforcement experts should unambiguously communicate which methods and standards are acceptable for use in a court of law, as well as the implications of departing from the examination plan.

4.2. SUBSAMPLING

For bulk nuclear or radioactive material samples, the entire sample may be larger than the sample size requirements described in the analytical plan. There may also be limits on the mass or activity that can be received and analysed at a laboratory. Therefore, it may be necessary to divide the material, referred to as subsampling, prior to shipment to the analysis laboratory. Given the potential heterogeneity of a forensic sample, subsampling protocols require special consideration and methods to ensure subsamples are truly representative of the bulk material. Any limitations of these methods should be described in the analytical plan.

Regardless of whether subsampling is done at the laboratory performing analysis or at another location prior to shipment, techniques should be used for representative sampling that minimize the possibility of potentially misleading results attributable to the heterogeneity of the evidence. In extreme cases, the need for representative samples might require analysis of individual particles; more commonly bulk analysis is sufficient. When the amount of available material is small, subsampling may not be required or may prove difficult; however, in such cases, the nuclear forensic analytical plan must prioritize the allocation of the limited amount of material. In these cases, it is important that all non-destructive analyses be performed prior to performing any analyses that will consume or might alter the sample characteristics. In addition, for small samples, trace and micro-analytical techniques may be more appropriate than techniques optimized for larger amounts of material. Subsampling has the potential to introduce contamination or to compromise evidence and appropriate caution should be taken.

4.3. EVIDENCE DISTRIBUTION

Once the forensic examination plan and analytical plans have been established and any required subsampling has been done, the evidence will then need to be distributed to the laboratories performing the analyses.

Forensic samples should be transported to laboratories using methods that maintain chain of custody (e.g. the use of sealing devices or tags, if deemed necessary). In order to minimize potential alteration of the evidence during transport, the effects of the transportation conditions such as temperature, humidity or vibrations may need to be addressed. The transport of nuclear and other radioactive materials requires careful planning, and having individuals available with expertise in the transport of hazardous materials, including nuclear materials, is required. Additionally, reliable and sustained communication between the shipper and receiver will ensure required procedures are followed for introducing nuclear or other radioactive samples into a laboratory.

5. FORENSIC EXAMINATIONS OF EVIDENCE CONTAMINATED WITH RADIOACTIVE MATERIALS

Examinations of physical and documentary evidence conducted in traditional forensic disciplines are a routine element of investigations conducted by investigating authorities. Examples of these disciplines include fingerprints; genetic markers (such as nuclear and mitochondrial DNA); shoe and tire impressions; toolmarks; explosives, paints and other chemicals; metallurgy; questioned documents;

trace evidence, such as fibres, hairs, and pollens; and forensic medicine. (Additional comments on these disciplines are given in Appendix III.)

The conduct of examinations in traditional forensic disciplines complements nuclear forensic examinations. Both yield results that might aid in determining whether linkages exist among people, places, events and processes and whether those linkages are diagnostic of where regulatory control of the nuclear or other radioactive material was lost. These results can prove especially useful where they permit individualization (association with a single source – person, place, thing or event) or they allow certain sources to be excluded from further consideration. The potential for radioactive material to be present as a contaminant on physical evidence presents a unique challenge for examinations conducted in traditional forensic disciplines.

5.1. CONTAMINATED EVIDENCE

Any evidence associated with a nuclear security event must be examined to determine whether radioactivity is detected. Evidence found to be free of radioactive material can be submitted directly for forensic examinations, once released by the competent authority, as there is no risk of a radiation hazard. Similarly, evidence that is determined not to be contaminated with radioactive material presents no concern that the character of the evidence might be degraded by radiation.

Special considerations are required when evidence is known or suspected to have radioactive material present. Such evidence is often referred to as 'contaminated'. However, the term 'contaminated evidence' connotes a different meaning for the forensic scientist and for the nuclear forensic scientist, and the term merits discussion.

In one sense of the term, 'contaminated evidence' refers to the direct or indirect transfer of extraneous material to a forensic sample or scene of a crime. This meaning is commonly used in the forensic science community, and may also be referred to as 'cross contamination'. Evidence that is contaminated with extraneous material, and thus compromised, has limited or no value for investigative purposes and must be evaluated carefully; thus, such contaminated evidence is to be largely avoided for forensic examination purposes.

In the second sense of the term, 'contaminated evidence' refers to the presence of radioactive material on or within physical evidence. This meaning is commonly used by nuclear forensic practitioners and is the intended meaning in this document (also referred to herein as evidence contaminated with radioactive material). Evidence that is contaminated with radioactive material may affect the manner and timeliness in which the evidence is examined or may alter the signature that is the goal of the forensic examination. Therefore, in the context of nuclear forensics, the examination of 'contaminated evidence' requires special planning and procedures.

5.2. HANDLING EVIDENCE CONTAMINATED WITH RADIOACTIVE MATERIAL

When confronted with the need to conduct examinations in traditional forensic disciplines on evidence contaminated with radioactive material, two approaches are possible. The first approach involves removal or separation of the radioactive material from the evidence prior to conducting any examinations. This is often referred to as decontamination of the evidence. The second approach involves the conduct of these examinations directly on the evidence contaminated with radioactive material. Both approaches may require input from multiple agencies, in particular from agencies outside the law enforcement community. For this reason, there may be a need for extensive consultation between the relevant experts for the development of the forensic examination plan and prior to the handling of evidence contaminated with radioactive material. Each approach offers certain advantages and suffers from certain disadvantages that must be evaluated during the course of the investigation and are described below.

5.2.1. Removal of the radioactive material

Radioactive material may be removed from the evidence by physical or chemical processes. Various techniques exist for this purpose, and the selection of the best one will depend on, among other factors, the form of the evidence, the form of the radioactive material present, the type of examination to be performed and practices dictated by national or local considerations. Removal of the radioactive material prior to the conduct of an examination in a traditional forensic discipline offers several advantages. Among them are:

- The removal of the radioactive material permits closer contact between the examiner and the evidence, since the risk of any exposure to radiation has been minimized;
- The processing of the evidence can be performed in a manner similar to that for evidence that has not been contaminated with nuclear or other radioactive material, eliminating any need to develop, train and, where applicable, certify the person(s) in radioactive material handling techniques;
- The need for specialized infrastructure to support the conduct of the examination is avoided.

There are, however, some disadvantages associated with the removal of the radioactive material prior to the conduct of an examination in a traditional forensic discipline. These include:

- The time and expert resources that are typically required to remove the radioactive material;
- The potential for evidence to be altered in some manner that might render any findings inaccurate or degrade the feature that is the subject of the examination;

— The potential for incomplete removal of the radioactive material increases the possibility of introducing radiation effects on the examination, as well as inadvertent exposure of examiners, although strict adherence to operating procedures to verify the removal of radioactive materials would alleviate the potential for unintended exposure;

— The need to manage the evidence and waste generated from the removal of the radioactive material.

Research into the effects of different removal techniques on individual physical examinations has been conducted internationally [24]. This work highlights some conclusions regarding when it is appropriate to attempt removal of the radioactive material from certain types of evidence. These conclusions, and further research, should be used to develop protocols for handling evidence contaminated with radioactive material. These protocols must be considered in advance of the conduct of an examination related to an investigation of a nuclear security event.

5.2.2. Examination in the presence of radioactive material

Examinations on evidence contaminated with radioactive material can alternatively be conducted without removal of the radioactive material. This approach has several advantages, including:

— Minimizing the possible loss or degradation of features important to the examination that might have been caused by the process used to remove the radioactive material;

— Expediency of the examinations, which can commence immediately upon receipt of the evidence (assuming the availability of qualified personnel, appropriate equipment and instrumentation and a written analytical plan).

However, directly examining physical evidence in the presence of radioactive material carries certain disadvantages, including:

— The need for specialized facilities that can perform examinations in traditional forensic disciplines in the presence of radioactive material, including equipment and instruments that may need to be dedicated to use in these facilities;

— Extensive preplanning may be required for each type of examination to establish protocols for performing the examinations within the specialized facility and to demonstrate that results are equivalent to those obtained for the same examination conducted on evidence that is not contaminated with radioactive material;

— Examiners must be trained to work in the specialized facilities and must demonstrate their proficiency at processing their examinations under these modified conditions or alternatively nuclear or radiation laboratory personnel must be trained to process evidence for examinations in traditional forensic disciplines;

- Prolonged exposure to radiation may degrade or otherwise alter forensic attributes that are the target of the examination. Research may be required to determine whether such exposure has any effects and, if so, whether these effects might be mitigated. This should be done in advance of the investigation.

5.2.3. Determination of the appropriate approach

The decision of whether to attempt removal of the radioactive material from the evidence or to conduct examinations in the presence of the radioactive material will be included in the forensic examination plan and be dependent on factors such as:

- Nature of the examinations to be performed;
- Availability of required resources for the conduct of these examinations;
- Information and findings obtained to date from investigative or intelligence methods, and from any related examinations that have been performed;
- National policies and procedures for responding to nuclear security events.

Consideration of these and other factors reinforces the need to plan and develop procedures, as a part of a national response plan, for the conduct of examinations on evidence contaminated with radioactive material in advance of any nuclear security event.

6. NUCLEAR FORENSIC LABORATORY ANALYSIS

Based on the on-scene categorization and the forensic examination plan, the need for further characterization of the nuclear or other radioactive material may be necessary. This characterization should take place in a designated nuclear forensic laboratory. Prior to commencing analysis, the laboratory should develop a nuclear forensic analytical plan, which will be agreed to by the investigative authority, as discussed in Section 4.1.

6.1. NUCLEAR FORENSIC CHARACTERIZATION

Nuclear forensic characterization follows the on-scene categorization performed at the onset of an investigation into a nuclear security event. The goal of characterization is to determine the properties of the nuclear or other radioactive material through physical, chemical, elemental and isotopic analysis, including major, minor and trace constituents, as necessary. Nuclear forensic characterization does not typically include analysis using traditional forensic disciplines, nor does it comprise interpretative steps to include reactor modelling and searches of a national nuclear forensics library to identify probable origins of the material. As such, the characterization will take less time than full interpretation.

6.2. DESIGNATED NUCLEAR FORENSIC LABORATORY

Designated nuclear forensic laboratories are those laboratories that have been identified by a State as being capable of receiving samples of nuclear and/or other radioactive materials for the purposes of supporting nuclear forensic examinations. The criteria and decision process for identifying a laboratory as a designated nuclear forensic laboratory is the responsibility of each State. Once the investigating authority has determined that a nuclear forensic examination is required, the evidence should be sent to a laboratory that has been identified as being prepared and equipped to receive the samples (nuclear material, radioactive material, evidence contaminated with radioactive material or a combination thereof) and analyse them using the required combination of analytical techniques. Communication between the investigating authority and the laboratory should commence as early as possible following the response to the event so that laboratory requirements and capabilities can be communicated and planning and preparations for sample receipt and analysis can be made through the development of the forensic examination plan and the nuclear forensic analytical plan. When transporting the evidence to, and admitting evidence at, a designated nuclear forensic laboratory, due regard to the evidence handling should be observed, including appropriate chain of custody arrangements for sample handling.

The extent of capabilities available at designated nuclear forensic laboratories is likely to vary from State to State. Some States may not have a designated nuclear forensic laboratory of their own and will rely on bilateral or multilateral assistance for material characterization. Other States may have established designated laboratories for undertaking some aspects of material characterization or for some types of material, with plans in place to request assistance for specialized techniques. Only a few States worldwide have laboratories possessing a full complement of the required nuclear forensic analytical tools and techniques. It is important for a State to have a thorough understanding of its capability to ensure it is prepared for any eventuality, including the potential to request, receive or provide assistance to undertake nuclear forensic analysis in support of an investigation into a nuclear security event.

It is important for the State to ensure that any designated nuclear forensic laboratory is capable of undertaking a nuclear forensic examination and that they have validated analytical methods, staff with demonstrated competencies and documented procedures. Accreditation of the laboratory to an internationally recognised quality standard (e.g. ISO 9001, ISO 14001, ISO/IEC 17025, OHSAS 18001) is advantageous. In addition, the designated nuclear forensic laboratory needs to be appropriately licensed to receive the nuclear and other radioactive material, with the ability to handle large amounts (in terms of mass and activity) of material, while still being able to analyse trace constituents. Designated nuclear forensic laboratories should possess glove boxes or, for cases where highly radioactive samples are anticipated, hot cells. The designated nuclear forensic laboratory should also have appropriate laboratory facilities and operational procedures to ensure minimization of the risk of cross-contamination between samples.

The designated nuclear forensic laboratory should be fully compliant with environmental, safety and health protocols, hazardous waste disposal procedures and hazardous material handling and storage. The laboratory should also have appropriate physical protection measures implemented and have proper procedures in place as necessary for the accounting and control of nuclear material.

6.3. ANALYTICAL TOOLS

The nuclear forensic scientist has a wide array of tools to use for measuring properties of nuclear and other radioactive material. Appendix II provides descriptions of many of the analytical techniques used for nuclear forensic characterization. These individual techniques fall into three broad categories: imaging, bulk analysis and microanalysis tools.

Imaging tools produce high magnification images or maps of the material surface and provide information on sample homogeneity or heterogeneity and microstructure. Assessing the degree of sample heterogeneity is important. If the material is heterogeneous, bulk analysis will not be representative of the signatures from the individual components. Imaging can reveal the spatial and microstructural features (e.g. texture, grain structure) that may provide information about the thermodynamic or mechanical processing of the sample.

Bulk analysis tools allow characterization of either an entire sample or a portion of the sample to determine the average properties of the material. Characterization may include physical, chemical, elemental and/or isotopic measurements. For bulk analysis it is necessary to have sufficient material to measure trace constituents accurately and precisely. The presence or absence of trace constituents and their corresponding concentration are often important for providing information about manufacturing processes used. If imaging analysis confirms that the sample is heterogeneous, then microanalysis[3] tools can quantitatively or semi-quantitatively characterize the individual constituents of the material. Microanalysis tools also incorporate surface measurements, which can identify trace surface

[3] Microanalysis involves the chemical identification and or quantitative analysis of very small samples (generally less than 1 milligram).

contaminants or measure the composition of thin layers or coatings, which could provide important information for interpretation.

6.4. SEQUENCING OF TECHNIQUES AND METHODS

Many of the analytical tools used in the analysis of nuclear or other radioactive material are destructive techniques, i.e., the sample is consumed during the preparation or analysis. Therefore, the proper selection and sequencing of analytical techniques is critical and should be detailed in the nuclear forensic analytical plan. The analysis to be performed as part of characterization will initially be guided by the categorization of the material. The sequencing of analytical techniques should be based upon the questions to be answered from the investigating authority according to the forensic examination plan, taking into account the amount of sample available for analysis, information already available, and the potential signatures (physical, chemical, elemental and isotopic) that might lead to precise interpretation.

The Nuclear Forensics International Technical Working Group (ITWG) as association of nuclear forensics practitioners has developed a recommendation on the sequencing of techniques to provide the most valuable information as early as possible in the analysis process. This recommendation is based on expert opinion and on experience gathered from three collaborative analytical exercises undertaken by the ITWG Nuclear Forensic Laboratories (INFL[4]). Table 4 shows the generally accepted sequence of analysis, broken down into techniques that could be performed within 24 hours, one week or two months from the sample arrival at the designated nuclear forensic laboratory (see Appendix II for descriptions of frequently used techniques). Some techniques can also be used at a later time, to achieve more precise analytical results using longer measurement times. The use of such timescales to complete material analyses may also guide the expected intervals of reporting results, which may correspond to 48 hours, two weeks, and four months, depending on the situation. The length of the characterization process will depend on the workload of the laboratory, the nature of the sample and the requirements of the investigation detailed in the forensic examination plan, but with a goal of completion within two months after receipt of the sample(s).

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[4] The INFL is composed of those laboratories that have participated in one or more of the ITWG collaborative exercises, which are discussed in Appendix IV, and demonstrated its analytical capability in nuclear and other radioactive material analyses.

TABLE 4. LABORATORY METHODS AND TECHNIQUES WITH TYPICAL TIMESCALES FOR COMPLETION OF ANALYSES

Techniques/methods	**Conducted within**		
	24 hours	**One week**	**Two months**
Radiological / health and safety	- Dose rate (α, β, γ, n) - Surface contamination - Radiography		
Physical characterization	- Visual inspection - Photography - Weight determination - Dimensional determination - Optical microscopy - Density	Microstructure, morphology, etc. - Scanning electron microscopy (SEM) - X ray diffraction	Nanostructure, morphology, etc. - Transmission electron microscopy
Isotopic analysis	- High resolution gamma ray spectrometry (HRGS)	- Thermal ionization mass spectrometry (TIMS) - Inductively coupled plasma mass spectrometry (ICP-MS)	- Secondary ion mass spectrometry (SIMS) - Radioactive counting techniques
Radiochronometry	- HRGS (for Pu)	- ICP-MS	- HRGS (for U) - Alpha spectrometry
Elemental/chemical composition	- X ray fluorescence	- ICP-MS - Chemical assay - Fourier transform infra-red spectrometry - SEM / X ray spectrometry - Isotope dilution mass spectrometry	- Gas chromatography mass spectrometry
Traditional forensic science disciplines	- Collection of evidence associated with traditional forensic disciplines		- Analysis and interpretation of evidence associated with traditional forensic disciplines

6.5. SAMPLE ANALYSIS

After the arrival of the sample at the laboratory, it is useful to repeat the categorization of the material under controlled conditions. Repetition confirms the on-scene analysis, and could provide new information, including the total amount of nuclear or other radioactive material present. High resolution gamma ray spectrometry (HRGS) is essential for the categorization at the designated nuclear forensic laboratory.

The characterization of nuclear or other radioactive material may consist of physical, chemical, elemental, and isotopic measurements, as described below and in Table 4.

6.5.1. Physical measurements

The first step in sample characterization usually involves a visual inspection of the material, photographic documentation, and, in the case of bulk solid items, documentation of the dimensions and mass of the item. The physical characteristics of the item, for example its dimensions, diameter, height, colour, weight and density may reveal sufficient information at the macroscopic scale to identify the sample. For example, in the case of nuclear reactor fuel pellets, the dimensions and geometry of a fresh nuclear fuel pellet are often unique to a given manufacturer. For sealed radioisotope sources, the size, activity and the means and material of encapsulation often provide insights regarding the manufacturer of the sealed source.

On the microscopic scale, microstructural features enable comparisons of materials. For example, the grain size distribution and the grain structure of uranium oxide fuel pellets can provide information about their production processes. In the case of powder or swipe samples, particle morphology may exhibit distinguishing features that result from different production processes.

6.5.2. Chemical and elemental measurements

The chemical form of the nuclear material (metal, oxide or an intermediate product, e.g. ammonium diuranate) or other radioactive material is an important indicator that may reveal information about the production process of the material, and may provide insight about its intended use. In the case of a uranium intermediate product, the compound can give an indication about the process used to produce the material, and as a result, narrow the number of possible production facilities.

Besides the nuclear or other radioactive materials of interest, many other elements may be present in the investigated material, sometimes at concentrations exceeding that of the radioactive component. These additional components can be added intentionally to the material to achieve certain material properties (e.g. gallium to stabilise the δ phase of plutonium or erbium and gadolinium to control nuclear fuel reactivity). Unintentional chemical impurities can also be present as a result of residual elements from the initial feed materials or residuals from chemicals added during the production process (e.g. acid residues), as well as from corrosion or abrasion of vessels and pipe work. If these elements are present at the trace level, they are referred to as impurities. Therefore, the measurement of these elements for nuclear forensics is of utmost importance, as they can provide information not only on the intended lawful use, but also on the source material or on the production facility.

6.5.3. Isotopic measurements

Isotopic measurements are made to determine the isotopic abundance of elements present in the nuclear or other radioactive material. The isotopic abundance provides information about the material history and its intended use, e.g. is the material of natural isotopic composition, has it been enriched or reprocessed, is it for nuclear fuel use, is it enriched for potential use in a nuclear explosive. Besides the major fissile isotopes (^{235}U and ^{239}Pu), the minor isotopes of uranium and plutonium (e.g. ^{236}U and ^{240}Pu, ^{238}Pu) may reveal any previous irradiation history of the material.

Radiochronometry uses isotope measurements to determine the amount of time that has elapsed since nuclear or other radioactive material was last chemically purified; in other words, the time when daughter nuclides were removed from their parent nuclides is the point at which 'the radiochronometer age was reset to zero'. The concentration of decay products of uranium and plutonium, referred to as the 'daughter' products (e.g. ^{230}Th, ^{241}Am), can be measured and compared to the concentration of the 'parent' isotope, thereby determining the age of the nuclear material. Radiochronometry is also applicable to radioisotope sources such as ^{137}Cs, which decays to ^{137}Ba, and thus forms a parent-daughter pair.

Besides the isotopic composition of the fissile elements and their decay products, the presence and isotopic composition of some other elements can be exploited in order to provide information about the origin of a sample, based on known natural isotopic variations worldwide. The isotope ratios of such elements in a sample can be indicative either of the process and the production location (e.g. ^{18}O/^{16}O ratio) or of the feed material (e.g. ^{87}Sr/^{86}Sr, ^{143}Nd/^{144}Nd ratio).

7. NUCLEAR FORENSIC INTERPRETATION

Nuclear forensic interpretation involves the association of analytical data with existing information on types of material, origins and methods of production of nuclear or other radioactive material, and with prior cases involving similar material. Nuclear forensic interpretation provides context, explanations for the analytical results, and the basis of nuclear forensic findings.

7.1. PROCESSES OF INTERPRETATION

Nuclear forensic signatures are the data characteristics or set of characteristics of a given sample of nuclear or other radioactive material that enable the sample to be distinguished, by way of either exclusion or inclusion. These signatures may help to identify the processes that created the material and its subsequent history.

In order to predict and understand relevant signatures throughout the nuclear fuel cycle and to interpret analytical results both an empirical approach, involving the previous analysis of nuclear and other radioactive materials, and a modelling approach, based upon the chemistry and physics of nuclear fuel cycle processes, are used. Knowledge of analytical science can guide the selection of the appropriate methods to verify the presence or absence of nuclear forensic signatures.

Nuclear forensic interpretation requires comparison of the results from the sample in question with existing or known materials information. In general, a single signature of a material (e.g. an isotopic measurement) is usually not sufficient to discern a specific sample from known classes of similar materials. Unlike traditional fingerprint analysis, it is impractical for nuclear forensics to rely on sample-to-sample matching. However, combinations of signatures, such as isotopic measurements, impurities and microstructure, when used together, provide increased confidence in associating a specific sample with known classes of similar material. The use of signature combinations also enables the exclusion of a specific sample from known classes of materials, which is also valuable for nuclear forensic interpretation.

Resources that may assist in comparisons with known classes of material information include national nuclear forensics libraries, knowledge of nuclear fuel cycle processes and radioactive source manufacturing, existing literature and archived samples that could be reanalysed for comparison.

Table 5 lists some information which may be required to answer questions about a plutonium sample and the signatures used to obtain the information.

TABLE 5. EXAMPLES OF RELEVANT RADIONUCLIDE SIGNATURES IN PLUTONIUM

Information required	Signature
Chemical processing date	In-growth of daughter isotopes
Chemical processing techniques	Residual elements (U/Pu ratio)
Use as energy source	Activity of Pu isotopes (^{238}Pu)
Neutron spectrum and burn-up of the fuel in the reactor	Pu isotope ratios (e.g. ^{240}Pu/^{239}Pu)

7.2. DEVELOPMENT OF A NATIONAL NUCLEAR FORENSICS LIBRARY

A national nuclear forensics library is an organized collection of descriptions and data characteristics of nuclear and other radioactive materials produced, used or stored within a State. In some cases archives of physical samples may be included in a national nuclear forensics library. The library is established, maintained and controlled by individual States at all times and are commensurate with the size and complexity of a State's nuclear and other radioactive material holdings. A national nuclear forensics library provides a mechanism for comparing and associating measured characteristics of seized nuclear or other radioactive material with signatures of classes of known material (e.g. isotope ratios, chemical composition, impurities, physical characteristics). The most important purpose of a national nuclear forensics library is to assist a State to assess whether material encountered out of regulatory control is or is not consistent with nuclear or other radioactive material produced, used or stored within the State. Thus, a national nuclear forensics library is an invaluable tool for nuclear forensic interpretation.

With the development of national nuclear forensics libraries using a common conceptual organizing framework, as described in the IAEA implementing guide Development of a National Nuclear Forensics Library [6] currently in preparation, nuclear forensic information can be compared voluntarily between States with confidence.

7.3. KNOWLEDGE OF NUCLEAR FUEL CYCLE PROCESSES AND RADIOACTIVE SOURCE MANUFACTURING

Nuclear forensic signatures are imparted to nuclear and other radioactive materials at various points in their history, including during their manufacture. Understanding how these signatures are created, persist, and modified during material production processes is critical to nuclear forensic interpretation. As a result, knowledge of nuclear fuel cycle processes and the manufacturing of radioactive sources is fundamental for the effective interpretation of laboratory measurements. Such knowledge is obtained from subject matter expertise, usually resident in a variety of international, national and non-governmental entities.

Modelling or simulation of nuclear fuel cycle or material production processes can predict how signatures are imparted to nuclear and other radioactive materials during their production. Modelling may also improve the understanding about phenomena that create or modify signatures, as well as those that enable the persistence of signatures. Knowledge gained through process modelling helps provide the context for subsequent laboratory measurements and may also help reveal new signatures.

Comparing the results of material characterization with signature families from process information (e.g. isotopic measurements, impurities, microstructural features) provides an understanding about how the material may have been made and its intended use. Conversely, such comparisons also enable production processes and intended uses to be excluded from consideration, if no association is established between characterization results and specific signature families.

7.3.1. Archived material

Comparative analyses of archived nuclear and other radioactive material, including seized material, can greatly contribute to confidence in nuclear forensic findings. These analyses allow the nuclear forensic expert to establish connections between the material and the processes used in its production or manufacture. As new signatures are discovered that depend on new analytical methods, it becomes increasingly important that archived data be accompanied by archived material. Then, the old material can be re-analysed using new analytical methods and the resulting data evaluated for the presence or absence of the newly discovered signatures. Sample archives maintained by operators, producers, regulators, environmental laboratories, and others can include previously analysed samples, reactor fuel, quality control samples and industrial radioactive sources. Any existing archived samples should be recorded in a national nuclear forensics library.

7.3.2. Open literature

Many of the basic nuclear processes are documented in textbooks, reports and journal articles in the open literature. These documents can be found in technical libraries and on the Internet. The IAEA nuclear information website (http://nucleus.iaea.org/), for example, has a number of databases that document publicly available information about nuclear facilities around the world.

7.3.3. Closed literature

Proprietary or classified information or processes may only be documented in ‘closed’ literature. Companies may be willing to share proprietary information with nuclear forensic authorities or national laboratories after the execution of an appropriate non-disclosure agreement. In addition, nuclear institutes, relevant ministries and national laboratories may be able to access the classified literature within their own State, but are not likely to access those of other States.

7.4. DEDUCTIVE AND ITERATIVE PROCESS

Nuclear forensic analysis and interpretation is a deductive and iterative process, as depicted in Figure 2. Executing the analytical plan produces results that can be compared with existing or known materials information, and such comparisons lead to interpretation, the context of the analytical results. The comparative process involving analytical results and known material information is iterative because each comparison provides new information that can identify further analyses or comparisons that may uncover additional and discriminating signatures. This comparative process is also deductive because it will inherently exclude materials from potential processes, locations or other origins. For example, comparisons of analytical results from seized nuclear material with known production processes will identify likely production processes that could have made the seized material, as well as those processes that could not have made the seized material. Additional comparisons with other existing production processes or analytical measurements will serve to narrow the list of likely production processes responsible for the production of the seized material. In general, comparisons with known or existing class characteristics may lead to exclusion of classes from further consideration.

Access to nuclear forensic expertise, a national nuclear forensics library, and archived samples if available, are important tools that allow the nuclear forensic expert to compare analytical results with known or existing materials information. Each of these tools enables comparisons that will generate "next step" comparisons or analytical measurements that will provide context for the analytical results.

As results of the analyses are received and interpreted, they may yield information that law enforcement personnel might use for purposes of the investigation. There may be times when a nuclear forensics examination cannot definitively conclude how a material was made or where it may have originated, but may still be able to exclude processes that are inconsistent with the material's production history. Both actions – generating investigative leads and excluding certain scenarios – serve to narrow the focus of the investigation. Finally, the results of investigative activities undertaken by law enforcement can aid in uncovering additional evidence that might allow the development of linkages between the nuclear or other radioactive material and people, places, times, events and production processes.

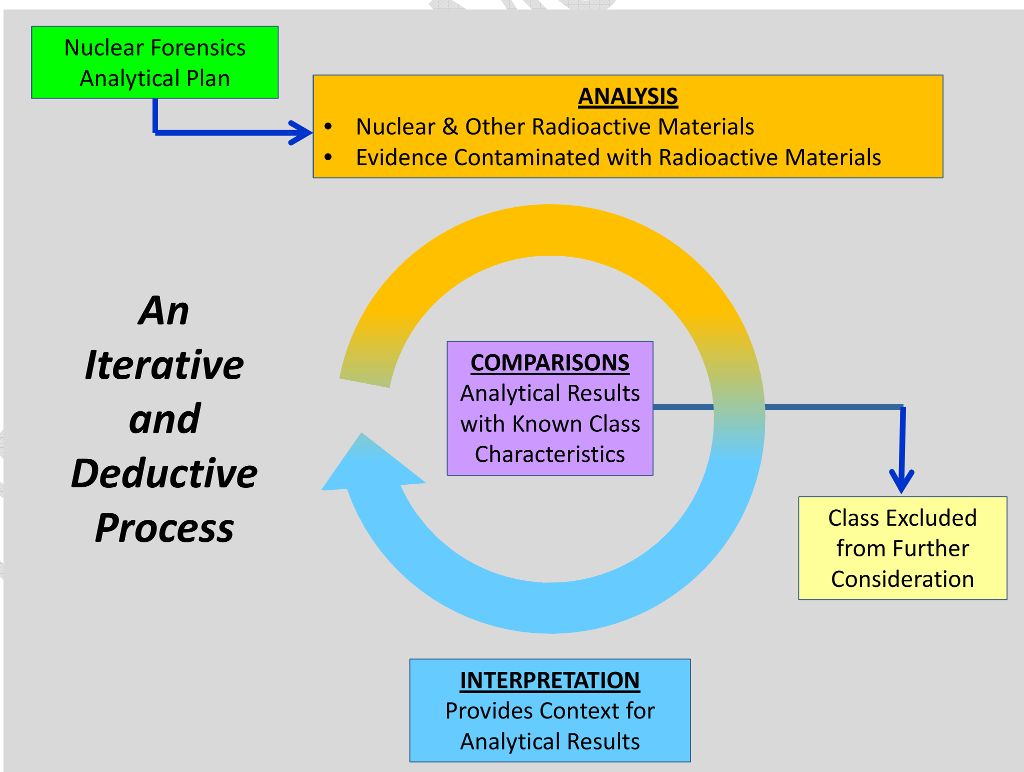

FIG 2. Nuclear forensics analysis, comparisons and interpretation: an iterative and deductive process to provide context for analytical results

8. NUCLEAR FORENSIC FINDINGS

Nuclear forensic findings are the product of nuclear forensic analysis and interpretation. They may be obtained to support a law enforcement investigation or support regulators, policy makers and other relevant stakeholders in improving nuclear security and preventing future nuclear security events. The key questions posed in all scenarios would likely be the same: type of material, possible origin of the material, and probable method(s) of production.

8.1. CONFIDENCE IN FINDINGS

In general, confidence in analytical results depends upon three factors: 1) validated methods, 2) certified reference materials and 3) demonstrated competencies. Use of validated methods ensures that the analysis is suitable for the material and capable of measuring the analyte(s) of interest. The use of certified reference materials ensures that measurements are benchmarked against known and certified values. Validated methods and certified reference materials provide confidence in findings through demonstrating a measure of reliability in the procedures by which they are obtained. The use of demonstrated competencies provides confidence in the individual(s) performing the analyses.

Confidence in interpretation relies upon the articulation of uncertainties in analytical measurements, results of iterative comparisons with existing class information, and consideration of alternative explanations pertaining to interpretation of analytical results. Taken together, these three factors provide defensibility of the interpretation and its associated confidence level through demonstrated understanding of the basis of its formulation.

It is essential that any nuclear forensic analyses and interpretation are defensible because nuclear forensic findings may be used in court in a criminal prosecution or to identify nuclear security vulnerabilities. Strict adherence to chain of custody procedures throughout the investigation and implementation of quality assurance and quality control procedures within the laboratories contribute to confidence in the analytical results. Additionally, execution of an analytical plan that uses multiple results that converge on specific findings (e.g. associating or excluding certain classes of materials) increases the confidence in the findings and conclusions.

8.2. COMMUNICATION OF FINDINGS

All nuclear forensic findings should be communicated in a written report in a timely manner. The reports may be acceptable as a scientific report or may be submitted per a standard format or statement as required by the national authority or the lead investigative agency.

It is imperative that confidence in the interpretation of results be clearly communicated in accordance with the requirements set out in the forensic examination plan. The nuclear forensic findings will be combined with findings and information from other disciplines, including other forensic science disciplines and information provided by other authorities such as national security services, in order to advance the investigation. The results of the nuclear forensics analysis and the confidence levels associated with the findings should be conveyed in a manner that best meets the needs of the investigation.

In the time sensitive environment following a nuclear security event, there may be a need to obtain reliable initial information in as little time as possible. Nuclear forensic findings will be requested by investigators, as well as decision makers and other officials well before full analysis and interpretation of measurements are completed. Ideally, a method for articulating the confidence levels associated with preliminary reports should be in place. To address timely information requests by investigators and decision makers, a summary of preliminary nuclear forensic findings should be developed that report the key findings along with key assumptions, the confidence levels for these findings and any alternative explanations.

To assist with expectation management concerning the reporting of results, the forensic examination plan will outline the specific form and timeframes in which findings should be communicated. Reports on the status and findings of the nuclear forensic examinations may be issued periodically, both during and after the conclusion of a nuclear security event. The preparation of reports may adhere to the 24 hours, one week, and two month reporting timeline as outlined in Table 4. A final report is also to be issued after the conclusion of the investigation. The final report should identify all data and other information used in the assessment and should describe the rationale, including assumptions, for the findings. Any data or information that is not consistent with the findings should also be identified within the report, along with the rationale for excluding or discounting that information.

8.3. AFTER ACTION REVIEW

Following the conclusion of an investigation and completion of all related legal proceedings, an after action review may be conducted. This review is a useful exercise for assessing which of the various analyses and procedures performed during the course of the investigation met expectations and which failed to meet expectations. The purpose of an after action review is not to focus exclusively on the shortcomings, but also to understand what contributed to the success of those actions that met or exceeded expectations. Conducting an after action review provides an opportunity to learn from experience and to provide feedback into the processes used to plan for and execute nuclear forensic examinations in the future.

Given the nearly universal need to strengthen means of conducting nuclear forensic analysis, States are encouraged to share with their counterparts in other States any lessons learned from actual nuclear security events or from the conduct of exercises.

9. INTERNATIONAL COOPERATION AND ASSISTANCE

International cooperation and assistance is available in advance of, during or following a nuclear security event. The scope of international cooperation and assistance in nuclear forensics includes a range of activities that span awareness raising, research and development, international assistance and capacity building.

9.1. INTERNATIONAL COOPERATION

A number of international organizations, groups and intergovernmental collaborations promote awareness of the importance of nuclear forensics as well as various forms of nuclear forensics support. The Global Initiative to Combat Nuclear Terrorism (GICNT), the IAEA, INTERPOL and the Nuclear Forensics International Technical Working Group (ITWG) provide various forms of training, guidelines and assistance. States may also choose to cooperate bilaterally or multilaterally in the field of nuclear forensics. In addition, some States have national programs that can provide support to international partners.

9.1.1 Global Initiative to Combat Nuclear Terrorism (GICNT)

The GICNT is a voluntary partnership working to strengthen global capacity to prevent, detect and respond to the shared threat of nuclear terrorism. Through its Nuclear Forensics Working Group, the GICNT is developing tools to assist political leadership in partner nations to build domestic capacity in nuclear forensics, including tools to raise awareness of nuclear forensics; foster intergovernmental relationships; conduct joint exercises; and promote best practices for nuclear forensics.

9.1.2 International Atomic Energy Agency (IAEA)

The IAEA provides support to Member States in their efforts to establish and maintain an effective nuclear security infrastructure, including nuclear forensic capabilities. This is accomplished through the Nuclear Security Series of publications, including guidance on the development of a national nuclear forensics library and the application of the nuclear forensic model action plan; training on nuclear forensic awareness, radiological crime scene management and nuclear forensic methodologies; and coordinated research projects.

9.1.3 INTERPOL

INTERPOL is an international organization engaged in supporting police organizations in preventing and combating criminality, including radiological and nuclear terrorism. Its primary activity is to facilitate the exchange of information, including investigative information, between member States. In addition, INTERPOL conducts intelligence analysis, delivers training to include managing a radiological crime scene and is able to provide operational support during an event.

9.1.4 Nuclear Forensics International Technical Working Group (ITWG)

The ITWG is an informal working group of nuclear scientists, law enforcement personnel, first responders and nuclear regulatory experts that collectively form a body of nuclear forensic practitioners. The objective of ITWG is to advance the discipline of nuclear forensics through developing effective technical solutions and providing advice to national and international authorities to best respond to criminal and intentional unauthorized acts involving nuclear or other radioactive materials. The ITWG develops information and technical guidelines, conducts nuclear material analysis exercises, table top exercises and promotes outreach internationally.

9.2. NUCLEAR FORENSICS ASSISTANCE DURING THE INVESTIGATION OF A NUCLEAR SECURITY EVENT

Assistance during the investigation of a nuclear security event may be facilitated through international organizations, as well as bilateral/multilateral agreements and arrangements. Assistance may include support for evidence collection, optimizing methods of analysis, conducting nuclear forensic analysis, improving confidence in the analyses, collecting data to help in nuclear forensic interpretation or provision of other types of information upon request.

When formulating a request for assistance, the requesting party should consider whether the request (not listed in priority order):

- Is in response to a specific event in which nuclear or other radioactive material has been found out of regulatory control or is part of a strategy to prepare for such events;
- Is to be considered a sensitive matter and, therefore requires protection of sensitive information or sensitive information assets;
- Permits the sharing of results by the assisting party with a third party or others not directly involved in providing the assistance and, if so, under what circumstances and how this sharing is to be accomplished;
- Requires the assisting party to collect, package and transport the nuclear or other radioactive material from the territory of the requesting party to a facility in the territory of the assisting party;
- Requires the assisting party to adhere to chain of custody and other related evidence handling requirements that prevail in the legal system of the requesting party;
- Requires Ministerial level approval from the requesting and assisting parties and if so how these approvals will be obtained;

— Involves an expectation that the assisting party will be reimbursed for costs incurred in honouring the request or will be expected to absorb such costs;

— Requires the provision of testimony by experts from the assisting party and, if so, under what conditions such testimony might be needed (for example, in person, in writing or via a communication link of some sort);

— Involves consideration of the return of nuclear or other radioactive material to the requesting party. With regard to this point, both the requesting and the assisting parties should be mindful of obligations arising from international legal instruments with regard to nuclear and other radioactive materials, such as those contained in the Convention on the Physical Protection of Nuclear Material [7], the International Convention for the Suppression of Acts of Nuclear Terrorism [9] and within Safeguards Agreements and relevant export control regulations.

One approach to facilitate a request for assistance is to develop a Statement of Work or similar document that might be executed between the requesting party and the assisting party or parties. This document should address these issues as well as specify the expectations with regard to timeliness and means of reporting; development of an analytical plan (if required by the nature of the request); manner of reporting results; and methods to be used. A less formal approach might be appropriate when the request does not require laboratory analyses, such as a request to share best practices in nuclear forensics, to offer expert advice on the conduct of nuclear forensic related exercises or to assist with plans for enhancing national capacities for nuclear forensics.

As such arrangements involve multiple and complex issues, it is advisable that, within its national response plan, each State defines and includes the arrangements that may be needed in an actual event in relation to the provision of or request for international assistance.

10. NUCLEAR FORENSICS CAPACITY BUILDING

The implementation and sustainment of a nuclear forensics capability is a State’s responsibility. Elements, including infrastructure, legal and regulatory frameworks, operations, human capital and specialized equipment and knowledge, are critical to an effective nuclear forensic capability.

As such, strategies for implementing, testing and sustaining nuclear forensic capability and capacity are essential to enabling a suitable response to a nuclear security event. These strategies will include building awareness of nuclear forensics for stakeholders at all levels, appropriate training of existing and future personnel, exercising response actions, design of research and development programs to include effective knowledge management in anticipation of future requirements, and effective education in nuclear science to foster and sustain capabilities.

10.1. AWARENESS

A key element in developing a State's nuclear forensics capability is awareness of the contribution of nuclear forensics to the State's nuclear security infrastructure. Increasing awareness of nuclear forensics for all stakeholders within the State can:

- Promote the understanding of nuclear forensics with facilitators and implementers of a nuclear forensic capability;
- Clarify roles and responsibilities;
- Increase the knowledge of nuclear forensics and allow a broader understanding;
- Encourage the use of a common terminology among varying organizations and disciplines.

10.2. TRAINING

A State is responsible for ensuring that its national nuclear security infrastructure is supported by appropriately trained personnel. Technical training and human capital development must encompass the complexities of nuclear forensics as a preventive measure and a capability for response. Training is an essential component of a sustainable programme in nuclear forensics as it provides essential information on the requirements of an investigation into a nuclear security event, recommended methods for analysis and interpretation, and the role of nuclear forensics in a State's nuclear security infrastructure. Training may also be supported through international nuclear forensics partnerships (see Appendix IV for some specific examples of training, as well as exercises and research and development being implemented through international organizations and groups).

Training requirements should be tailored to the audience. For example, to be effective in communicating scientific results to law enforcement and policy or decision makers during a nuclear security event, it is important for nuclear forensic specialists to be trained in effective communication for these types of situations. Similarly, the IAEA has developed introductory training, as well as training focused on specific technical analytical methodologies used in the nuclear forensic laboratory.

10.3. EXERCISES

An effective nuclear forensic capability requires collaboration between science and technology organizations, law enforcement agencies and other government agencies both nationally and internationally. The development of shared collaboration and cooperation processes and mechanisms is essential for the continued development of nuclear forensic capabilities. The planning and execution of nuclear forensic exercises is a key component of bolstering this capability.

Nuclear forensic exercises allow States to test and develop confidence in their response to a nuclear security event by placing decision makers and personnel in a realistic and risk-free situation before an event occurs. Exercises are often scenario-based or analytical in scope. Through exercises, stakeholders can evaluate their capabilities and determine performance under realistic conditions, while also assessing roles and responsibilities and information sharing pathways and mechanisms. Exercises allow the opportunity to refine response and recovery plans and coordination between stakeholders. The outcomes and findings from exercises should be used to identify remedial actions, develop techniques and provide new ideas to improve the overall response. Additionally, by sharing the findings with trusted partners, States can enhance their collective capacity to address emerging threats.

10.4. RESEARCH AND DEVELOPMENT

Nuclear forensics is an emerging science. In order to build confidence in nuclear forensic findings and evaluate the viability of nuclear forensic signatures to determine origin and history, research and development is essential. In particular, research focus area include improved procedures and analytical techniques for the categorization and characterization of nuclear and other radioactive materials, identification of nuclear forensic signatures for inclusion in a national nuclear forensics library, understanding how signatures are created, persist and are modified throughout the nuclear fuel cycle, and how the signatures can be accurately measured.

Engaging in research and development that promotes the science of nuclear and radioactive material analysis can maintain and improve a national nuclear forensic capability. Additionally, peer review through the scientific process promotes acceptance and confidence in techniques for nuclear or other radioactive materials analysis and interpretation. Acceptance by the scientific community positions these tools to be adopted subsequently in a nuclear forensic examination.

10.5. EDUCATION AND EXPERTISE DEVELOPMENT

Education and expertise development are key elements of an effective, sustainable nuclear forensics capability. A State must have access to technical staff possessing expertise spanning nuclear and geochemical scientific disciplines most relevant to nuclear forensics. To ensure a sufficient nuclear forensics workforce, it will be critical to grow the next generation of scientists by creating an academic pathway from undergraduate to post-doctorate study in areas such as radiochemistry, nuclear engineering and physics, isotope geochemistry, materials science and analytical chemistry. Practical measures may include:

— Encouraging collaboration and exchange between the academic, scientific and policy communities within the State, to include students, university faculty, technical experts working in the State’s laboratories and government officials;

— Providing resources, such as scholarships, fellowships, and internships, to students in the fields listed above at the undergraduate, graduate and post-graduate levels, including opportunities for practical research at laboratory facilities;

— Providing assistance to universities to support the building of educational programs relevant to nuclear forensics, including the promotion of an interdisciplinary approach (for example, bringing together the chemistry and physics departments to teach a joint nuclear forensics curriculum);

— Facilitating the capture and transfer of the unique technical knowledge of current experts through the mentoring of younger nuclear forensic scientists.

APPENDIX I: TOOLS FOR ON-SCENE ASSESSMENT OF RADIATION SAFETY HAZARDS

The radiation hazards at the scene should be determined by a qualified health physics professional and once understood, are the basis for selection of personal protective equipment (PPE), dosimetry, and contamination control or decontamination requirements for working at the scene and handling radioactive material. This assessment also determines any off-scene risks to the public or to the environment that should be mitigated or monitored. When possible, radiation fields should be reduced using shielding until sources of radiation can be safely transported from the scene. In cases where airborne radioactive material is present, additional internal dosimetry measurements or bioassay monitoring should be considered. The radiation safety hazards assessment may be part of a larger common hazards assessment used to evaluate hazards present at the scene, as described in Section 3.2. Any equipment for the radiation safety assessment should be properly maintained to ensure it is operational when needed, including instrument response verification and calibration using appropriate reference materials. It may be necessary to have a dedicated vehicle to transport radiation detection and measurement instruments, shielding, and consumable supplies including specialized PPE.

TABLE 6. EXAMPLES OF EQUIPMENT AND INSTRUMENTS FOR ON-SCENE RADIATION SAFETY ASSESSMENT

Objective	Equipment / instrument
Protect personnel from external and internal contamination	Standard PPE including gloves, protective suits, shoe covers, respiratory protection
Monitor radiation dose to personnel	Personal dosimeters; thermoluminescent dosimeters (TLDs), electronic dosimeters to provide real-time readings
Monitor source and area dose rates, map radiation fields, identify source, determine types of radiation emitted	Beta, gamma and neutron dose rate meters (may require a telescopic arm for situations involving high dose rates)
Monitor personnel, equipment and scene for contamination, identify contaminated areas and source locations	Beta / gamma survey meter (Geiger-Müller), alpha survey meter, swipe or smear material

Objective	Equipment / instrument
Monitor for airborne radioactive materials	Continuous air monitor or air sampler with filters that can be measured with a survey meter
Reducing radiation fields and dose to on-scene personnel	Portable shielding including for beta, gamma and neutron radiation, this can include rubber or plastic mats and panels for beta; concrete, steel or lead bricks for gamma; and boron-doped plastics for neutrons

APPENDIX II: TECHNIQUES FOR NUCLEAR FORENSIC CHARACTERIZATION

This appendix describes some of the most commonly used techniques in nuclear forensic analysis, as shown in Table 4. This list of techniques is representative and not exhaustive, and there are additional techniques that could be of value for nuclear forensics examinations [26].

II.1. Physical characterization including visual inspection and photography

Visual inspection of a sample provides information as to a possible identity for the sample especially if serial numbers or other identifying marks are evident. Size and shape can be sufficient to identify some items. A combination of dimensional measurements and weight of the sample can be used to calculate the density. For some chemical compounds the colour of the material can be an important indicator. Having a calibrated length and colour scale available facilitates the documentation of these physical measurements.

II.2. Optical microscopy

Optical microscopy is the first method to inspect the sample using higher magnification. An optical microscope uses magnifying light optics and reflected or transmitted methods of sample illumination to present magnified images of the sample to the user's eyes. Viewing samples under transmitted polarized light can also reveal information. Light microscopes can readily magnify an image up to 1000x.

II.3. Scanning electron microscopy (SEM) / X-ray spectrometry

SEM provides image magnifications up to 10 000x with a conventional thermal filament source or 500 000x with a field emission source. In SEM, a finely focused electron beam is scanned over the sample. The interaction of the energetic incident electron beam and the sample produces backscattered electrons, secondary electrons and X rays. By measuring the signal produced as a function of scan position, an image or map of the sample can be displayed. Each type of signal conveys different information about the sample. For example, secondary electrons convey high resolution information about sample morphology. A map of the relative intensity of backscattered electrons will show the spatial distribution of material composition based on average atomic number.

The X rays generated during SEM or electron microprobe analysis are a way of measuring the elemental composition of samples. The X rays can be analysed by either of two methods. First, an energy dispersive X ray spectrometer (EDX) uses a solid state detector to simultaneously measure the energy and rate of incident X rays. Second, in an electron microprobe configuration, a wavelength dispersive X ray spectrometer (WDX) uses an analysing crystal to sequentially diffract selected X rays into a gas proportional counter. X ray analysis is limited to a spatial resolution of around 1 μm. The detection limit of X ray analysis is approximately 0.1%, which is element dependent. SEM coupled with EDX or WDX can be used to map the abundance and spatial distribution of the elements in the sample.

II.4. X ray fluorescence analysis (XRF)

XRF analysis is useful for non-destructive elemental quantification of a wide variety of samples. An incident X ray beam excites characteristic secondary X rays in a solid sample that are counted on a solid state or proportional counter. The detection limits for XRF are in the range of 10 parts per million (ppm). Despite the low X ray energies emitted, analysis of the light elements (e.g. boron, oxygen, and carbon) is possible using mass absorption corrections and an analysing crystal.

II.5. X ray diffraction analysis (XRD)

XRD analysis is a method for identifying the chemical structure of crystalline material. An X ray beam that impinges on regularly ordered lattices undergoes constructive and destructive interference that depends on the spacing of the lattice, the wavelength of the X rays, and the angle of incidence of the X ray beam. By rotating the sample relative to a fixed X ray source, variations in interference occur, leading to characteristic diffraction patterns. These diffraction patterns can be compared to reference spectra to identify the specific crystalline phase. XRD cannot generate diffraction patterns from amorphous (non-crystalline) material.

II.6 Fourier Transform Infrared spectrometry (FTIR)

FTIR is useful for the identification of chemical compounds. The sample is exposed to a broad band of infrared frequencies, and the intensity of the reflected or transmitted infrared radiation is measured as a function of frequency. From this, an infrared absorbance spectrum is constructed. Absorption at specific frequencies is characteristic of certain bonds. Thus, the infrared spectrum identifies the various bonds and functional groups within the molecule. There are also libraries of infrared spectra that help identify unknown compounds or, at least, place them into certain classes of molecules.

II.7 Radioactive counting techniques

Each radioactive isotope emits radiation of known types and energies at a known rate determined by its activity. By measurement of the radiations emitted from a sample it is possible to quantify the amount of each isotope measured present. There are four types of radiation that could be considered for measurement, alpha, beta, gamma and neutron. Each type of radiation has its own properties and methods of detection. The two most important for nuclear forensics are gamma and alpha spectrometry and they are further described below.

Gamma spectrometry is the first technique that is used when seized nuclear material is investigated. Due to the ease of making measurements and the fact that it is a non-destructive technique and can require no sample preparation. Gamma rays, i.e., photons with energies from ten up to several hundred keV, are measured, although they are attenuated by packing or shielding material, especially lead. The initial categorization measurements on the scene are carried out with portable gamma spectrometers, eg. sodium iodide hand-held identifiers or portable HPGe. In laboratories, more sophisticated gamma spectrometry systems with better sensitivity and resolution are used. Thus gamma rays with smaller abundances can be measured with higher resolution. Energies close to each other can be resolved in the spectrum. Commercially available software is used to deconvolute the low-energy spectra observed for plutonium and uranium, and allow calculation of the isotopic composition of the material. It should, however, be noted that some nuclides like ^{242}Pu or ^{236}U cannot be detected by gamma spectrometry; in these cases mass spectrometry is used.

Gamma spectrometry also plays a key role in neutron activation analysis, where it is used to measure those nuclides created by activation of samples in a reactor or neutron generator.

Alpha spectrometry detects alpha particles, which are He^{2+} ions with energies of 3–8 MeV. They are easily stopped for example by a paper sheet, because of their strong interaction with matter and hence radiochemical preparation of samples for counting by alpha spectrometry is required. Alpha spectrometry is thus a destructive technique.

Radiochemistry followed by alpha spectrometry is important for measuring plutonium atom ratios. The radiochemical separation of Pu and Am is especially important because the alpha particles emitted by ^{238}Pu and ^{241}Am have similar energies and thus overlap in the spectrum. Similarly, the alpha energies of ^{239}Pu and ^{240}Pu are very close and cannot be resolved in the spectrum. Consequently they are measured as a sum. The atomic ratio of $^{240}Pu/^{239}Pu$ is obtained by the use of mass spectrometry.

II.8. Chemical assay

Chemical titration and controlled potential coulometry are standard methods for the determination of the elemental concentration of uranium, plutonium, neptunium or other major components of nuclear fuel material for accountability measurements or accountability verifications. In chemical titration, the sample is made to react with an exactly measured amount of a selective reagent of known composition, leading to the completion or characteristic end point of a well-known stoichiometric reaction. Titration methods are designated, *inter alia*, according to the mode of detection of the end point, e.g. potentiometric and spectrophotometric titrations. In controlled potential coulometry the element to be analysed is selectively oxidized or reduced at a metallic electrode maintained at a suitably selected potential. The number of electrons used in the oxidation or reduction is a measure of the amount of element present in the sample.

The precision and accuracy of these methods is better than 0.1% using a typical sample size of a few hundred milligrams. The methods are well established and used routinely in nuclear accountancy and safeguards laboratories. They can therefore be very effective for the characterization of nuclear material, provided that samples of at least a few tenths of a gram can be made available.

II.9. Radiochemistry

Many samples are too complex for all of the radioactive isotopes present to be measured without initial separation and purification. By utilizing the differences in chemical properties of the elements it is possible to devise schemes to separate elements, or groups of elements, to allow the measurement of the isotopes present by radioactive counting methods or mass spectrometry. The isotopes measured are related back quantitatively to the original sample by referencing to an internal isotopic standard called a ‘spike’. The chemical separation and purification steps increase both the sensitivity and selectivity of the technique. Radiochemistry is especially important to allow measurement of isotopes that are present at low activity and are best measured by their alpha emissions or by mass spectrometry. Radiochemistry in combination with radioactive counting techniques and mass spectrometry has the potential to measure down to femtogram (10^{-15} grams) level for some isotopes.

II.10. Self-Radiography

Radiography techniques may be beneficial for determining the spatial distribution and activities of radionuclides in a sample. For example, fission track analysis and alpha track analysis can locate and quantify actinides within a sample using solid state nuclear track detectors (SSNTD), and methods using photographic films or modern charged couple device (CCD) based technologies can locate and quantify beta or alpha emitters.

II.11. Mass spectrometry

Mass spectrometry is used to determine the isotopic composition of elements in the material. Mass spectrometry can also provide quantification (often called an ‘assay’ when applied to major constituents of the sample) of these elements by adding a known quantity of a specific isotope; this is known as isotope dilution mass spectrometry. Mass spectrometric methods are able to determine both radioactive and stable isotopes. In mass spectrometry, atoms or molecules are converted into positively or negatively charged ions. The resulting ions are then separated according to their mass to charge ratio, and the intensities of the resulting mass separated ion beams are measured. Elemental mass spectrometric techniques generally have high selectivity due to the mass analysis step, except in specific cases of isobaric interferences. Mass spectrometry offers extremely high precision and accuracy of analysis as well as high abundance sensitivity.

II.12. Thermal ionization mass spectrometry (TIMS)

In TIMS, a sample is deposited on a metal filament, which is heated in a high vacuum by passing a current through it. If the ionization potential of a given element is low enough, compared to the work function of the filament, then a fraction of the atoms of that element are ionized via interaction with the filament surface at high temperature. The masses are then resolved in a mass spectrometer under high vacuum using a magnetic sector. The specificity of the TIMS analysis can be provided both by chemical separation steps and by the ionization temperature. TIMS is capable of routinely measuring isotopic ratios on picogram (10^{-12} gram) to nanogram (10^{-9} gram) samples or, for rare samples, down to tens of femtograms (10^{-15} grams) using special pre-concentration techniques. TIMS routinely measures differences in isotope mass ratios on the order of 1 part in 10^6.

II.13. Inductively coupled plasma mass spectrometry (ICP-MS)

In ICP-MS, the sample is aspirated as a solution into an inductively coupled plasma, where the high temperature of the plasma breaks the sample down into its constituent atoms and ionizes these species. In addition to measuring isotope ratios, ICP-MS is useful both as a sensitive elemental survey tool and as a method for precisely quantifying trace elemental constituents of a sample. The detection limits range from 0.1 parts per billion (ppb) to a few tens of ppb in solution. ICP-MS is problematic for the measurement of some elements due to background, interferences, or poor ionization efficiency, e.g. carbon, oxygen, phosphorous, potassium, sulphur, and silica.

II.14. Secondary Ion Mass Spectrometry (SIMS)

SIMS is used for both elemental and isotopic analysis of samples, including small particles. SIMS uses a finely focused primary ion beam, e.g. O_2^+, Cs^+, or Ga^+, to sputter the sample surface. The sputtering process produces secondary ions (ions characteristic of the sample) that can be analysed by a mass spectrometer. In the ‘microscope’ mode a relatively large primary ion beam bombards the sample, and the spatial position of the resulting secondary ions is maintained and magnified throughout the mass spectrometer. A position sensitive imaging detector displays and records the isotopic image. In the ‘micro beam’ mode a finely focused primary ion beam is scanned across the sample in a manner similar to an electron microscope. The resulting secondary ion signal is then measured and correlated with the position of the primary ion beam to generate the isotope image. Sample ablation of the focused ion beam on the sample yields a depth profile through the sample surface that is extremely valuable to document compositional gradients or surface alteration.

II.15. Gas chromatography mass spectrometry (GC-MS)

GC-MS is a technique useful for detecting and measuring low level trace organic constituents (i.e, parts per million - ppm) in a bulk sample. In GC-MS, the volatile components of a sample are separated in the gas chromatograph and identified in the mass spectrometer. The mass spectrometer ionizes and fragments each component as it elutes from the chromatography column. Many different ionization methods can be used, but the most common for GC-MS is electron impact. The mass spectrometer measures the intensity of ions of various masses, either by simultaneous or sequential detection, depending on the type of mass spectrometer. The resulting plot of relative intensity versus mass to charge ratio is a ‘mass spectrum’. There are extensive libraries of mass spectra that help identify unknown compounds using GC-MS.

II.16 Transmission electron microscopy (TEM)

In TEM, an energetic electron beam is transmitted through an ultra-thin sample (~100 nanometers thickness). TEM is capable of higher magnifications than SEM and is able to image extremely fine sample structure. Transmitted electrons can undergo diffraction effects, which can be used like XRD to identify crystal phases in the material.

APPENDIX III: FORENSIC SCIENCE DISCIPLINES

This appendix provides descriptions of some of the major forensic science disciplines, with a focus on disciplines deemed likely to yield results useful to the needs of an investigation of a nuclear security event.

The majority of these disciplines have considerable history within the forensic sciences; hence, these are referred to as 'traditional forensic science disciplines'. The investigative value of binary form data ('digital evidence') has been recognized for decades, but the growth in the numbers and types of devices that capture digital evidence has increased its importance for investigative purposes. Because the tools and techniques for analysing digital evidence and for interpreting results continue to evolve and are important to the forensic examination, they are considered in a later section on emerging forensic science disciplines [24].

III.1. TRADITIONAL FORENSIC SCIENCE DISCIPLINES

III.1.1. Analysis of biological evidence

Specimens of biological origin that might be recovered as evidence from a scene or from a person, place or thing of interest to an investigation of a nuclear security event include blood, semen and saliva. Human biological evidence containing nuclear deoxyribonucleic acid (nDNA) can be of particular value because it is possible to associate the test results with one individual with a degree of reliability that is acceptable for criminal justice purposes (that is, test results are capable of individualization).

Mitochondrial DNA (mtDNA) is inherited through the maternal line and would be shared in common among all maternally related individuals (for example: siblings, mother and maternal grandmother). Consequently, mtDNA results are less useful for purposes of individualization but might assist in narrowing the focus of the investigation. Mitochondrial DNA can be recovered from biological specimens where nDNA concentrations are insufficient for any meaningful analysis. These specimens include naturally shed hairs, hair fragments, bones and teeth, any of which might be recovered from a scene of a nuclear security event.

A second category of specimens of biological origin include materials of animal, plant or fungal origin, such as feathers, plant matter (for example: leaves, pollen, seeds and stems) and spores. Analysis of such materials might offer clues as to, for example, geographical areas associated with the packaging, storage or transport of the nuclear or other radioactive material.

III.1.2. Analysis of patterns and impressions

The analysis of the patterns found in fingerprints (fingermarks), palm prints and sole prints is known as 'friction ridge analysis'. This technique has been used for more than a century to identify individuals. Friction ridge analysis and nDNA analysis are the primary forensic disciplines whose results can be considered to permit individualization. Use of friction ridge analysis might yield similar results to those of nDNA analysis and should be considered in developing the analytical plan, especially if fingerprints, palm prints or sole prints can be recovered from the scene of the event itself or from the nuclear or other radioactive material or the container used to store or transport this material. Various databases[5] of fingerprints and palm prints are available as an aid in associating these patterns with an individual and are accessible to law enforcement, such as through requests made to INTERPOL.

In addition to fingerprints, palm prints and sole prints, other patterns might be found at a crime scene or at other scenes associated with the investigation. These patterns are often referred to as impression evidence and occur when an object such as a shoe or tire leaves an impression. Other patterns that might be analysed include markings on bullets and on cartridge cases, ear prints, lip prints, some bloodstains, bite marks and glove prints. However, unlike friction ridge analysis, analysis of these other patterns is unlikely to allow individualization. Instead, the results permit the pattern to be associated with a class of people or objects – for example, a brand and size of shoes or tires. Such results can be important to narrowing the focus of any investigation of a nuclear security event.

III.1.3. Analysis of toolmarks and firearms

Analysis of toolmarks and firearms takes advantage of the markings generated when a hard object, such as a tool or the firing pin of a firearm, comes into contact with a relatively soft object. Comparisons of toolmarks and markings from firearms can be considered a specialized form of impression analysis. Analysis of marks left by a tool or firing pin can be used to narrow the focus of an investigation, both by indicating certain manufacturers or manufacturing processes of tools or firearms and by eliminating others. These marks might be found on the nuclear or radioactive material itself, on the container used to store or transport the material or on other objects recovered from the crime scene or other scenes of interest to the investigation.

III.1.4. Analysis of hair

Human and other animals routinely shed hair. These hairs might be left at a crime scene or might be transferred to another individual at the scene or at another location of interest for investigative

[5] In a forensic context, a database is a searchable collection of data or information, usually but not necessarily, in an electronic/digital format. The Automated Fingerprints Integrated System (AFIS) in the USA is one such example. [25]

purposes. Therefore, any investigation of a nuclear security event should consider the possibility that hair might have been shed onto or in the vicinity of the nuclear or other radioactive material out of regulatory control. Microscopic analysis of hair is useful with regard to class characteristics, however, rather than individual characteristics. That is, results can associate the hair with a type of person (based, for example, on hair colour or use of dye) rather than on a unique individual. But such results can be useful in excluding certain persons from the pool of possible sources of the hair, thus narrowing the focus of the investigation.

III.1.5. Analysis of fibres

Analysis of fibres by microscopic examination has a long history of use in forensic science. These fibres can include synthetic materials, such as acrylic, nylon, and polyester, as well as botanical fibres, such as those used in many ropes and twines. Such examinations are similar to those done on hairs and carry similar limitations – namely that class characteristics can be identified but that individualization is impossible. More recently, modern methods of instrumental analysis, such as Fourier transform infrared spectrophotometry (FTIR), have been used on fibres. Instrumental methods yield additional information of potential value to an investigation. Overall, results from analysis of fibres can be useful in excluding certain people, places or things as possibly associated with nuclear or other radioactive material out of regulatory control, thus narrowing the focus of the investigation.

III.1.6. Examination of questioned documents

Examination of questioned documents involves comparison and analysis of documents themselves and of the printing and writing instruments associated with these documents. Goals of such examinations include:

— Identifying or eliminating individuals as the source of the handwriting;

— Determining whether a document is the output of mechanical or electronic imaging devices such as printers, copying machines and facsimile equipment;

— Identifying or eliminating particular machines as the source of printing or typewriting;

— Revealing alterations, additions or deletions;

— Deciphering and restoring damaged, deleted or obscured parts of a document;

— Estimating the age of the document;

— Recognizing and preserving other physical evidence that might be present on the document, such as hairs, fibres and other biological materials.

Therefore, such examinations should be considered in developing the analytical plan whenever documents are recovered in association with nuclear or other radioactive material out of regulatory control.

III.1.7. Analysis of paints, coatings and other polymeric materials

Analysis of paints, coatings and other polymeric materials can be valuable to the investigation of a nuclear security event, especially in situations where containers or similar holding devices are recovered in connection with nuclear or other radioactive material. Such containers might have writing or other markings on them or within. Similarly, the containers might have polymeric materials used, for example, to cushion the material or as a seal. Analysis of the components of any paints, coatings and other polymeric materials might yield results that aid in identifying regions of the world from which they might have originated.

III.1.8. Analysis of explosives

Analysis of explosives is performed on a range of materials. For an explosively configured device that failed to function, both the explosive and the device are of evidentiary value. In the event the device did detonate, evidence of interest includes unburned or unconsumed powders, liquids or slurries; fragments of the device; and objects in immediate vicinity of an explosion that may contain residue from the explosive or the device. Analysis results might suggest a particular group or individual, based on the design, the materials of construction and records of purchase of these materials. Consequently, all analytical plans will be strongly influenced by the presence or absence of any explosive at the crime scene.

III.1.9. Forensic medicine

Through its two main branches, clinical forensic medicine and forensic pathology, forensic doctors could give expertise in cases related to nuclear forensics.

Clinical forensic medicine involves the clinical examination of the living subjects in cases of injuries, burns, explosives and complications occurring related to the effects and consequences of nuclear security event. Clinical forensic expertise is concerned with the type and nature of injuries (or burns), its cause whether it is caused by exposure to nuclear or other radioactive material or not, date of injuries, period of treatment, resulted complications and if there is any disability (temporary or permanent).

Forensic pathology involves the application of medical knowledge to the examination of human remains. The primary tool used for this purpose is the autopsy. Typical goals of forensic pathology include determining the cause and manner of death, identifying the nature and extent of injuries and establishing the identity of the remains.

Many laboratory methods can be used to aid forensic medicine, including those methods associated with nuclear and mitochondrial DNA examinations (see Section III.1.1), methods of examining humans (e.g., X ray imaging, magnetic resonance imaging (MRI) and computer axial tomography (CT-scan)) and modern instrumental methods of analysis (such as gas chromatography, liquid chromatography and inductively coupled plasma mass spectrometry).

In the case of victim of a nuclear security event, forensic pathology can be useful in determining whether a victim succumbed to the effects of exposure to radiation or to some other cause. For a nuclear security event in which there is dispersal of nuclear or other radioactive material, the findings of examinations conducted by forensic pathologists might prove useful in estimating the distance of each victim from the dispersal source. For an event that includes an explosive charge that has functioned, the forensic pathologist might establish whether a suicide bomber could have been involved, based on the pattern victims and of human remains that are recovered.

III.2. EMERGING FORENSIC SCIENCE DISCIPLINE

III.2.1. Analysis of digital evidence

The importance of the analysis of digital evidence – most often, of binary form data – has grown with the expansion in both the types of devices that record such data and the numbers of such devices in use by individuals, businesses and localities. Potential sources of digital evidence include desktop, laptop and tablet computers, as well as the hard disk computer drives, floppy disk drives, electronic memory cards, and USB flash drives associated with these computers; mobile phones; security and surveillance cameras, such as those used by banks at Automated Teller Machines (ATMs), and by many businesses and some residential buildings or communities; traffic cameras, used to spot traffic infractions or to monitor traffic flow; portable media players; and digital cameras. In the context of an investigation of a nuclear security event, such devices or evidence from such devices might be recovered on or near the scene where nuclear or other radioactive material is seized; along routes that the material might have travelled; and from individuals suspected of association with events culminating in the seizure of the material. The proliferation of digital recording devices opens the prospect that such devices have become a witness to daily activities, thus enhancing the possibility that the movement of the nuclear or other radioactive material might be mapped both chronologically and geographically.

APPENDIX IV: EXAMPLES OF EDUCATION, TRAINING, EXERCISES AND RESEARCH AND DEVELOPMENT ACTIVITIES

This appendix provides descriptions of some of the capacity building activities being implemented internationally.

IV.1. EDUCATION

In 2010 the IAEA established the International Nuclear Security Education Network (INSEN) to ensure the effective nuclear security practices by developing, sharing, and promoting educational excellence. INSEN includes educational and research institutes involved in or planning to be involved in nuclear security education. Members of INSEN collaborate on development of textbooks, teaching tools, and instructional material, professional growth of faculty, student exchange to foster information sharing, research and development to promote technical confidence, evaluation of academic theses and dissertations, and performance metrics on the effectiveness of nuclear security education.

IV.2. TRAINING

The IAEA has designed a series of training courses to satisfy the requirements of different audiences covering various facets of nuclear forensics in support of an investigation into a nuclear security event. These include courses such as: “Nuclear Security Awareness: Introduction to Nuclear Forensics”, “Nuclear Forensics Methodologies” and an affiliated course “Radiological Crime Scene Management”. More information is available from the IAEA Nuclear Security Training Catalogue accessible on the IAEA Office of Nuclear Security website: http://www-ns.iaea.org/

INTERPOL, the organization for police cooperation, also provides training to interagency multinational groups of law enforcement and scientific personnel on best practices in radiological and nuclear crime scene management.

In addition, training courses are being provided nationally and internationally by Member States.

IV.3. EXERCISES

The ITWG has conducted a number of analytical and scenario-based exercises providing an opportunity for laboratories to assess their performance on analysis as well as demonstrate capabilities. The ITWG’s Exercise Task Group has been crucial in planning, implementing and reporting on collaborative exercises – called “round robins”, during which all participating laboratories receive identical samples and are tasked to perform analyses. The participants report findings on a 24 hour, one week and two months schedule (see also Table 3). Involvement in the “round robins” is completely voluntary and open to laboratories that self-declare their measurement capabilities. The results are coded so that the results from each laboratory are reported anonymously and are known only to the exercise coordinator. Outcomes of the exercises demonstrate individual laboratory performance relative to declared analytical capability, while also identifying the utility of different analytical methods applied to a common sample. "Round robins" involve international laboratories and varied materials. Three ITWG "round robins" have been conducted to date:

1) 1998 - 2000 exercise involved six laboratories analysing plutonium oxide;
2) 2000 - 2002 exercise involved ten laboratories analysing HEU oxide;
3) 2010 exercise involved nine laboratories analysing HEU metal.

The GICNT's Implementation and Assessment Group (IAG) has conducted activities involving tabletop exercises and seminars in 2011 and 2012. The exercises aimed to develop and foster a common understanding of nuclear forensics capabilities and principles, emphasize the importance of nuclear forensics to policy and decision makers, discuss the relationships of the various communities (including law enforcement, policy and technical) involved in nuclear forensics, explore the policy aspects of sharing information to advance the investigation of nuclear security events, and identify potential cooperative information sharing partnerships, both nationally and internationally.

The Nuclear Threat Initiative has conducted two bilateral US-Russian table top exercises simulating an event involving a seizure of kilogram quantities of nuclear weapons usable material [25]. The exercises were designed to illuminate the issues, choices and constraints that officials would confront while coordinating a joint response to a nuclear security event and highlighted actions that should be taken in advance of such a contingency.

IV.4. RESEARCH AND DEVELOPMENT

In order to build confidence in nuclear forensics, to further the study of nuclear forensics signatures, to facilitate the development of national nuclear forensics libraries, and to promote international collaboration, the IAEA initiated the following coordinated research projects (CRPs):

1) 2008 – 2011 (CRP now closed): "Application of Nuclear Forensics in Illicit Trafficking of Nuclear and Other Radioactive Material"
2) 2012 – to present (CRP now active): "Identification of High Confidence Nuclear Forensic Signatures for the Development of National Nuclear Forensics Libraries"

More information is available on all IAEA CRPs at http://www-crp.iaea.org/.

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DEFINITIONS

bulk analysis. The analysis of either an entire sample or a portion of the sample to determine the average properties of the measured portion.

categorization. The process of assessing nuclear or other radioactive material, involved in a nuclear security event, by making preliminary determinations of the relevant radionuclides present and their associated levels of radioactivity. [see also *characterization*]

chain of custody. The procedures and documents that account for the integrity of physical evidence by tracking its handling and storage from its point of collection to its final disposition. Other terms for this process are ‘chain of evidence’, ‘chain of physical custody’, and ‘chain of possession’.

characterization. The process of determining the physical, chemical, elemental and isotopic attributes of the nuclear or other radioactive material. [see also *categorization*]

class characteristic. An attribute or feature shared by all members of a class. Examples include hair colour, eye colour, shoe size, size and brand of tire, and calibre of ammunition. A class characteristic is incapable of identifying a unique person, place or thing but might be useful in narrowing the focus of an investigation, especially by excluding certain persons, places or things from further consideration.

competent authority. A governmental organization or institution that has been designated by a State to carry out one or more nuclear security functions. Example: Competent authorities include regulatory bodies, law enforcement, customs and border control, intelligence and security agencies, health agencies, etc.

designated nuclear forensic laboratory. A laboratory that has been identified by a State as being capable of receiving samples of nuclear and/or other radioactive materials for the purposes of supporting nuclear forensic examinations.

examination. A procedure used to obtain information from evidence in order to reach conclusions concerning the nature of and/or associations related to evidence.

individualization. The ability to associate a result or a set of results with a single source, such as a person, place or production process.

national nuclear forensics library. An organized collection of descriptions, data characteristics and, in some cases, samples of nuclear and other radioactive materials that are produced, used or stored within a State.

nuclear forensic science, referred to as **nuclear forensics**, is a discipline of forensic science. Nuclear forensics is the examination of nuclear or other radioactive material, or of other evidence that is contaminated with radioactive material, in the context of legal proceedings, including national or international law or nuclear security.

nuclear forensic interpretation. The process of correlating sample characteristics with existing information on types of material, origins and methods of production of nuclear and other radioactive material, or with prior cases involving similar material.

nuclear material. Any material that is either special fissionable material or source material as defined in Article XX of the IAEA Statute.

nuclear security event. An event that has potential or actual implications for nuclear security that must be addressed.

out of regulatory control. The phrase "out of regulatory control" is used to describe a situation where nuclear or other radioactive material is present without an appropriate authorization, either because controls have failed for some reason, or they never existed.

radioactive material. Any material designated in national law, regulation, or by a regulatory body as being subject to regulatory control because of its radioactivity.

radiation detection instrument. A device that detects and displays the characteristics of ionizing radiation with a certain level of confidence.

radiochronometry. The use of radioactive decay to determine the time since the last separation of progenies from the "parent" material (and thus, the "age"). Another term is "age-dating". Separation can occur in many fuel cycle processes such as enrichment and reprocessing. Consequently, accuracy in radiochronometry assumes both a clean separation between parent and progeny nuclides and a closed system until sampling and analysis of the material. Incomplete separation results in a calculated age that is older than the actual age of the material.

radiological crime scene. A crime scene in which a criminal act or other intentional unauthorized act has taken place or is suspected, with nuclear security implications and involving nuclear or other radioactive material.

signature. A characteristic or a set of characteristics of a given sample that enables that sample to be distinguished, by way of either exclusion or inclusion.

trace element. A trace element is an element in a sample that has an average concentration of less than 1000 microgram / gram (µg/g) or 0.1% of the matrix composition.