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DEVELOPING A NUCLEAR FORENSICS LIBRARY IN UKRAINE: CURRENT STATUS AND LESSONS LEARNED

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ABSTRACT

The Institute for Nuclear Research of the National Academy of Sciences of Ukraine developed a pilot nuclear forensic database in cooperation with LLNL/Department of Energy NA-242 and with support from the US Department of State (STCU Partner Projects P459). Ukraine plans to use this database as a component of a national nuclear forensic database as well as an on-line point of contact for any authorized representatives involved in countermeasures when nuclear and other radioactive materials are found out of regulatory control.

User needs are the main priority of the INR database development team. Rather than adapting existing standard database models (relational) to the needs of Ukraine, the INR team is leveraging the extensive database and interface experience of the project team to develop a database design satisfying user needs. This requires developing a database structure that is flexible to allow for multiple user interfaces and that may also incorporate diverse data sets.

Based on our approach to database development, we have constructed database core layers that are general with the goal of not modifying the core structure throughout the life cycle of the information system. Moreover, by not following a standard relational database model, we hope to eliminate limitations that are necessary when data are grouped into object categories and/or object attribute lists, or when data are reported with different units and physical values. The main structure of the INR database stores all objects in a single table, and composite names are defined to make relations between objects and to form links between objects and their attributes.

Tests of the pilot database are carried out by various user groups: INR experts; representatives from State Border Guard Service of Ukraine and State Nuclear Regulatory Inspectorate. Initial testing suggests that the database format is robust and that the main structure of core layers will not require modification for both present and future tasks.

Further improvements to database development will include: multilingual capabilities; graphical information representation to make data more user-friendly; development of a Web-interface with simplified methods to use the database - especially for less-trained users; developing statistical analysis tools for attributive data.

INTRODUCTION

To characterize an unknown nuclear or other radioactive material (NRM), the material is analyzed to establish nuclear forensic signatures. Nuclear forensic signatures are the attributive data, or set of characteristics, of a given sample of NRM that enable the sample to be distinguished [1]. Forensic signatures are then used for nuclear forensic interpretation, which involves the comparison of analytical data collected from the unknown NRM to existing information and to prior forensic cases involving similar material [2]. Unlike traditional

fingerprint analysis, it is impractical for nuclear forensics to rely on sample-to-sample matching. However, using a combination of signatures obtained by different analytical techniques has the potential to provide increased confidence in associating a specific unknown sample with known classes of similar material.

One of the most efficient methods for interpreting analytical data from nuclear interdictions is the existence of a reference database and materials library. Before the development of the INR database described here, within Ukraine databases existed containing NRM information. For example, existing databases within Ukraine include: Database of Nuclear Material Accounting and Control; National Register of Source of Ionizing Radiation; Ukrainian Division of IAEA ITDB (Incident and Trafficking Database). However, the main objective of these databases is accounting and control of NRM. Therefore, these databases were not designed for comparative nuclear forensic analyses and their information content is very limited. The INR database for nuclear forensics in Ukraine is being developed to serve as a resource of NRM information to which nuclear forensic samples may be compared.

The INR database will consist of information and data from open sources related to nuclear fuel cycle processes and radioactive source manufacturing as well as existing published NRM data and data from archived Ukrainian NRM samples. We hope that the INR database will be implemented within a future larger structure of a Ukrainian National Nuclear Forensics Database (NNFD) as an on-line resource to support the efforts of an NNFD administrator and nuclear forensic experts.

To ensure the usability of the developed database at INR, the main priority for the INR development team has been user needs. INR has defined a database "user" as any authorized representative of the Ukrainian organizations, which, in accordance with Decree of Cabinet of Ministers of Ukraine No. 813 as for June 02, 2003 [3], are involved in countermeasures when nuclear and other radioactive materials are found out of regulatory control. One of the primary user suggestions was to develop an on-line information system. By establishing on-line access to the INR database, the database can play a significant role as an access point for the exchange of knowledge between experts and first responder groups in the case of a radiological event. To avoid any issues concerning the management of sensitive data in an on-line information system, only open-source data are used for the developed pilot INR database.

DATA MODEL AND DATABASE STRUCTURE

The characterization of NRM consists of physical, chemical, and elemental characterization as well as isotopic measurements and other analyses that vary based on material type. Examples of information that forms nuclear forensic signatures of NRM are: macroscopic parameters (dimensions); morphology; particle size and size distribution; grain size and size distribution; porosity size distribution and density; elemental composition; isotopic composition, etc. To obtain signatures of NRM many different analytic techniques have to be applied [1]. For example techniques may include high-resolution gamma-spectrometry (HRGS), inductively coupled plasma mass spectrometry (ICP-MS), X-ray diffraction, scanning electron microscopy (SEM), thermal ionization mass spectrometry (TIMS), secondary ion mass spectrometry (SIMS), gas chromatography mass spectrometry, XRF spectrometry, alpha spectrometry, and others. Data collected on a sample from this vast list of analytical techniques are generally classified as "attributive data" for the INR database. Having a large amount of attributive data stored in the INR database is useful for comparative analysis between an unknown sample and known materials.

When a nuclear forensics expert extracts a set of attributive data from the INR database this data may have been obtained from a variety of different sources. The user may, therefore, want to request additional information about the types of techniques used to collect the data or about the laboratory or organization that conducted the analyses. This type of information is included in the INR database model (shown below in Figure 1) as metadata. Metadata allow an expert to quickly and easily obtain required information that supplements attributive data. Using Metadata enables an expert to analyze the attributive values obtained for specific material and their dependence on the methods used to collect the data and the laboratories involved in data collection. This type of analysis allows the expert to determine the most reliable data.

The data model that has been developed for the INR database is conceptually divided into two main parts: 1) the core elements (object and attributive data), and 2) metadata that describe the object and attributive data (Figure 1). In the data model, we use the term "object" in the broad sense as "a named thing" that has a set of attributes.

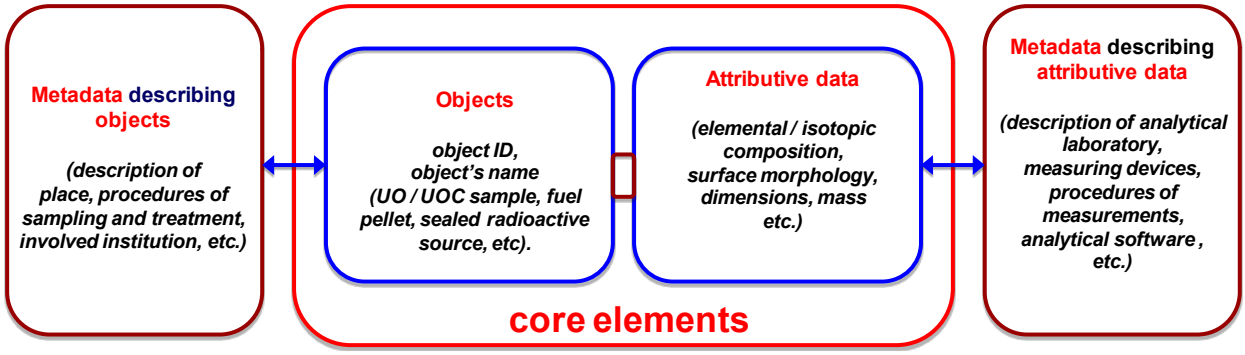

Figure 1. The data model for the INR database.

In the INR database data model, the design allows the divisions of object, attributive data and metadata to be flexible and represent a conditional partition. For example, in the case of a radiological event with a sealed radioactive source in a shielding container detected out of the regulatory control, the "shielding container", "sealed radioactive source" and "radiological event" can be classified as objects, attributive data or metadata depending on the expert's needs.

In addition to the data model, the INR database has a defined structure that is divided into the three separate layers (Figure 2).

The layers of the database structure are:
1) System layer. The system layer includes tables that contain information about: users and user groups; user profiles; access rights for different users or user groups; log of data entry and modification, etc.
2) Target data layer. The target data layer includes a set of related tables, which contain information about objects, their attributive data and metadata.
3) View, control and interface layer. The interface layer includes: tables derived from the target data layer; views; and templates. The contents of the interface layer can be used to create a more user-friendly representation of information, for the simplification of database queries, visualization of query results and for other user needs.

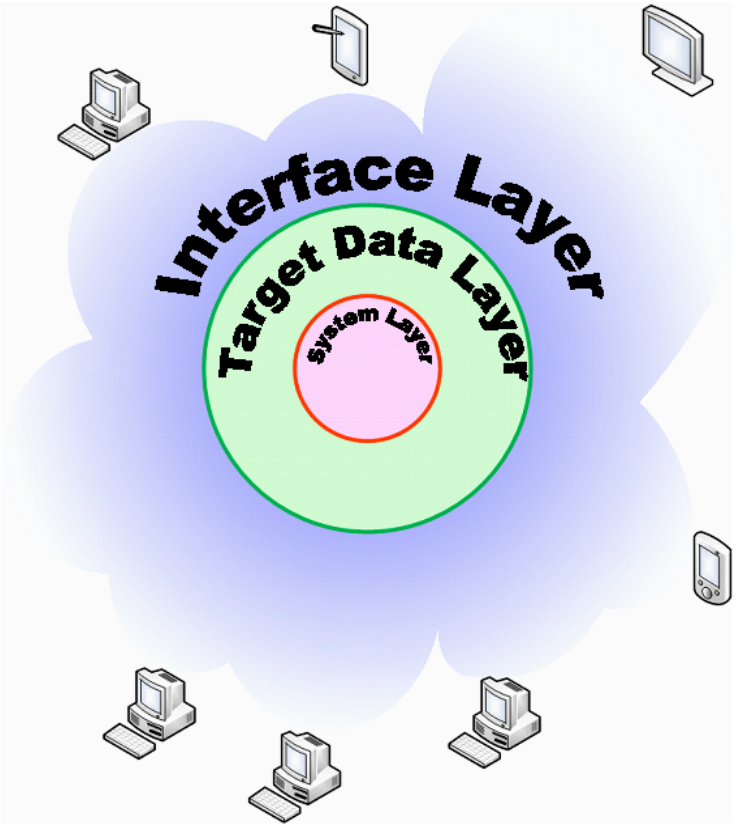

Figure 2. INR database structure.

The system and the target data layers form the core of the INR database structure. The structure of tables and their relationships within the core is designed in such a way that in the future, no alteration of the database structure will be required even if INR or Ukraine organizations need to significantly expand the list of object categories and their attributes. In addition, the core layers of the database structure remain separate from the interface layer - the tables within the core layers do not reference records in the tables of the interface layer. This isolation of the interface layer allows database experts to continuously develop the interface layer in order to satisfy growing user needs without the changing the core layers.

The INR database was developed based on the relational model of data [4]. However, INR staff members have developed modifications to the traditional relational database design, which we predict will enable the INR database to be used to solve both present and future tasks without considerable structure modifications. The traditional approach to database design gives each type of object described in a database its own table [5]. Tables in a nuclear forensic database may include a table of uranium ore and uranium ore concentrates, a table of fresh nuclear fuel materials, a table of sealed radioactive sources, a table of organizations, and many other tables. Each table contains rows representing the instances of those types of objects and columns representing values attributed to each instance. Each row in a table has its own unique key that allows for rows in one table to be linked to rows in other tables [4]. Due to the simplicity and the ability for non-database experts to understand this design, such an approach is very popular. However, if a user needs to extend the types of objects and/or change a list of columns (an attribute or a parameter of objects) the user is faced with the need to significantly rebuild the database table structure, queries, screen forms, and other components. To avoid this need for significant rebuilding of the database in the future, the INR database is designed such that all

objects are stored in a single table that contains only three main columns (fields): object id (unique, long integer, auto increment); short name (unique, string, 64 symbols); and full name (unique, string 255 symbols). This main table (Table Obj in Figure 3) is linked by many-to-many relationships with four different types of attributive data tables: 1) data of digital type, 2) data of string type, 3) data of memo type (text), and 4) data of URL type. All four tables also have a simple structure and contain two main columns (fields): value id (unique, long integer, auto increment); and value of the corresponding type. The table for digital data also has fields that contain information concerning the date of determination, type of uncertainties, and units of measurements.

A fifth table, that is the same Table Obj or, more correct, an "alias" of the Table Obj exists within the database and enables the flexibility described above for a user (expert) to divide object, attributive data and metadata based on user needs. Many-to-many relationships in the database are implemented via a junction table, also called a cross-reference table [4]. All five cross-reference tables have only three main fields: 1) identifier (id) of objects, 2) id of the composite name of an attribute/relationship, and 3) id of an attribute value. In the case of fifth cross-reference table, that links Table Obj with its alias, another object is used as attributive data for a studied object. Using this fifth table makes it possible to organize objects in hierarchical structures and to establish the various relationships between objects that belong to different categories.

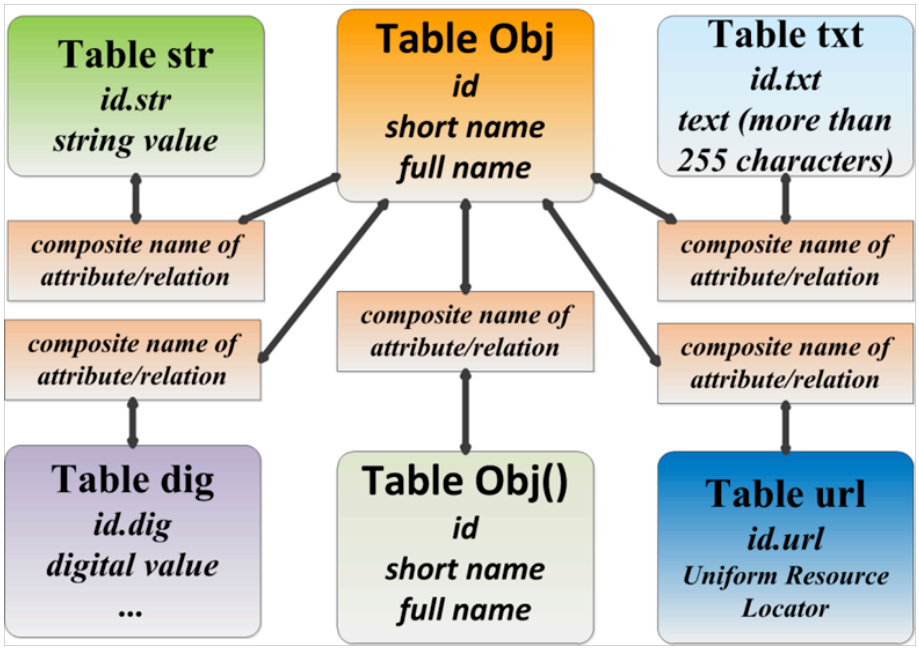

Figure 3. Basic scheme of relationships between the main tables of the INR database.

The structure of the INR database core tables gives INR users the ability to develop sets of queries, form views, reports, and perform other functions. Because of this structure, these tasks should not require modification during an extensive period of database use. Moreover, a user (expert with appropriate permissions) can (without any support of technical staff) extend the types of objects or the list of object attributes within the database.

COMPOSITE NAMING OF ATTRIBUTES AND OBJECT RELATIONSHIPS

In order to systematize objects, organize a hierarchy of structures, and establish different relationships between objects and their attributive data we proposed and implemented the concept of composite names for attributes and relationships. Composite names are composed from *primary* and the *secondary* parts described below.

The primary part of a composite name can be described as the part that identifies the type of relationship. For example, the primary part "is a" indicates a hierarchical relationship between objects that belong to the same category or class. Whereas, the primary part "mass fraction" is a digital attribute of an object, that indicates the ratio of the mass of one substance (element, isotope) to the mass of the total mixture (matrix). In the latter case, we can connect a list of the dimensions of physical quantity to the primary part. For example, for mass fraction it may be mg/kg, ppm, ppb, or percent.

The secondary part of a composite name refines the meaning of the composite name. In the case of hierarchical primary part "is a" described above, the secondary part would then define the type of hierarchical relationship. An example of a secondary part joined to “is a” may be, "subclass", "part", or "instance". For the primary part "mass fraction" the secondary part may define, for example, the name of isotope or element.

To compose the primary and secondary components of a composite name, we use the objects that were entered into the main Table Obj. This helps us guarantee the uniqueness of the composite name of an attribute or object's relationship. In addition, a user can clarify the meaning of a composite name by studying the descriptions and attributive data for objects, which form both primary and secondary parts of the composite names. The implemented method of composite naming simplifies the extension of an object's class and the introduction of new object attributes. To advance the database, we developed tools for the automatically selection of units for physical values for the specific primary part of an attribute composite name. Because of this, all digital values can be automatically recalculated to SI units or a different user-preferred system of units. This advancement significantly simplifies the data entry process and decreases the likelihood for operator errors.

DOMAIN EXPERTS, USER RIGHTS, AND ACCESS PROTECTION

In the organization structure of the INR database users or operators who are involved in the processing of data, domain experts play the principal role [5]. A domain expert is a selected expert with experience and knowledge in a certain domain of nuclear forensic expertise - for example, sealed radioactive sources. The domain expert determines which objects and which object attributes are relevant and therefore should be included in the nuclear forensics database. The expert also creates a hierarchy of corresponding objects and selects the sources of information that should be included in the database. Domain experts, as heads of appropriate user groups, help the main database administrator with the organization of the system of user rights and the also help to support the integrity and security of the database.

The overall INR database system security is generally composed of the host system (server-side) security and the security of provided services (client-side). The host system security is provided by the network filter, which allows access only for clients with a specified IP and MAC address. Access to the server is carried out via an encrypted channel (ssh connection, https protocol). The INR database system security is also ensured by group policy. An access control list (usually a table) represents a list of group permissions to the system resources. In addition, permissions for

user groups and other users can be set for each record. To prevent a case in which a change to the executable modules of the database takes place resulting from actions beyond a user's approved rights, the access control list table also contains a digital signature for executable modules. This preserves the INR database integrity and serves as a control against the possibility of a backdoor intrusion. When the module is executed, its digital signature is checked. If the stored value of the previously computed checksum does not match the computed checksum for the current data input, that module is considered to be corrupted and cannot be executed.

ENTERING AND RETRIEVING DATA

Data contained within the INR database are stored and accessed through a client - server architecture. The architecture that was chosen for the web server is similar to the common open source server architecture, LAMP. The acronym "LAMP" refers to a solution stack of software that is used to run dynamic Web sites or servers. This software is usually open-source and free to the public. The original software stack expansion is as follows: Linux (the operating system), Apache (the Web server), My SQL (the database management system), PHP (the scripting language).

The client portion of the client-server system will be based on standard Internet browsers (FireFox, Safari, Opera, Google Chrome) and does not require any special software from remote users. A user can use practically all internet-connected devices (smart-phones, laptops, etc.) in conjunction with the database, and the user also will be able to select his or her preferable languages for the interface and contents of the database, the skin of Web-interface, and other database functions or components.

The goal of the construction of the INR database is to provide flexibility within the data organization. However, the result of including flexibility is that increased staff effort is required for the time-consuming process of analyzing and systematizing data during the stage of data entry into the INR database. We note that our approach for data storage not only forms links between objects and their attributive data, but also constructs links that describe "where", "when", "by whom" and "how" these data were obtained. To limit the amount of staff effort required for data entry, INR has developed a special procedure with the working name, "cloning with mutation". This procedure consists of the following: the user selects an object that is most compatible with the new object to be entered. The "cloning with mutation" script is used providing the user with a new object with the attributes, relationships and metadata, which the original object within the database had previously. In such manner, the user obtains a preprinted form, and then the form can be rapidly changed and adapted to user's needs without any developer effort. The user should only amend and save new entries. Tests of the "cloning with mutation" technique show significant simplification of the data entry process (especially in the case of bulk data entry with a regular structure) and a decrease in the probability of data entry errors. This procedure also simplifies the organization of a standard form for data entry in a case where the attributive data should be entered in the specific order.

During the development of the pilot INR nuclear forensics database, the majority of effort was spent developing procedures for object and attributive data systematization as well as data entry and storage. In addition to this effort, we also developed a set of tools to query the data and present retrieval data in forms that the user can use for statistical analysis of the data. One such tool developed is the "Table Wizard". The Table Wizard can be used to select a specific set of objects, for example: uranium ore concentrates (UOC) or sealed radioactive sources (SRS) with a specified range of attributive data. Once the data are retrieved, the Table Wizard presents the data in table form. Users can then export the retrieved data to CSV files for further statistical

analysis using programs not contained within the INR database itself. These functions of the Ukraine nuclear forensic database allow nuclear forensic experts quick access to data needed for forensic applications.

TESTING AND LESSONS LEARNED

Testing of the INR database was directed towards examining the following: durability and stability of the server-client configuration; SQL-query performance; PHP-script performance; the suitability of the configuration for data storage and retrieval; compliance of the developed interface and data content with user needs.

Local authorized users (the INR nuclear forensic experts) are continually testing the INR database system on regular basis. Feedback from this authorized user testing as well as from other organizations was obtained during meetings between INR staff and representatives from: the State Nuclear Regulation Inspectorate of Ukraine; the training course for representatives from State Border Guard Service of Ukraine (Training Course for Response Forces on the Use of Equipment for Detection of Nuclear and Radioactive Material, 22-26 December 2014, GKTC, INR, Kyiv); representatives of authorized organizations from Ukraine, Moldova, Azerbaijan, Georgia and Armenia (in the frame of STCU project P460).

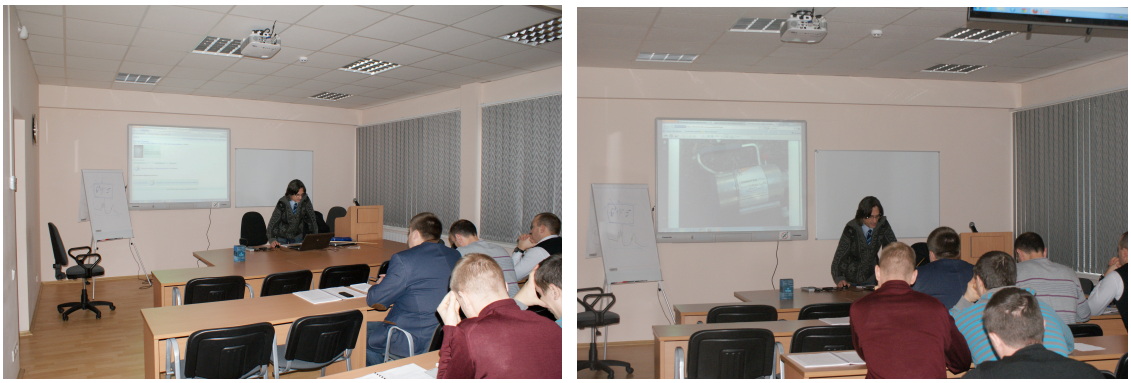

Figure 4. Testing of the INR database during the Training Course for Response Forces INR, Kyiv, 22-26 December 2014.

Database testing showed that the basic approaches to the development of a database structure, to the arrangement of the Web interface, as well as tools for database protection from unauthorized access were quite robust. The database contains the function of entering physical values in the original system of units measured with a subsequent recalculation of units into other unit systems. This function was also tested and received positive feedback from users and operators of the INR database. Analysis of user feedback demonstrated the ability to facilitate data entry process due to the implementation of the procedure "cloning with mutation" and the automatic recalculation of values to the selected system of dimension of physical quantity.

CONCLUSIONS

At present, the INR database contains open-source attributive data for different nuclear and other radioactive materials. Examples of data included in the INR database are fuel elements for research and power nuclear reactors, uranium ores and UOC, sealed radioactive sources, Chornobyl "hot" particles and soil samples. In addition, the database contains large amounts of different related information. For example, information about radiological events when nuclear or other radioactive materials have been found out of the regulatory control in stored within the

database. Further improvements to database development will include: multilingual capabilities; graphical information representation to make data more user-friendly; development of a Web-interface with simplified methods to use the database - especially for less-trained users; developing statistical analysis tools for attributive data.

The preliminary discussions with the representatives of authorized organizations from GUAM region (Georgia, Ukraine, Moldova and Azerbaijan) have shown that the INR database can be considered as a starting basis to develop a regional on-line information resource to support nuclear forensics investigations, improve communication between national expert groups and facilitating of joint efforts to prevent incidents of NRM illicit trafficking.

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