IAEA NUCLEAR SECURITY SERIES NO. XX

NST018
DRAFT, February 2013

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

DEVELOPMENT OF A NATIONAL NUCLEAR FORENSICS LIBRARY

DRAFT IMPLEMENTING GUIDE

INTERNATIONAL ATOMIC ENERGY AGENCY

VIENNA, 20XX

FOREWORD

[TO BE ADDED LATER]

CONTENTS

1. INTRODUCTION

1.1 BACKGROUND

The international community has recognized the serious threat posed by nuclear and other radioactive material out of regulatory control. To address these concerns, the Office of Nuclear Security of the International Atomic Energy Agency (IAEA) is developing, inter alia, guidance for nuclear forensics to assist Member States. Nuclear forensics is the comprehensive scientific analysis of nuclear and other radioactive materials or evidence contaminated with radioactive material in the context of national and international law and nuclear security. A nuclear forensics examination may involve direct measurements of these materials and their comparison with reference information.

A national nuclear forensics library consists of descriptions, and in some cases samples, of nuclear and other radioactive material produced, used, or stored within a State. The library is a compilation of this reference information. In the context of this document, “used within a State” may also include materials transported within or through a State, and when practical, such materials may be included in the national nuclear forensics library. It is at the discretion of the State to decide the extent to which transported materials within their borders are included in the library.

A library enhances a State’s ability to identify their own inventories of nuclear and other radioactive material and promote good practices for maintaining material under regulatory control. A national nuclear forensics library also provides the basis for conducting comparative assessments of material encountered out of regulatory control, and thus is an important part of an effective nuclear security infrastructure. Because States are responsible for the development and implementation of an effective national nuclear security infrastructure, the creation of a national nuclear forensics library strengthens nuclear forensics as a means to ensure the security of nuclear and other radioactive material.

A national nuclear forensics library augments a State’s ability to assess whether nuclear and other radioactive material encountered out of regulatory control originated from within that State or elsewhere. Such a library consists of an organized collection of information, and in some cases samples, of nuclear and other radioactive material produced, used or stored by a State. Much of the information in a national nuclear forensics library may already exist in a State, having been collected at other times and for other purposes. Using a national nuclear forensics library, the characteristics of nuclear and other radioactive material found out of regulatory control may be compared with those of material organized within the national nuclear forensics library to provide information about the material’s origin and history. The responsibility for establishing and maintaining a nuclear forensics library as part of comprehensive nuclear security infrastructure rests with the State.

The isotopic, chemical and physical properties of nuclear and other radioactive materials provide information on their provenance, manufacture, and processing, and could therefore serve as important indicators of the materials' origin and history. Comparative assessments of these characteristics with existing information could be used to identify or exclude possible origins and production history of nuclear or other radioactive material out of regulatory control. This capability allows nuclear forensics to serve both as a means to assist investigations and, increasingly, due to its ability to track and trace material, as a preventive measure to discourage the diversion of nuclear and other radioactive materials out of regulatory control [1]. There is a possibility the information provided by the library may be used in a criminal investigation and used as evidence in a court of law.

The 2010 through 2012 IAEA General Conference resolutions on nuclear security and IAEA Nuclear Security Series No. 15 on Nuclear Security Recommendations on Nuclear and Other Radioactive Material out of Regulatory Control [2] include statements that endorse the development of a national nuclear forensics library as part of a State's nuclear security infrastructure. Additionally, the need for States to develop and maintain a national nuclear forensics library were emphasized in the communiques from both the 2010 Nuclear Security Summit convened in Washington, DC USA and the 2012 Nuclear Security Summit convened in Seoul, Republic of Korea.

Recent efforts at the IAEA have focused on the technical approach for States to develop a national nuclear forensics library. This work has benefitted from the strong partnership between the IAEA and the Nuclear Forensics International Technical Working Group. The IAEA and its experts also recognize that a centralized international database is impractical, given the sensitivity of information related to a State's individual holdings of nuclear and other radioactive material due to the national security or the proprietary nature of such information. For this reason, the IAEA is providing States with guidance on developing a national nuclear forensics library that use similar conceptual frameworks and have components in common. Such a common approach should allow States to support the security of nuclear and other radioactive material under their regulatory control and encourage States to work together to identify material that is found out of regulatory control, deliberately or accidently.

In this document, the term 'national nuclear forensics library', rather than 'nuclear forensics database', is used to indicate that data, information and input from technical experts may all be included in such a library and that this library of information may be distributed involving many individual databases. The library may encompass individual databases that include current and historical information on nuclear and other radioactive materials used, produced, or stored within a State. The control of nuclear forensic data and library holdings is recognized as being the responsibility of individual States.

1.2 OBJECTIVES

The objectives of this publication are to promote awareness about the importance of a national nuclear forensics library, and to provide broad guidance on the development of a national nuclear forensics library.

1.3 SCOPE

This publication identifies a national nuclear forensics library as a core component of a State’s national nuclear security infrastructure and provides guidance for States on collecting and organizing information about nuclear and other radioactive material based on nuclear fuel cycle stages and radioisotope source types. It also provides a context for using a national nuclear forensics library in material comparisons and addresses how States might use a national nuclear forensics library in domestic investigations and international cooperation.

This publication does not include specific instruction on: how to construct a national nuclear forensics library; how to establish a material sample archive (complementary to a nuclear forensics library); legal, policy, and financial aspects regarding the establishment of a nuclear forensics library; what, if any, information should be shared with other States; how to share that information; and advice on how to conduct nuclear forensic investigations. General guidance on this last topic is however provided by the IAEA Nuclear Security Series No. 2 publication entitled Nuclear Forensics Support [1].

1.4 STRUCTURE

This publication is organized as follows: Section 2 articulates the need for a national nuclear forensics library to be developed and maintained by individual States. Section 3 describes the information necessary for the development of a national nuclear forensics library. Section 4 presents the technical basis for the design of a national nuclear forensics library. Section 5 provides data tables for the characteristics of nuclear and other radioactive material included in the library. Section 6 describes how information in a national nuclear forensics library enables comparative analyses with known class characteristics. Section 7 illustrates the application of a national nuclear forensics library in the context of nuclear or other radioactive material encountered out of regulatory control. Section 8 presents the rationale for a proposed international directory of States with a national nuclear forensics library. Section 9 provides a description of international cooperation utilizing a national nuclear forensics library. Section 10 describes IAEA outreach available to States to assist in the development of a national nuclear forensics library. Appendix I provide example data entries from a hypothetical library and Appendix II lists recommended units for library data. A list of definitions used in the publication is also provided.

2. NEED FOR A NATIONAL NUCLEAR FORENSICS LIBRARY

The most important purpose of a national nuclear forensics library is to enhance a State's ability to assess 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. Nuclear forensics utilizes information inherent to the material, such as chemical composition, isotope ratios and physical dimensions arising from geologic or manufacturing processes. These indicators, often referred to as signatures, form the basis for nuclear forensic comparisons and are the information at the core of a national nuclear forensics library. However, for many States with limited amounts of nuclear and other radioactive material, non-technical indicators (such as serial numbers for radioactive sources) may be all that are required to definitively identify material consistent with a State's holdings.

Nuclear forensics can provide information on the origin and process history of nuclear and other radioactive materials. Isotopic, chemical or physical signatures incorporated during the production process are essential to these assessments. Process information includes information associated with the mining, extraction, concentration, isotopic enrichment, manufacture, use, reprocessing, or disposal of material from the nuclear fuel cycle and similar processes for radioactive sources. Nuclear forensics requires validated scientific measurements to utilize nuclear forensic signatures to determine the origin and process history of material through comparisons using a national nuclear forensics library.

By providing information on the provenance of nuclear and other radioactive material found out of regulatory control, nuclear forensics contributes to a State's nuclear security infrastructure. By potentially identifying vulnerabilities where nuclear and other radioactive material may be diverted out of regulatory control, nuclear forensics supports improvements in material accountability and physical protection measures. Illicit trafficking of nuclear and other radioactive material is a transnational concern. For example, materials may be legitimately mined and milled at one location, isotopically enriched and manufactured into fuel pellets at a second location, and subsequently diverted outside of regulatory control at a third. For this reason, the establishment of a national nuclear forensics library by more States promotes improved nuclear security practices and as a result helps strengthen nuclear security internationally.

The library is useful for nuclear forensic examinations both now as well as in the future, long after nuclear and other radioactive material production processes are complete. The library comprises information and knowledge on the holdings of nuclear and other radioactive materials and assists in sustaining nuclear fuel cycle knowledge in the absence of subject matter experts with direct experience.

A national nuclear forensics library allows investigative leads to be prioritized. The library enables rapid comparisons and the exclusion of signatures that are inconsistent with measurements. Using prioritized signatures derived from a national nuclear forensics library increases the confidence of nuclear forensic conclusions.

In the context of investigating a nuclear security event, the ability to include or exclude likely origins of material provides a powerful deterrent to the unauthorized diversion or theft of nuclear and other radioactive material. As more States develop a national nuclear forensics library, the confidence that nuclear forensics assists in identifying the origin and process history of nuclear and other radioactive materials is strengthened. The IAEA is working with States to raise awareness of the need for a national nuclear forensics library as a core component of a State's nuclear security infrastructure.

3. DEVELOPMENT OF A NATIONAL NUCLEAR FORENSICS LIBRARY

3.1 LIBRARY SCALE

Ideally, a national nuclear forensics library is commensurate with the State's activities and the size and complexity of its nuclear and other radioactive material holdings. Developing a national nuclear forensics library involves a coordinated national effort that uses existing technical expertise and information from a State's experience with nuclear and other radioactive material (see Fig. 1). For example, this information may include a registry of radioactive sources, regulatory reports, information supporting nuclear materials accountancy and production information on nuclear and other radioactive material.

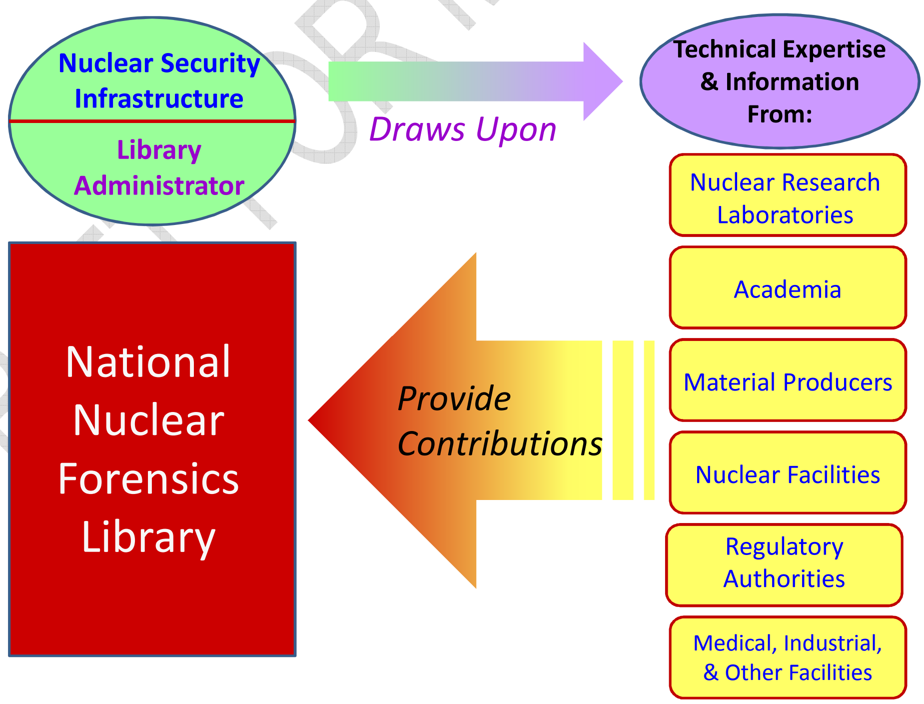


FIG 1. The association between a State's existing technical expertise and information required for its national nuclear forensics library.

3.2 GENERAL REQUIREMENTS

Development of a national nuclear forensics library likely requires, at a minimum, the identification of responsible personnel and the provision of computer hardware and software with regular maintenance. Depending on a States interests and needs, it may also necessitate the allocation of resources and people to provide products and equipment to verify and harmonise data, to analyse samples and possibly to develop and apply new nuclear forensics techniques.

3.3 USE OF EXISTING INFORMATION

Much of the data and information necessary for a national nuclear forensics library may have been generated in the past. It is probable that a significant portion of this information has been collected for purposes other than nuclear forensics. Information sources may include nuclear research laboratories, academia, material producers, nuclear facilities, regulatory bodies, and medical, industrial or other facilities. Data from disparate sources may need to be converted to a standard format (e.g. SI units) prior to incorporation into the library to facilitate comparisons of material out of regulatory control with library data. A State should ensure that processes are established to provide current and validated information to the national nuclear forensics library.

3.4 LIBRARY ADMINISTRATOR ROLE

To ensure successful organization of this information, it is suggested that a library administrator is designated by the State to oversee and manage its national nuclear forensics library. The library administrator may be an individual or a team in a State with technical comprehension and access to the domain expertise represented by the national nuclear forensics library, enabling routine and comprehensive access to the library contents. The library administrator should be familiar with the domestic nuclear fuel cycle, isotope production, and nuclear and other radioactive material holdings, and administer the national nuclear forensics library in a manner that allows for accurate retrieval of information. A library administrator is responsible for identifying and organizing information from relevant organizations, institutes and facilities for inclusion in the national nuclear forensics library. In some instances, specific agreements may be needed to arrange information sharing between the library administrator and the information provider.

3.5 GRADUAL DEVELOPMENT PROCESS

The development of the library is a gradual and on-going process of surveying, collecting and organizing information about nuclear and other radioactive material produced, used or stored in the State and should be established in advance of a nuclear security event to enable timely interpretations and response.

3.6 USE OF PATTERNS AND TRENDS IN MATERIALS INFORMATION

It is anticipated that a consolidated view of a State's materials information helps to reveal patterns or trends in characteristics of domestic nuclear and other radioactive materials that should enhance a State's ability to compare their own materials with forensic samples. It may also identify gaps that need to be filled. Having a national nuclear forensics library allows States to develop signatures for their domestic materials based on discriminating material characteristics (e.g. major and minor isotopes, age of the sample, and physical dimensions) that should assist nuclear forensic examinations in determining if materials encountered outside of regulatory control are or are not consistent with a State's material holdings. Harmonization or regular updating of the information in the national nuclear forensics library is essential for maintaining the value of the library as a State's material holdings and analytical capabilities evolve.

3.7 MATERIAL ARCHIVE

A national nuclear forensics library may be complemented by a collection of archived nuclear and other radioactive materials. Maintaining an archive of these materials provides exemplars representative of fuel cycle or types of radioactive sources available that can be studied in detail for forensic characteristics, and direct comparison to forensic samples. In some cases, it may be more cost effective to hold representative materials in an archive by deferring detailed and often expensive analysis until funds are available, or even until analytical capabilities are established and validated. The study of archive samples may be valuable for identifying material characteristics and signatures important for comparative analysis. Additionally, archive samples may be useful for validating analytical procedures and for training personnel in forensic analysis methods. It may be impractical to archive short-lived radioisotopes.

4. TECHNICAL BASIS FOR THE DESIGN OF A NATIONAL NUCLEAR FORENSICS LIBRARY

To assist States with organizing their information on nuclear and other radioactive material in a national nuclear forensics library, the IAEA has devised an organizational scheme that aligns material information with stages of the nuclear fuel cycle or types of radioactive sources (see Fig. 2). The organizational scheme builds upon three sequential steps. First, nuclear fuel cycle processes are determined. Second, for each nuclear fuel cycle process step selected, key discriminating material characteristics (e.g. isotope abundance, trace element concentration) are identified. Third, a data discriminator (high, medium or low) is assigned to each material characteristic to indicate the characteristic's significance as a parameter for comparing materials with different production histories, but from the same step in the fuel cycle. The tables should be considered as guidance, and may not be entirely applicable to a State's library effort. For example, a State with minimal material holdings may find it adequate to keep track of sources by serial numbers and a few basic parameters rather than catalogue all of the information recommended in the table.

Fig. 2 summarizes nuclear fuel cycle and radioactive source production processes associated with nuclear and other radioactive material in a national nuclear forensics library.

NUCLEAR FUEL CYCLE STAGES	EXAMPLE MATERIALS
1. Geologic Deposition	Ore, ore body
2. Uranium Mining, Milling, and Extraction	Ore concentrate, yellow cake
3. Uranium Conversion	UF_6, UF_4, UO_2, U_3O_8, uranium metal and alloys
4. Uranium enrichment	UF_6, UF_4, UCl_4, uranium metal
5. Uranium Fuel Fabrication	UO_2, U_3O_8, pellets, rods/plates, elements, scrap
6. Mixed Oxide (MOX) Fuel Fabrication	MOX powder, pellets, rods, scrap
7. Fresh Nuclear Fuel	Fuel assemblies
8. Irradiated (Spent) Nuclear Fuel	Spent fuel
9. Reprocessing	Plutonium nitrate, uranyl nitrate, plutonium oxide, uranium oxide, mixed oxide, other actinides
10. Radioactive Waste Processing, Handling and Storage	Radioactive waste forms

TYPE OF RADIOACTIVE SOURCES	EXAMPLE MATERIALS
11. Sealed Radioactive Sources	Radiography, well logging sources, sterilizers, therapeutic medicine
12. Unsealed Radioactive Sources	Tracer studies, research and development, diagnostic or therapeutic medicine, irradiated targets

FIG 2. Summary of the stages of the nuclear fuel cycle and radioactive source production associated with material in a national nuclear forensics library

A notional structure of a national nuclear forensics library is illustrated in Fig. 3. A national nuclear forensics library consists of a material master index, domain expertise, and data and information organized according to relevant stages of the nuclear fuel cycle or production of isotopes for radioactive sources. The material master index provides a summary of all information in the library, and can be used by the library administrator to locate specific information and also contact the appropriate technical expert. Domain expertise (provided by an individual expert or specialists) assists the library administrator to identify and organize information from a specific nuclear fuel cycle stage or type of radioactive source. Such expertise also helps in analysing the information for patterns or trends that enhance a State's ability to determine distinguishing features about its own material holdings. It should be noted that the population of the library is, in some cases, an on-going process; and that it should be developed in a flexible manner which would allow additional information and/or the creation of additional fields to be included at a later date.

A State's national nuclear forensics library is usually expected to be a smaller subset of all the fields illustrated in Fig. 3, as the library scales with size and complexity of a State's nuclear or other radioactive material holdings

FIG 3: Notional structure of a national nuclear forensics library incorporating stages of the nuclear fuel cycle and types of radioactive sources illustrated in Fig. 2. A State's national nuclear forensics library is usually expected to be a smaller subset of all the fields illustrated in Fig. 3, as the library scales with size and complexity of a State's nuclear or other radioactive material holdings. Therefore, a State's national nuclear forensics library will only include domain expertise for materials consistent with a State's holdings.

5. NUCLEAR FUEL CYCLE AND TYPES OF RADIOACTIVE SOURCES DATA TABLES

Developing a national nuclear forensics library begins with identifying and organizing existing material information from relevant stages of the nuclear fuel cycle and types of radioactive sources to include the production and use of radioactive sources. For example, information may be found in a State's registry of radioactive sources and production records for nuclear materials. Domain experts determine which material characteristics are relevant and should be included in a national nuclear forensics library. A batch of nuclear or other radioactive material is assumed to incorporate a unique nuclear forensic identity (or set of signatures). For each batch, the general information (e.g. name and address of material custodian, supplier address, batch identification) in combination with specific isotopic, chemical and physical data bearing on material origin and process history helps to identify the material. The national nuclear forensics library also includes information pertaining to material from intermediate processes that could possibly be diverted (e.g. process archive samples).

The organizational scheme for linking nuclear fuel cycle and isotope production processes and corresponding data categories is presented in Tables 1–12. Each table represents a process step in the nuclear fuel cycle or type of radioactive source and includes the key material characteristics corresponding to each process step. For each process step, the associated key material characteristics are assigned a data discriminator of high, medium or low denoting the significance of the key material characteristic's contribution to a nuclear forensic signature (for example its ability to be a distinguishing feature).

5.1 GENERAL INFORMATION TO BE INCLUDED

In addition to the material data and information contained in Tables 1–12, general information for inclusion in a national nuclear forensics library may include the following:

- Data record date (inclusion date into library);
- Name and address of the custodian of the nuclear and other radioactive material (e.g. production or storage facility or installation);
- Name and address of the analytical laboratory and laboratory identification number with the date of analysis of the nuclear and other radioactive material;
- Country of origin of the nuclear and other radioactive material;
- Name and address of the supplier (i.e., originator) of the nuclear and other radioactive material;

— Nuclear and other radioactive material batch identification and process date from supplier (to the extent possible, such information may already be available within a State, and such existing information is helpful for a library);

— Shipper/carrier and receiver information, including dates;

— Data vetting information (e.g., determination of data quality, pedigree and completeness);

— Variation in the range of a data characteristic (e.g., technical specifications). For example, low enriched uranium used in commercial light water reactors typically ranges in isotopic enrichment between 3 to 5% ^{235}U;

— Information acquisition date, including stating if archived information was used.

The general information topics that would be associated with materials information in a national nuclear forensics library will depend on a State's requirements. Thus, a State will include topics of general information as they deem appropriate for their needs, and these topics may differ from the suggested topics listed above.

5.2 SPECIFIC INFORMATION: NUCLEAR FUEL CYCLE STAGES AND TYPES OF RADIOACTIVE SOURCES

Analytical measurement data included in a national nuclear forensics library should use consistent units to help facilitate timely and meaningful comparisons. SI units should be used wherever possible; isotopic compositions should be reported as atom ratios, with all isotopes of uranium reported relative to ^{238}U (e.g., $^{235}U/^{238}U$) and ^{239}Pu for plutonium. Sometimes, due to existing data streams or other circumstances, it may be easier to capture data in the library using non-SI units. For this reason, careful attention should be paid to ensuring unit agreement between data from disparate sources.

Radionuclide or isotope ratio measurement results should be reported with a reference date, to facilitate quality comparative analysis. This is especially true for measurements that include shorter-lived radionuclides (e.g. ^{241}Pu). Inclusion of measurement reference dates or production dates may also help facilitate the application of radiochronometry measurements to help identify whether or not a seized material is consistent with materials found in the library. For example, if the $^{230}Th/^{234}U$ ratio measured in uranium fuel indicates it is 30 years old, and the only plant in a State producing material began operations 10 years ago, then based on age alone the forensic sample is not consistent with material produced by the State. Radiochronometers are generally only applicable to relatively pure materials, typically found in the later stages of the fuel cycle, and it is important to understand limitations of radiochronometry measurements if they are to be effectively used as forensic signatures.

It is also important, wherever possible, to include analytical uncertainties for each measurement result included in a library. Ideally, analytical uncertainties would be estimated using internationally accepted practices, for example those found in the Guide for the Estimation of Uncertainty in Measurement (GUM) [3]. Acknowledging that data included in the library may have been generated for other purposes (e.g. for process quality control), uncertainties may not always be available. In these cases, data may still be valuable, but a thorough understanding of any limitations concerning data accuracy or poor precision is important before including data in a national nuclear forensics library or using data for a comparative analysis.

In summary, when beginning to develop a national nuclear forensics library, the first step is for the State to collect and organize its existing material information. It may be valuable to identify and engage a set of domain experts knowledgeable of the nuclear and other radioactive material operations within a country; the measurements made on those materials for process control, quality assurance, or accountancy; techniques for organizing large data sets; and querying, filtering, and performing comparative analysis of data. The second step is to use the following tables, as they pertain to the State's fuel cycle activities, type of radioactive source, and material holdings, as a guide to organizing existing data in the context of material production processes and use of material.

5.3 TECHNICAL GUIDANCE PROVIDED IN THE TABLES

Tables 1 through 12 serve as technical guidance for categorizing and organizing information for inclusion in a national nuclear forensics library. These tables are not intended to be data input templates, but rather they are lists of information categories and material characteristics that may be helpful in organizing a State's material holdings information for forensic purposes. State's may adopt or modify these guidance lists as they deem appropriate to meet their needs for a national nuclear forensics library.

The material characteristics presented in Tables 1 through 12 are not listed a priority order. Rather, the characteristics are listed in a sequence that generally follows typical material examinations: non-destructive measurements would be performed before using destructive methods. For example, visual inspections and optical microscopy would generally be performed before isotopic analyses.

The Tables have been constructed to be applicable to all nuclear fuel cycles. Although the tables specifically include characteristics and processes associated with uranium and plutonium, because these are the most common, the table are also applicable to other fuel cycles, such as thorium. Depending on the needs of a State, the tables could be adapted where applicable to other fuel cycles, and the characteristics that would be included in national nuclear forensics library would be similar. For example, for a thorium fuel cycle, Table 3 on conversion would be the same but with thorium replacing uranium in the table.

TABLE 1. GEOLOGIC DEPOSITION (ORE AND ORE DEPOSITS)

Characteristic	Characteristics — Data elements	Data Discriminator	Notes
Geology	• Mine location • Geological formation • Deposit types • Mining technique • Colour	High	Relevant description of the geology of the material (ore) deposit and body (e.g. vein, sedimentary deposit, etc.)
Mineralogy	• Minerals present • Chemical composition of minerals • Volume percentages of minerals	Low	Mineral identified as part of exploration and mining processes
Uranium concentration	• Uranium concentration • Uranium concentration uncertainty	Low	Typically expressed in g/tonne
Uranium isotopes	• Isotope ratios (^{238}U in the denominator) • Isotope ratio uncertainty	Low	$^{235}U/^{238}U$ and $^{234}U/^{238}U$
Stable isotopes	• Isotope name • Use standard units for particular isotope system • Uncertainty	High	Add isotope ratios similar to Pb Per mil (‰) for C, O, N, S $^{87}Sr/^{86}Sr$ ratio for Sr ε_{Nd} for Nd Isotope ratios for Pb ($^{208}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, $^{206}Pb/^{204}Pb$)
Trace element	• Trace element concentration • Trace element concentration uncertainty	High	Typically expressed in µg/g sample

TABLE 2. URANIUM MINING, MILLING, AND EXTRACTION (ORE CONCENTRATE, YELLOWCAKE)

Characteristic	Characteristics — Data elements	Data discriminator	Notes
Chemical form	• Compound name • Stoichiometry deviation	High	U_3O_8, $((NH_4)_2U_2O_7)$
Physical characteristics	• Density	Low	Density expressed in g/cm^3
Morphology/ Crystallography	• Lattice structure • Aspect ratio • Porosity • Colour • Particle size (and distribution) • Shape • Surface features (e.g. scratches)	Low	Descriptive shape of individual grains (e.g. round, oval, square, smooth, rough)
Uranium concentration	• Uranium concentration • Uranium concentration uncertainty	Low	Expressed in g/g
Uranium isotopes	• Isotope ratios (^{238}U in the denominator) • Isotope ratio uncertainty	Low	^{235}U/ ^{238}U and ^{234}U/ ^{238}U
Uranium decay series radionuclides	• Isotope name • Activity concentration • Activity concentration uncertainty	High	Radioactive disequilibrium indicates chemically processed materials
Stable isotopes	• Isotope name • Use standard units for particular isotope system • Uncertainty	High	Per mil (‰) for C, O, N, S ^{87}Sr/^{86}Sr ratio for Sr ε_{Nd} for Nd Isotope ratios for Pb (^{208}Pb/^{204}Pb, ^{207}Pb/^{204}Pb, ^{206}Pb/^{204}Pb)
Trace element	• Trace element concentration • Trace element concentration uncertainty	High	Typically expressed in µg/g sample
Process information (In context of how it affects material)	• Mining and milling process • Location of processing site • Dates when production occurred (range)	High	Process description, location of plant and dates of production

TABLE 3. URANIUM CONVERSION (INCLUDING UF6, UF4, UO2, U3O8, METAL OF NATURAL URANIUM, DEPLETED URANIUM, LOW ENRICHED URANIUM AND HIGHLY ENRICHED URANIUM)

Characteristic	Characteristics — Data elements	Data discriminator	Notes
Physical characteristics	• Density • Solid, liquid, gas • Mechanical properties (e.g., tensile strength, hardness, ductility, etc.)	High	Density expressed in g/cm^3
Morphology/ Crystallography	• Lattice structure • Aspect ratio • Porosity • Colour • Particle size (and distribution) • Shape • Surface features (e.g. scratches)	Medium	Descriptive shape of individual grains (e.g. round, oval, square, smooth, rough)
Chemical form	• Compound name	High	
Uranium concentration	• Uranium concentration • Uranium concentration uncertainty	Medium	Expressed in g/g
Trace element	• Trace element concentration • Trace element concentration uncertainty	Medium	Typically expressed in µg/g sample
Uranium isotopes	• Isotope ratios (^{238}U in the denominator) • Isotope ratio uncertainty	High	$^{235}U/^{238}U$, $^{234}U/^{238}U$, $^{236}U/^{238}U$, $^{233}U/^{238}U$, $^{232}U/^{238}U$
Process information (In context of how it affects material)	• Process type • Date range for production • Location of processing site	Medium	Process description (e.g. fluorination),location of plant and dates of production
Container	• Container type • Volume • Dimensions	High	Primarily for UF_6

TABLE 4. URANIUM ENRICHMENT (UF6, UF4, UCl4, U METAL)

Characteristic	Characteristics — Data elements	Data discriminator	Notes
Physical characteristics	• Density • Solid, liquid, gas • Mechanical properties (e.g., tensile strength, hardness, ductility, etc.)	Low	Density expressed in g/cm^3
Morphology/ Crystallography	• Lattice structure • Aspect ratio • Porosity • Colour • Particle size (and distribution) • Shape • Surface features (e.g. scratches)	Medium	Descriptive shape of individual grains (e.g. round, oval, square, smooth, rough)
Chemical form	• Compound name	High	
Uranium concentration	• Uranium concentration • Uranium concentration uncertainty	Medium	Expressed in g/g
Trace element	• Trace element concentration • Trace element concentration uncertainty	Medium	Typically expressed in µg/g sample
Uranium isotopes	• Isotope ratios (^{238}U in the denominator) • Isotope ratio uncertainty	High	$^{235}U/^{238}U$, $^{234}U/^{238}U$, $^{236}U/^{238}U$, $^{233}U/^{238}U$, $^{232}U/^{238}U$
Process information (In context of how it affects material)	• Process type • Date range for production • Location of processing site	Medium	Process description (e.g. fluorination),location of plant and dates of production
Container	• Container type • Volume • Dimensions	High	Primarily for UF_6

TABLE 5. URANIUM FUEL FABRICATION (INCLUDING NATURAL URANIUM, DEPLETED URANIUM, LOW ENRICHED URANIUM AND HIGHLY ENRICHED URANIUM): UO2, U3O8, ALLOY AND MATRIX FUELS, PELLETS, RODS/PLATES, ELEMENTS, SCRAP AND WASTE

Characteristic	Characteristics — Data elements	Data discriminator	Notes
Physical characteristics	• Description for fuel (pellet, pebble, etc.) and dimensions (for rods, plates, etc.) • Density • Solid, liquid, gas • Mechanical properties (e.g., tensile strength, hardness, ductility, etc.) • Cladding information (type) • Fuel coating information	High	Density expressed in g/cm^3 Plans, technical drawings or photographs of rods, plates and pellets
Serial number	• Serial number	High	Could be individual serial numbers or ranges of serial numbers associated with a particular design
Morphology/ Crystallography (for fuel and cladding material)	• Lattice structure • Aspect ratio • Porosity • Colour • Particle size (and distribution) • Shape • Surface features (e.g. scratches)	Medium	
Chemical form	• Compound name • Type (e.g., alloy or matrix)	High	
Elemental concentrations	• Element concentration • Element concentration uncertainty	Medium	Expressed in g/g sample To include U and burnable poisons
Trace element	• Trace element concentration • Trace element concentration uncertainty	Medium	Typically expressed in µg/g sample
Uranium isotopes	• Isotope ratios (^{238}U in the denominator) • Isotope ratio uncertainty	High	$^{235}U/^{238}U$, $^{234}U/^{238}U$, $^{236}U/^{238}U$, $^{233}U/^{238}U$, $^{232}U/^{238}U$
Process information (In context of how it affects material)	• Process type • Date range for production • Location of processing site	High	Process description, location of plant and dates of production

TABLE 6. MIXED OXIDE FUEL (MOX) FUEL FABRICATION: POWDER, PELLETS, RODS, SCRAP AND WASTE

Characteristic	Characteristics – Data elements	Data discriminator	Notes
Physical characteristics	• Description for fuel (pellet, pebble, etc.) and dimensions (for rods, plates, etc.) • Density • Solid, liquid, gas • Mechanical properties (e.g., tensile strength, hardness, ductility, etc.) • Cladding information (type) • Fuel coating information	High	Density expressed in g/cm^3 Plans, technical drawings or photographs of rods, plates and pellets
Serial number	• Serial number	High	Could be individual serial numbers or ranges of serial numbers associated with a particular design
Morphology/ Crystallography (for fuel and cladding material)	• Lattice structure • Aspect ratio • Porosity • Colour • Particle size (and distribution) • Shape • Surface features (e.g. scratches) • Plutonium homogeneity (i.e. distribution within the matrix)	Medium	
Chemical form	• Compound name (for U and Pu components)	High	
Elemental concentrations	• Element concentration • Element concentration uncertainty	High	Expressed in g/g sample To include U and Pu burnable poisons Expressed in g/g sample
Trace element	• Trace element concentration • Trace element concentration uncertainty	Medium	Typically expressed in µg/g sample
Uranium isotopes	• Isotope ratios (^{238}U in the denominator) • Isotope ratio uncertainty	High	^{235}U/^{238}U, ^{234}U/^{238}U, ^{236}U/^{238}U, ^{233}U/^{238}U, ^{232}U/^{238}U
Plutonium isotopes	• Isotope ratios (^{239}Pu in the denominator) • Isotope ratio uncertainty	High	^{238}Pu/^{239}Pu, ^{240}Pu/^{239}Pu, ^{241}Pu/^{239}Pu, ^{242}Pu/^{239}Pu
Process information (In context of how it affects material)	• Process type • Date range for production • Location of processing site	High	Process description, location of plant and dates of production

TABLE 7. FRESH NUCLEAR FUEL (ASSEMBLIES, ELEMENTS FOR POWER OR RESEARCH REACTORS; ISOTOPE PRODUCTION CAPSULES)

Characteristic	Characteristics — Data elements	Data discriminator	Notes
Physical characteristics	• Description for fuel assembly and dimensions (for rods, plates, etc.) • Cladding information (type) • Assembly structure	High	Plans, technical drawings or photographs of nuclear fuel assemblies
Serial number	• Serial number	High	Could be individual serial numbers or ranges of serial numbers associated with a particular design
Chemical form	• Compound name	High	
Elemental concentrations	• Element concentration • Element concentration uncertainty	High	Expressed in g/g sample To include U and Pu burnable poisons Expressed in g/g sample
Trace element	• Trace element concentration • Trace element concentration uncertainty	Low	Typically expressed in µg/g sample
Uranium isotopes	• Isotope ratios (^{238}U in the denominator) • Isotope ratio uncertainty	High	$^{235}U/^{238}U$, $^{234}U/^{238}U$, $^{236}U/^{238}U$, $^{233}U/^{238}U$, $^{232}U/^{238}U$
Plutonium isotopes	• Isotope ratios (^{239}Pu in the denominator) • Isotope ratio uncertainty	High	$^{238}Pu/^{239}Pu$, $^{240}Pu/^{239}Pu$, $^{241}Pu/^{239}Pu$, $^{242}Pu/^{239}Pu$
Process information (In context of how it affects material)	• Process type • Date range for production • Location of processing site	High	Process description, location of plant and dates of production

TABLE 8. IRRADIATED (SPENT) NUCLEAR FUEL

Characteristic	Characteristics — Data elements	Data Discriminator	Notes
Physical characteristics	• Description for fuel assembly and dimensions (for rods, plates, etc.) • Cladding information (type) • Assembly structure • Surface oxide thickness	High	Plans, technical drawings or photographs of nuclear fuel assemblies
Serial number	• Serial number	High	Could be individual serial numbers or ranges of serial numbers associated with a particular design
Chemical form	• Compound name	High	
Elemental concentrations	• Element concentration • Element concentration uncertainty	High	Expressed in g/g sample To include U and Pu burnable poisons Expressed in g/g sample
Trace element	• Trace element concentration • Trace element concentration uncertainty	Low	Typically expressed in µg/g sample
Uranium isotopes	• Isotope ratios (^{238}U in the denominator) • Isotope ratio uncertainty	High	$^{235}U/^{238}U$, $^{234}U/^{238}U$, $^{236}U/^{238}U$, $^{233}U/^{238}U$, $^{232}U/^{238}U$
Plutonium isotopes	• Isotope ratios (^{239}Pu in the denominator) • Isotope ratio uncertainty	High	$^{238}Pu/^{239}Pu$, $^{240}Pu/^{239}Pu$, $^{241}Pu/^{239}Pu$, $^{242}Pu/^{239}Pu$
Irradiation history	• Reactor type • Burn-up • Assembly power history • Operating records • Load and discharge dates	High	

TABLE 9. REPROCESSING (PLUTONIUM NITRATE, URANYL NITRATE, PLUTONIUM OXIDE, URANIUM OXIDE, MIXED OXIDE, OTHER ACTINIDES)

Characteristic	Characteristics — Data elements	Data discriminator	Notes
Physical characteristics	• Description for fuel (pellet, pebble, etc.) and dimensions (for rods, plates, etc.) • Density • Solid, liquid, gas • Mechanical properties (e.g., tensile strength, hardness, ductility, etc.) • Cladding information (type) • Fuel coating information	Low	Density expressed in g/cm^3
Chemical form	• Compound name	High	
Elemental concentrations	• Element concentration • Element concentration uncertainty	High	Expressed in g/g sample
Trace element	• Trace element concentration • Trace element concentration uncertainty	High	Typically expressed in µg/g sample
Uranium isotopes	• Isotope ratios (^{238}U in the denominator) • Isotope ratio uncertainty	High	$^{235}U/^{238}U$, $^{234}U/^{238}U$, $^{236}U/^{238}U$, $^{233}U/^{238}U$, $^{232}U/^{238}U$
Plutonium isotopes	• Isotope ratios (^{239}Pu in the denominator) • Isotope ratio uncertainty	High	$^{238}Pu/^{239}Pu$, $^{240}Pu/^{239}Pu$, $^{241}Pu/^{239}Pu$, $^{242}Pu/^{239}Pu$
Process information (In context of how it affects material)	• Process type • Date range for production • Location of processing site	High	Process description, location of plant and dates of production

TABLE 10. RADIOACTIVE WASTE PROCESSING, HANDLING, AND STORAGE (HIGH LEVEL RADIOACTIVE WASTE)

Characteristic	Characteristics — Data elements	Data discriminator	Notes
Serial number	• Serial number	High	Could be individual serial numbers or ranges of serial numbers associated with a particular design
Physical characteristics	• Activity • Density • Solid, liquid, gas (General description of matrix) • Mass • Dimensions	High	Density expressed in g/cm^3 Total activity or dose rate
Elemental concentrations	• Element concentration • Element concentration uncertainty	High	Expressed in g/g sample
Major isotopes	• Isotope name • Isotope activity • Isotope activity uncertainty	High	Expressed as activities in Bq, include reference date
Process information (In context of how it affects material)	• Process type • Date range for production • Location of processing site	High	Process description, location of plant and dates of production
Container	• Container type • Volume • Dimensions	High	

TABLE 11. TYPES OF RADIOACTIVE SOURCES: SEALED

Characteristic	Characteristics – Data elements	Data discriminator	Notes
Description of the source/package	• Source type (emission type, use type) • Quantity • Description and dimensions • Encapsulation or cladding • Serial number • Radiograph/photograph • Shipping/receiving history	High	Identifying information from the supplier
Source activity information	• Activity • Reference date of the activity • Neutron intensity/yield	High	Activities in Bq, [neutron/sec] with a radioactive decay reference date
Chemical form	• Compound name	High	
Elemental concentrations (in matrix)	• Element concentration • Element concentration uncertainty	High	Expressed in g/g sample
Major and minor isotopes	• Isotope name • Isotope activity • Isotope activity uncertainty	High	Expressed as activities in Bq, include reference date

TABLE 12. TYPES OF RADIOACTIVE SOURCES: UNSEALED

Characteristic	Characteristics — Data elements	Data discriminator	Notes
Description of the source/package	• Source type (emission type, use type) • Quantity • Description and dimensions • Radiograph/photograph • Shipping/receiving history	High	Identifying information from the supplier
Source activity information	• Activity • Reference date of the activity	High	Activities in Bq, with a radioactive decay reference date
Chemical form	• Compound name	High	
Elemental concentrations	• Element concentration • Element concentration uncertainty	High	Expressed in g/g sample
Major and minor isotopes	• Isotope name • Isotope activity • Isotope activity uncertainty	High	Expressed as activities in Bq, include reference date

7. COMPARATIVE ANALYSES WITH A NATIONAL NUCLEAR FORENSICS LIBRARY

To determine if a seized material is consistent with a State's holdings of nuclear and other radioactive material, a national nuclear forensics library enables forensic associations of the seized material with classes or families of materials with known signatures. However, unlike fingerprint analysis, it is often impractical for nuclear forensics to rely on sample-to-sample matching. Rather, nuclear forensics associates the seized sample with classes of material characterized by combinations of known quantifiable features (e.g. isotope ratios, chemical composition, impurities, physical characteristics). A hypothetical example of this association is illustrated in Fig. 4.

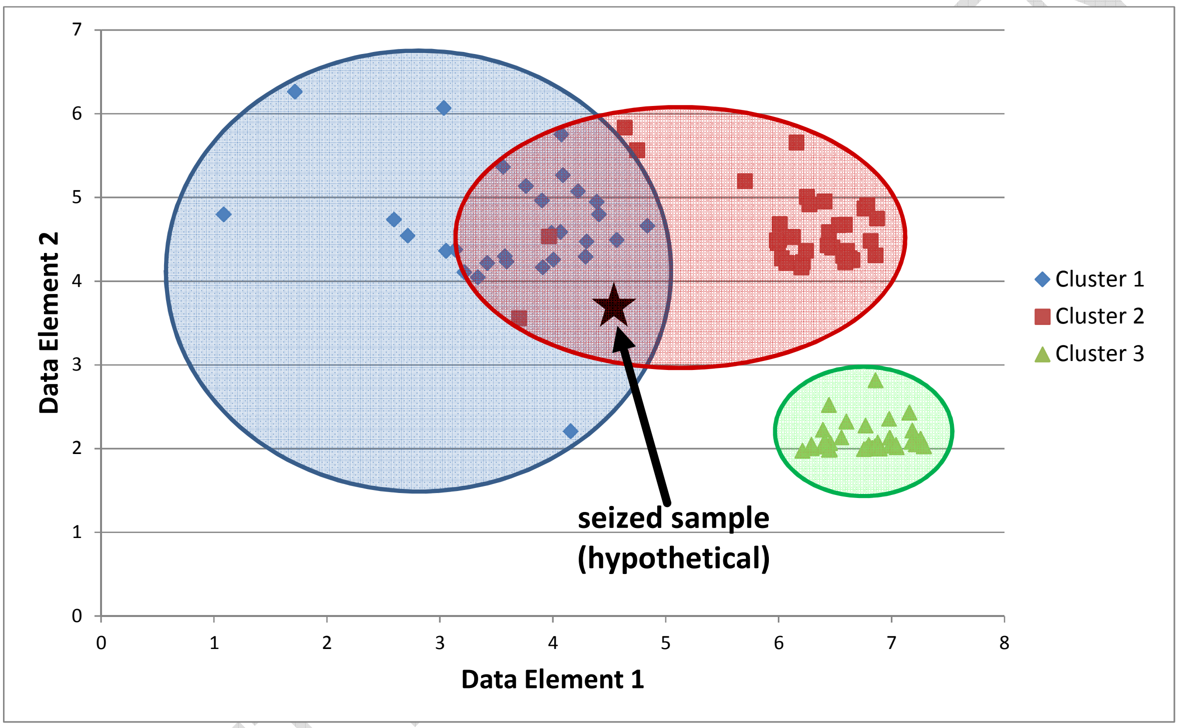


FIG 4. Use of multi-variate analysis (pattern classification) to associate a hypothetical seized sample with existing signature fields. The hypothetical seized material may possibly be consistent with cluster 1 or 2, but it is likely not consistent with cluster 3. Using existing information on nuclear or other radioactive material from a national nuclear forensics library, multi-variate analyses are used to include or exclude seized sample measurements relative to existing material families (classes). In nuclear forensics, associating with existing class information is the key, not sample-to-sample matching.

In this example, statistical techniques are used to associate discriminating features of hypothetical seized material with three known classes designated by the blue, red, and green fields. As shown in Fig. 4, features of the seized material may be consistent with characteristics represented by the blue and red clusters, but it is unlikely that the seized material is consistent with the green cluster. Thus, class information represented by the green cluster may be excluded from further consideration, and as a result, the investigative leads can be narrowed.

As illustrated in Fig. 4, a national nuclear forensics library may contain information that enables multiple evaluations to be performed that compare seized materials with known classes of materials. Taken together, these multiple evaluations aim to determine the appropriate signature combinations that identify a material as consistent or inconsistent with a State's holdings. Data evaluations using class associations are iterative deductive processes that enable States to formulate conclusions that exclude or include material produced, used or stored in the State from further consideration during a nuclear forensic investigation.

8. APPLICATION OF A NATIONAL NUCLEAR FORENSICS LIBRARY

In the instance of a nuclear security event in a State, a national nuclear forensics library would facilitate the ensuing investigation. Fig. 5 illustrates an example involving seized illicit material where a State's law enforcement agency would need to understand the characteristics of that material to assist in their investigation. The library administrator identifies the material with the possible assistance of the Domain Expert(s) and responds to the query with information on what the seized material is and/or is not.

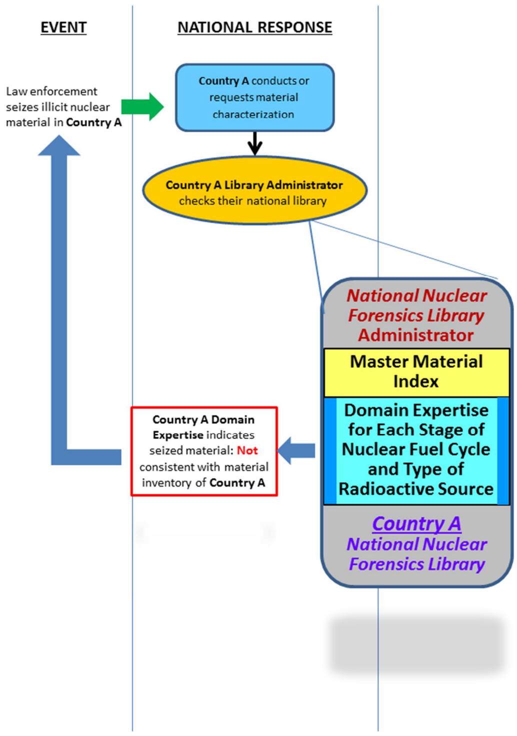


FIG 5. Schematic illustration of the application of a national nuclear forensics library in a hypothetical domestic smuggling incident. A national nuclear forensics library is used to forensically associate (or exclude) -seized material with State's material holdings to determine if the seized material is or is not consistent with its material holdings.

9. INTERNATIONAL DIRECTORY OF STATES WITH A NATIONAL NUCLEAR FORENSICS LIBRARY

A proposed international directory of States that have developed and maintain a national nuclear forensics library identifies national points-of-contact who can communicate through official channels concerning information about the national library. Cooperation between States during an investigation of a nuclear security event by exchanging queries about the material maintained in a national nuclear forensics library, without divulging further information on the content of the library, is an effective means to expand the knowledge base of materials information available to States during the course of an investigation.

The national point-of-contact (POC) of the national nuclear forensics library receives and replies to requests about information in a national nuclear forensics library from other States. The national point-of-contact may be an individual or a team and may be same as the national library administrator. The national point-of-contact should have sufficient technical expertise and comprehension to understand the information provided by the national library administrator.

The development of a proposed international directory of States with a national nuclear forensics library facilitates cooperation among governments investigating a transnational nuclear security event (e.g., diversion, illicit movement, or sale of nuclear or other radioactive materials out of regulatory control). Voluntary participation in the proposed international directory of national POCs i) identifies States that maintain a nuclear forensics library and ii) their national administrator who facilitates cooperation between States. The national POC of the national nuclear forensics library would serve as an interface to the national library from outside the State through official channels concerning nuclear and other radioactive materials in the library.

It should be emphasized that a State responding to a query is in no way obligated to share any information from their library, or even the results of a query. Information that might be shared between governments using their national library in the course of nuclear security event may not involve any sensitive or proprietary information contained in the national nuclear forensics library, unless appropriate arrangements are put in place to share sensitive or proprietary information. Even without sharing results, the act of asking another State to query their library has the potential to enhance overall nuclear security.

10. INTERNATIONAL COOPERATION AND NATIONAL NUCLEAR FORENSICS LIBRARIES

The conceptual application of a national nuclear forensics library in a hypothetical nuclear smuggling incident is schematically illustrated in Fig. 6. This process is equally relevant to radioactive material other than nuclear material found out of regulatory control. A State with seized illicit nuclear material conducts its own nuclear forensic analysis or may request analysis from a bi-lateral partner. With the analytical results and using a national nuclear forensics library, master index, and domain expertise, the library administrator determines that the seized material is not consistent with the content of their library. Through official channels, the national POC of the national nuclear forensics library may contact another State with a query about the seized material to determine if the material is consistent with the content of their national nuclear forensics library. If the material is consistent as determined by domain expertise, the two States may choose to work together through official channels to resolve the origin and history of the seized material and address any nuclear security vulnerabilities.

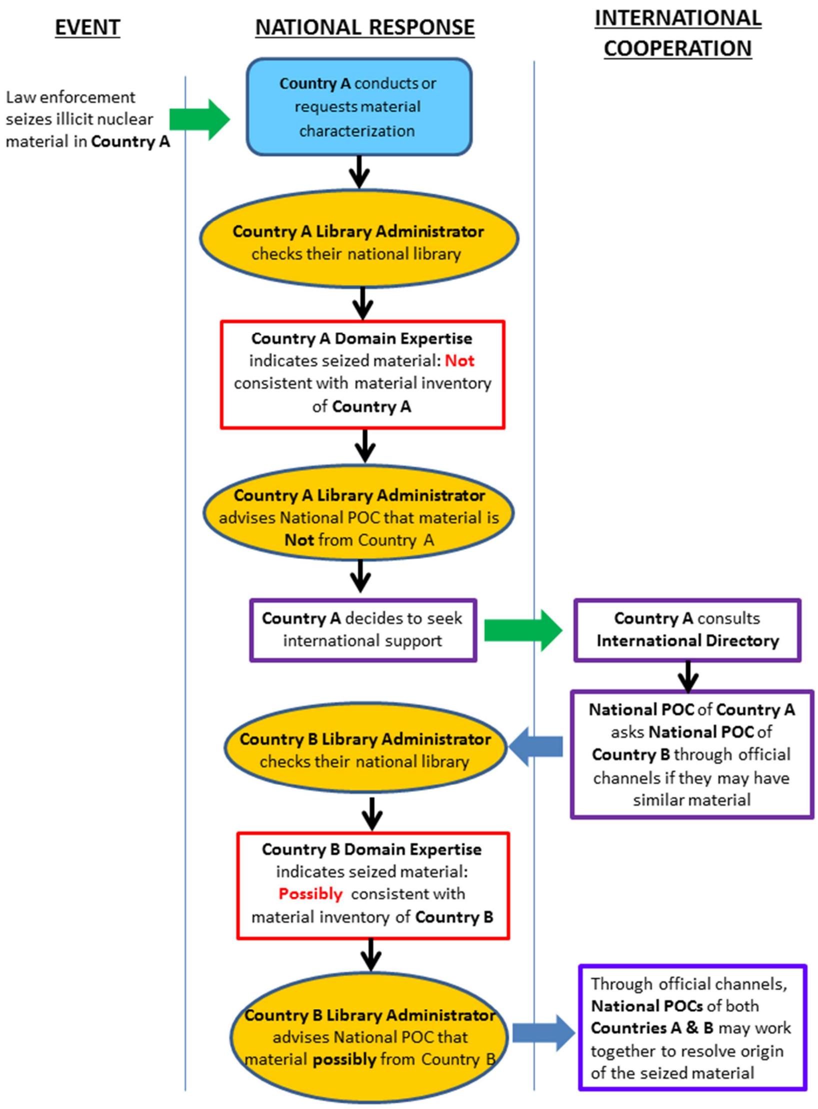


FIG 6. Schematic illustration of the application of a national nuclear forensics library in a hypothetical nuclear smuggling incident. A national nuclear forensics library is used to forensically associate (or exclude) - seized material with State's material holdings and thus refine investigative leads. However, Country A and Country B work through national points of contact for their national nuclear forensics library and do not share the contents of their respective national libraries.

11. INTERNATIONAL OUTREACH AND ASSISTANCE

Security events involving nuclear and other radioactive material are often transnational resulting from legal commerce as well as unauthorized transfers. International security is strengthened through cooperation between States. The IAEA will, on request, assist cooperation between States through programmes of research, technical guidance, outreach and training.

Such cooperation improves the identification of priority signatures, nuclear forensic analysis and interpretation, as well as outreach to promote the value of developing a national nuclear forensic library. The value of a national nuclear forensic library to a State is further enhanced by participation in the proposed international directory of national POCs of a national nuclear forensics library. Such participation enables States to provide and receive assistance in ensuring timely, comprehensive resolution of a nuclear security event.

As noted, a national nuclear forensic library is commensurate with the size and the complexity of a State's nuclear and other radioactivity material holdings. For this reason, data pertaining to material used, produced, or stored within a State may be incomplete relative the data characteristics set forth in Tables 1 through 12. Data gaps will identify which signatures are missing and the need to obtaining missing information. With comprehensive information, States can optimize the library for comparisons to ensure the security of nuclear and other radioactive materials for which they are responsible. The IAEA will assist States, upon request, in outreach and training supporting their development of a national nuclear forensics library.

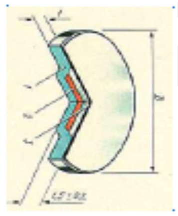
APPENDIX I: HYPOTHETICAL REPRESENTATIONS OF LIBRARY DATA FOR THREE DISTINCT MATERIALS

These hypothetical three library data representations are only a guide of what a subset of a library entry might contain. These data are not the only examples of what an entry in a national nuclear forensics library should include or what the library should look like.

It is likely that entries in a library will include fields appropriate to all categories of nuclear and other radioactive material. The fields will cover both general information and technical information. These hypothetical tables represent subsets of all the fields in library entries.

HYPOTHETICAL LIBRARY DATA SUMMARY: Sr-90 SEALED SOURCE

MATERIAL: Sr-90 Sealed Source	**DATA RECORD DATE**: 18 October 2012
CUSTODIAN/OWNER: **Tropical Medical Research Institute** **4371 Waterfall View Drive** **Rainforest, Iridium Island 20012**	**ANALYTICAL LABORATORY**: Not Applicable; Vendor Data
COUNTRY OF ORIGIN: **Polar Country**	**SUPPLIER**: Polar Commercial RADTECH, Inc. 3001 Nice Ice Lane Glacier Village, Articland, 60032
SHIPPER/CARRIER: **Ship Any Planet, Ltd.; Waybill No. 40512432**	**DATA VETTING**: Vendor Data: Model XZAP90-SR
DATE INFORMATION ACQUIRED: **28 June 2012**	**FINAL DISPOSITION** (if known): Tropical RAD Surplus, Ltd

CHARACTERISTIC	***CHARACTERISTICS—DATA ELEMENT***	***Sr-90 SEALED SOURCE***	***DATA DISCRIMINATOR***
SUPPLIER INFORMATION	**Packaging Type**	Al alloy backing covered with 0.05mm thick Al foil	High
	Drawings / Photographs		
	Description and Dimensions	Active core deposited on Al alloy backing d=143mm x h=1.5mm	
DESCRIPTION OF SOURCE / PACKAGE	**Encapsulation or Cladding**	Active core deposited on Al alloy backing and covered by 0.05mm thick Al foil, d=143mm x h=1.5mm	High
	Serial Number	5C0-(801-218)	
	Radiograph / Photograph	Not Provided	
	Shipping / Receiving History	Ship Any Planet Ltd. Waybill No. 40512432	
PHYSICAL CHARACTERISTICS OF SOURCE	**Activity (Bq)**	8.0E+1 to 2.1E+8 GBq	High
	Reference Date of Activity	31 March 2012	
	Description and dimensions	Diameter of emitting surface 113mm	
	Serial Number	5C0-(801-218)	
	Radiograph / Photograph	Not Provided	
CHEMICAL FORMS	**Compound Name**	$^{90}Sr/^{90}Y$	High
ELEMENT CONCENTRATION	**Element Name**	Strontium / Yttrium	High
	Element Concentration	Not Provided	
	Uncertainty	Not Provided	
ISOTOPES	**Isotope Name**	$^{90}Sr/^{90}Y$	High
	Activity, Uncertainty	Not Provided	

HYPOTHETICAL LIBRARY DATA SUMMARY: HEU PELLET

GENERAL INFORMATION

MATERIAL: Sample A-HEU RR3

DATA RECORD DATE: 18 October 2012

CUSTODIAN/OWNER:
Special Uranium Inc.
7482 Fantasy Dr.
Malibu, Skipper 45045

ANALYTICAL LABORATORY:
Dunlap Lab

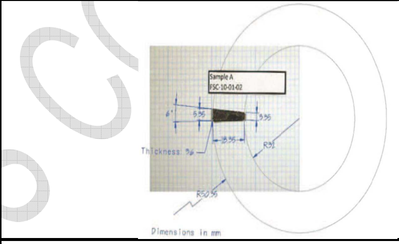
COUNTRY OF ORIGIN:
Cesium Islands

SUPPLIER:
Uran-E-Um, LLC
892 Sell It Dr.
Geomat, Cesium Islands 20012

BATCH ID AND PROCESS DATE:
Hollow Log 1943, 8 April 2003

SHIPPER/CARRIER:
Material Movers, Ltd
Waybill No. V283HG4

DATE INFORMATION ACQUIRED: 25 April 2011

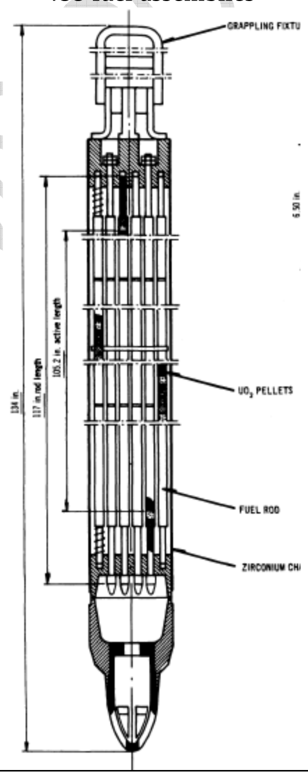
CHARACTERISTIC	*CHARACTERISTICS-DATA ELEMENTS*	*SAMPLE A—HEU RR3*	*DATA DISCRIMINATOR*
PHYSICAL CHARACTERISTICS	• **Rod/ plate/ pellet information**	4.5808-5.0915g	High
	• **Density (g/cm^3)**	No density given for pellet sample, only for angular inclusions	
	• **Surface roughness**	Angular inclusions	
	• **Dimensions of nuclear fuel pellets**	Large cylindrical mass of inner diameter ~32mm (~44mm actual)	
	• **Cladding (material, thickness)**	Not Provided	
	• **Plans/drawing**		
ITEM DESCRIPTION	• **Serial number format**	Hollow Log 1958	High
MORPHOLOGY	• **Grain/particle size**	0.0086 ±0.0035 (mm)	Medium
	• **Shape grains**	Angular, dendritic, cuboidal	
	• **Colour**	metallic silver	
CHEMICAL FORM	• **Compound name**	Highly Enriched Uranium	High
ELEMENTAL CONCENTRATION	• **Element name**	U	Medium
	• **Element concentration**	Total all %U-isotopes, get 100% U in sample , not measured	
	• **Uncertainty**	N/A	

HYPOTHETICAL LIBRARY DATA SUMMARY: HEU PELLET

TRACE ELEMENT CONCENTRATION	• **Trace element name**	Pu, Np, Al, B, C, Ca, Co, Cr, Cu, Er, Fe, Mg, Mn, Mo, Ni, P, Pd, Re, W, Zr	Medium
	• **Trace element concentration (µg/g)**	Pu: 0.0063-0.0081, Al: 10-215, B: 7-10, C: 260-1700, Ca: 3.4-56.2, Co: 0.59-1.74, Cr: 9.99-115, Cu: 8.0-37.3, Er: 0.16-8.23, Fe: 77.8-220, Mg: 0.22-34.9, Mn: 3.78-22.5, Mo: 51-380, Ni: 38-164, P: 10.1, Pd: 0.31-3, Re: 17.5-18, W: 34.2-69, Zr: 1.62-2200, Np-237:4.41-5.5 (µg/g)	
	• **Uncertainty**	Pu: 0.00024-0.0057 (µg/g)	
URANIUM ISOTOPIC COMPOSITION	• **Isotopic ratios (^{238}U in the denominator)**	Ratios not given, % each isotope given 238U: 5.49-6.35, 235U: 92.5-93, 234U: 0.89-1.1, 236U: 0.346-0.3884, 233U: 32.9E-6-0.0006, 232U: 0.1-1.25E-8 (atom %)	High
	• **Isotope abundance uncertainty**	238U: 0.0026-0.5, 235U: 0.004-2.64, 234U: 0.0004-0.09, 236U: 0.00056-0.5, 233U: 4.4E-6-0.0003, 232U: 0.03-0.3E-8 (atom %)	
PROCESS INFORMATION	• **Process type**	Cast on May 22, 2003	High
	• **Date and duration of the process**	3 parent items all briquettes formed from machine turnings (made Hollow log 1943 cast on Apr 8, 2003) + pallet scrap (consolidation item 1046 created Mar 31, 2003)	
	• **Location of processing site**	DOE NNSA Y-12 NSC	

HYPOTHETICAL LIBRARY DATA SUMMARY: NUCLEAR FUEL ASSEMBLY

MATERIAL: LEU Fuel Assembly	**DATA RECORD DATE:** 18 October 2012
BATCH ID AND PROCESS DATE: March 1959	**ANALYTICAL LABORATORY:** Not Applicable, Vendor Data
COUNTRY OF ORIGIN: Articland	**SUPPLIER:** General Electric Co.
CUSTODIAN/OWNER: Electro-Nuclear Inc. Steady Power Avenue Glowin City, Articland 82934	**SHIPPER/CARRIER:** Move Your Fuel, Inc 2930 Transport Lane Star Ice City, Articland 60032
DATA VETTING: Vendor Data: Assembly X320	**DATE INFORMATION ACQUIRED:** Archived Information, March 1959

CHARACTERISTIC	***CHARACTERISTICS — DATA ELEMENTS***	***DRESDEN (USA), MARCH 1959***	***DATA DISCRIMINATOR***
PHYSICAL CHARACTERISTICS	**· Density of fuel pellets**	Not Provided	High
	· Dimensions	0.494 d x0.5 high (in) form segment, 0.563 o.d. x 28 long (in), 4 segments form a rod 117 long (in)	
	· Cladding (material, thickness)	Zircaloy-2, 0.03 (in)	
	· Rod information	6x6 fuel rods in square assembly	
	· Assembly structure (Plans, schematic drawings or photographs)	488 fuel assemblies 	
SERIAL NUMBER	**· Serial number**	Not Provided	High
CHEMICAL FORM	**· Compound name**	UO_2	High
ELEMENT CONCENTRATION	**· Element name**	Not Provided	High
	· Element concentration		
	· Uncertainty		
TRACE ELEMENT CONCENTRATION	**· Trace element name**	Not Provided	Low
	· Trace element concentration		
	· Uncertainty		

HYPOTHETICAL LIBRARY DATA SUMMARY: NUCLEAR FUEL ASSEMBLY

URANIUM ISOTOPIC COMPOSITION	**· Isotope ratios (^{238}U in the denominator)**	Only enrichment given: 1.5% Enriched U-235	High
	· Isotope ratio uncertainty	Not Provided	
PLUTONIUM ISOTOPES FOR MOX FUEL	**· Isotope ratios (^{239}Pu, in the denominator)**	Not Provided	High
	· Isotope ratio uncertainty		
PROCESS INFORMATION	**· Date and duration of the process**	Not Provided	High
	· Location of processing site	General Electric Co.	

APPENDIX II: DESCRIPTION OF UNITS FOR MATERIAL CHARACTERISTICS

Using a standardized set of units for nuclear and radioactive material characteristics in a national nuclear forensics library facilitates rapid comparative analyses. While this standardization will likely entail converting units from those typically used to describe a particular characteristic, the conversion has the advantage of facilitating comparability between all materials in a library. Additionally, if unit conversions are completed prior to entering data into a library, it provides the opportunity to verify conversions are done correctly, and reduces the risks of unit conversion errors during library queries.

The following is a list of recommended units for describing material characteristics in a national nuclear forensics library. Generally, they are SI or CGS units, and were selected for ease of comparing a diverse set of materials from across the fuel cycle and a wide variety of radioactive sources. It is up to each State to decide if these units are appropriate for their library, and in some cases, where a State only has a very limited number of materials; it might be simpler to use alternative units. For example, if a State only mines uranium ore, it might be more appropriate to express uranium concentration in ore in units of g/tonne or g/kg instead of the recommended units of g/g, which are generally more useful for comparing uranium concentrations for materials from the rest of the nuclear fuel cycle.

TABLE II-1. RECOMMENDED UNITS FOR DESCRIBING MATERIAL CHARACTERISTICS IN A NATIONAL NUCLEAR FORENSICS LIBRARY

Characteristic	**Recommended Units**	**Rational**
Elemental Concentrations for Major Constituents	g/g	Generally used for elements with concentrations >0.1% by weight. Alternatively, it can include all elements intended to be a part of a material, for example all of the elements present in a metal alloy. For most fuel cycle materials or large radioactive sources, expressing concentrations in g element / g material works well.
Trace Element Concentrations	µg/g	Generally used for elements with concentrations <0.1% by weight. Alternatively, trace elements are sometimes defined as those elements that are impurities, or elements present in a material but not intentionally added.
Uranium isotopic compositions	Atom ratios: $^{232}U/^{238}U$, $^{233}U/^{238}U$, $^{234}U/^{238}U$, $^{235}U/^{238}U$, $^{236}U/^{238}U$	While uranium isotopic compositions are often expressed as atom percents, mass percents, or even just 235U enrichment level, these units are not ideal for library use. By using ratios, all uranium materials in a library are directly comparable, regardless of how many isotopes were determined in a particular material. If using atom or mass percents, materials with differing numbers of isotopes measured require isotopic compositions to be renormalized based on the sample with the fewest isotopes measured before they can be compared.

Characteristic	Recommended Units	Rational
Plutonium isotopic compositions	Atom ratios: $^{238}Pu/^{239}Pu$, $^{240}Pu/^{239}Pu$, $^{241}Pu/^{239}Pu$, $^{242}Pu/^{239}Pu$,	While plutonium isotopic compositions are often expressed as atom percents, mass percents, these units are not ideal for library use. By using ratios, all plutonium materials in a library are directly comparable, regardless of how many isotopes were determined in a particular material. If using atom or mass percents, materials with differing numbers of isotopes measured require isotopic compositions to be renormalized based on the sample with the fewest isotopes measured before they can be compared.
Density	g/cm^3	Alternately, the SI unit of kg/m^3 would also be appropriate.
Particle size	µm	Depending on the sophistication of the library, this could capture average particle size, or complete histograms of particle size distributions.
Porosity or specific surface area	m^2/g	Typical units for porosity or specific surface area measurements using BET and similar methods.
Carbon stable isotopes	Per mil (‰)	Expressed as $\delta^{13}C$
Nitrogen stable isotopes	Per mil (‰)	Expressed as $\delta^{15}N$
Oxygen stable isotopes	Per mil (‰)	Expressed as $\delta^{15}O$
Strontium stable isotopes	Atom ratio $^{87}Sr/^{86}Sr$	
Lead stable isotopes	Atom ratios $^{208}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, $^{206}Pb/^{204}Pb$,	
Neodymium stable isotopes	ε_{Nd}	
Activity	Bq	Used for radionuclide activity in radioactive sources
Specific activity	Bq/g	The activity of a radionuclide relative to the total mass of the element present (e.g. 50Bq ^{60}Co / g Co). Used to describe the radiochemical purity of radionuclides
Neutron intensity	n/s	Used to express the intensity of neutrons from neutron sources, e.g. ^{252}Cf or $^{241}AmBe$ sources

REFERENCES

1. INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Forensics Support, IAEA Nuclear Security Series No. 2, IAEA, Vienna (2006).
2. INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Security Recommendations on Nuclear and Other Radioactive Material out of Regulatory Control, IAEA Nuclear Security Series No. 15, IAEA, Vienna (2011).
3. JOINT COMMITTEE FOR GUIDES IN METROLOGY, Evaluation of measurement data — Guide to the expression of uncertainty in measurement, JCGM 100-2008 (2008).

DEFINITIONS

batch. A batch is the production of material in discrete runs or lots.

custodian. A custodian is the keeper or steward of the material.

database. A database is a searchable collection of data or information, usually but not necessarily, in an electronic/digital format.

domain expertise. Domain expertise (provided by an individual expert or specialists) assists the library administrator in identifying and organizing information from a specific nuclear fuel cycle stage or isotope production type for radioactive sources. Such expertise will also assist in analysing the information for patterns or trends that enhance a State's ability to determine distinguishing features about its own material holdings.

library administrator. The library administrator may be an individual or a team in a State with access to the domain expertise represented by the national nuclear forensics library enabling routine and comprehensive access to the library contents. The library administrator has overall responsibility for gathering information from relevant organizations, institutes and facilities for inclusion in the national nuclear forensics library.

materials master index. The material master index provides a summary of all information in the library, and can be used by the library administrator to locate specific information and also contact the appropriate technical expert.

morphology (materials science). Morphology is the study of shape, size, texture and phase distribution of physical objects.

national point-of-contact (POC) of a national nuclear forensics library Through official channels the national point-of-contact of the national nuclear forensics library voluntarily receives and replies to requests about information in a national nuclear forensics library from other States.

nuclear material. Nuclear material is defined to by any material that is either special fissionable material or source material as defined in Article XX of the IAEA Statute.

nuclear security event. A nuclear security event is 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. A radioactive material is any material designated in national law, regulation, or by regulatory body as being subject to regulatory control because of its radioactivity.

radiochronometry. Radiochronometry is the use of radioactive decay to determine the time since the last separation of progenies from the "parent" material (and thus, the "age").

seized material. Seized material is material encountered outside of regulatory control that is now under the control of the competent authorities.

signature. A signature is 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.