ENVIRONMENT PROTECTION

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URANIUM DEPOSITS DATABASE FOR THE PURPOSE OF NUCLEAR FORENSICS IN UKRAINE

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Abstract. *The problem of illicit trafficking of nuclear materials is reviewed. The IAEA statistical data on nuclear material trafficking for the period from 1993 to 2012 are analyzed. Uranium ores from operating deposits in Ukraine are examined taking into account their attributes and features for the purpose of nuclear forensics.*

Keywords: identification features; illicit trafficking; nuclear forensics; radioactive materials; uranium ore.

1. Introduction

Nuclear forensics is the analysis of nuclear or radioactive material and any associated information to determine the history of the sample material. Nuclear forensic analysis includes sample characterization, interpretation of data and event reconstruction and attribution [6].

Nuclear forensics was developed in the early 1990s when the first cases of illicit trafficking of nuclear materials were being reported. It is becoming an increasingly important tool in the fight against illegal smuggling and trafficking of radioactive and nuclear materials, including radiological materials intended for industrial and medical use, nuclear materials such as those produced in the nuclear fuel cycle, and much more dangerous weapons-usable nuclear materials (plutonium and highly enriched uranium). A major focus of nuclear forensics is identifying the physical, chemical, and isotopic characteristics that distinguish one nuclear or radiological material from another. These signatures enable researchers to identify the processes used to initially create a material [4].

Databases and knowledge management systems are needed to support nuclear forensics. This effort has begun to be developed but needs systematic additional support. For example, the joint report of the Nuclear Forensics working group [5] mentioned that the DOE has created a database containing information about uranium compounds (U ores, U ore concentrates, etc.), including trace element concentrations, isotopic compositions of uranium and other elements, and other descriptive parameters. Various other groups also hold substantial data, but the consolidation of these data into an accessible nuclear forensics database has not taken place and the tools to utilize the database have not been developed. Developing the desired database will require significant cooperation with foreign governments and corporations. Different open-source data resources have been used to compile a history of the malevolent use of radioisotopes, including a Global Chronology of Incidents of Chemical, Biological, Radioactive and Nuclear Attacks as of 1950–2005 [1]. All of these incidents were evaluated using several specific criteria such as specific material characteristics and the perpetrator's intent for the radioactive material.

Globally, there are a lot of places where radioactive materials that have passed through the nuclear cycle are produced, used, and stored. Ukraine has the most uranium ore resources in Europe and has accumulated a lot radioactive materials and wastes from the Chernobyl catastrophe and from uranium production (tailings, technological facilities, dumps) associated with the former USSR. This inventory of radioactive materials presents a real risk, and it is necessary to be able to identify radioactive materials (composition, origin, and place of extraction or production) for nuclear forensics.

2. Illicit trafficking of radioactive materials

Given the availability of transit routes and Ukraine's nuclear industry, as well as the numerous applications for radioactive sources inside the country, combating illicit trafficking of radioactive materials is a very important task that both Ukraine and its partners have focused on over the past decade.

The International Atomic Energy Agency (IAEA) Incident and Trafficking Database (ITDB) is a unique asset that assists the IAEA, participating States (120 countries as of 31 December 2012, including Ukraine) and selected international organizations in improving nuclear security. The ITDB System was established in 1995 to record and analyse incidents of illicit trafficking in nuclear and other radioactive materials. It accounts for all incidents in which nuclear and other radioactive material is out of regulatory control. The ITDB scope covers all types of nuclear material as defined by the Statute of the Agency (i.e., uranium, plutonium and thorium), naturally occurring and artificially produced radioisotopes, and radioactively contaminated material, such as scrap metal. States are also encouraged to report incidents involving scams or hoaxes where material is purported to be nuclear or otherwise radioactive.

As of 31 December 2012, the ITDB contained a total of 2331 confirmed incidents reported by participating States. Incidents may be categorized in more than one group: for example, the theft and subsequent attempted sale of a radioactive source. Therefore the sum of the incidents in the groups is greater than the total number of incidents. Of the 2331 confirmed incidents, 419 incidents involved unauthorized possession and related criminal activities (Fig. 1), 615 incidents involved reported theft or loss (Fig. 2) and 1244 incidents involved other unauthorized activities and events (Fig. 3). In the remaining 69 cases, the reported information was not sufficient to determine the category of incident [3].

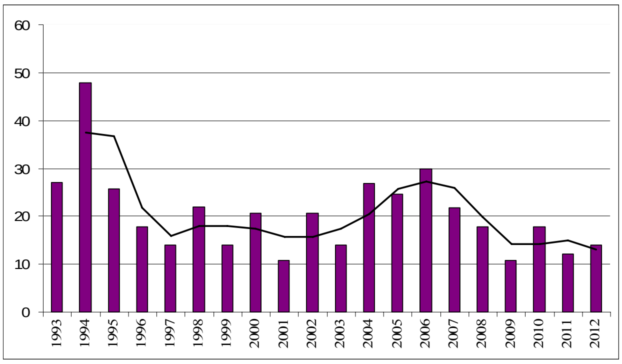

Fig. 1. Unauthorized possession and related criminal activities reported to the ITDB,1993-2012

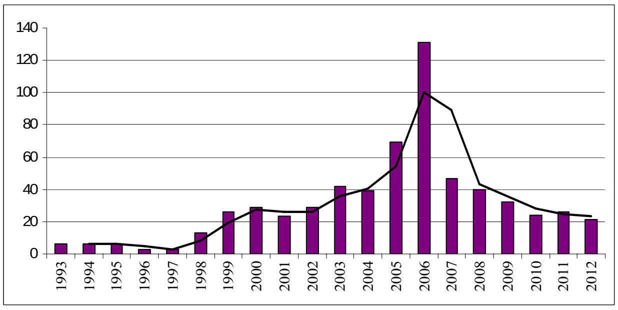

Fig. 2. Incidents reported to the ITDB involving theft or loss, 1993-2012

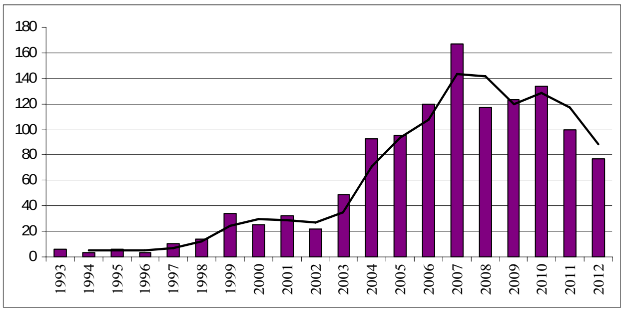

Fig. 3. Other unauthorized activities and events reported to the ITDB, 1993-2012

In the case of radioactive, non-nuclear material, trafficking is made possible by their ready availability. There are also weaknesses in the accountancy of radioactive sources and in the chain of regulation and control in the movement of these materials from their countries of origin, through their transportation routes and transhipment hubs, to the countries of receipt.

2.2. World Distribution of Uranium Deposits

Determining the origin of the radioactive material is one of the objectives of nuclear forensics. Uranium deposits are considered potentially dangerous nuclear facilities and potential sources of illegal radioactive material trafficking. Therefore, a uranium deposit database is very important for nuclear forensics as well as providing information on the global distribution of uranium resources. The World Distribution of Uranium Deposits (UDEPO) with Uranium Deposits Classification was published by the IAEA in 2009. The UDEPO includes classification of global uranium deposits, technical information, and detailed geological information about regions, districts and deposits.

As of 2012, there were 1520 reported uranium deposits worldwide. The information contained in the database can be useful for determining the origin of uranium ores. UDEPO can be divided into general (Fig. 4), technical (Fig. 5) and geological information (Fig. 6).

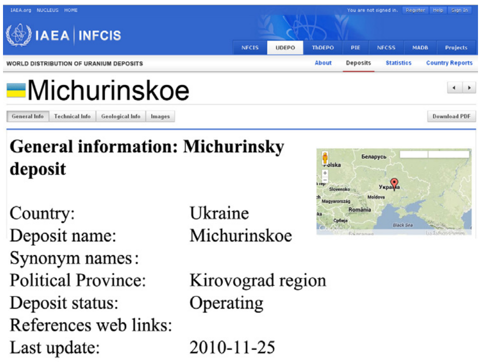

Fig. 4. UDEPO: General information

The UDEPO database can be used to determine the identifying features of uranium ores from different deposits, including data on their geological location, structural features, host rocks, mineralization, and ore mineral composition. This database mentions uranium deposits located in Ukraine but does not contain any specific information. As a result, the Scientific and Technical Centre of Ukraine (STCU) has initiated research on uranium ore from the operating deposits in Ukraine to identify features useful for nuclear forensics.

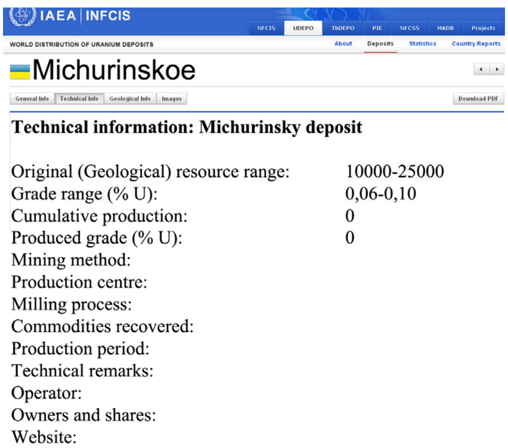

Fig. 5. UDEPO: Technical information

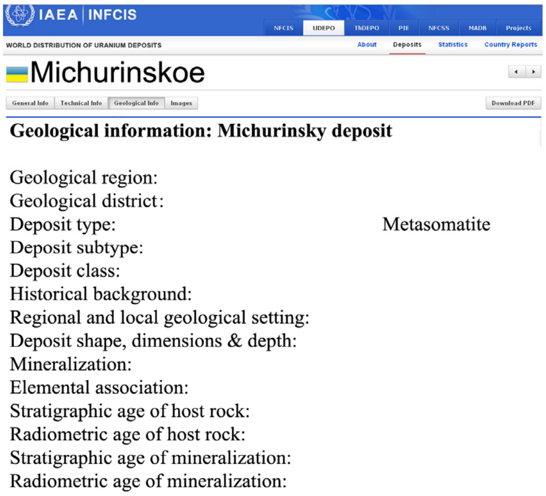

Fig. 6. UDEPO: Geological information

3. Nuclear Forensics steps in Ukraine

Uranium ores from three operating deposits, Michurins'ke, Central, and Vatutins'ke, were studied to identify specific characteristics relating uranium ore concentrates to their place of origin. Ore samples contain specific characteristics of uranium ore concentrates that can link the concentrates to their place of origin. This information is an important component of the Ukrainian database on uranium materials.

The deposits are genetically connected with the processes of ultra metamorphism of uranium-containing rocks. Post ultra-metamorphic solutions penetrated along long-lived fault zones and led to sodium metasomatism and ore formation in albitites. Uranium was transferred in hydrothermal solutions in the form of uranyl-sodium-carbonate or uranyl-potassium-carbonate ions (complexes). Diaphthorites (syenite-like desilicated rocks) were formed as a product of incomplete sodium metasomatism and are mainly contaminated with uranium and do not contain commercial ore mineralization [2, 7].

The primary rocks are different for each deposit. The ore-containing metasomatites that formed on the source rocks inherited their structural and textural peculiarities, percentage of dark colored minerals, etc. The ores from the Michurins'ke and Vatutins'ke deposits consist of apogranite, apomigmatite, and apogneiss albitites of Paleoproterozoic age. Apogneiss albitites are different from the first two types by higher content (up to 25-35%) of dark colored minerals. The ores from the Central deposit are represented by the only apogranitoid albitites, including albitites formed on fine-grained leucocratic and melanocratic aplite-like granites of the Lelekivs'ka suite.

Structural control of mineralization is obvious for each deposit and connected with correspondent faults in the tectonic and metasomatic zones.

The primary differences in composition between the three ore deposits included the sooty uranium content (a mixture of black microaggregate minerals), uranophane and primary U-silicates (coffinite and nenadkevite), as well as the occurrence of brannerite, a U-titanate mineral. The major commercial phases observed in the Michurins'ke deposit ores were sooty uranium and uranophane. The primary silicate mineral was nenadkevite, a mixture of boltwoodite and uraninite. The primary oxide mineral was uraninite. Uranium titanites, including brannerite and davidite, made up approximately 4% of the ore. Major non-metallic minerals included albite (up to 75-90%), aegirine, chlorite, phlogopite, riebeckite, and epidote. The major commercial minerals of the Central deposit were brannerite, oxidized or completely altered brannerite with leucoxene-like products, and uraninite. The major non-metallic minerals were albite, phlogopite, chlorite, and carbonate. More rarely, aegirine, riebeckite, epidote, and sometimes hematite were observed. The major commercial phases of the Vatutins'ke deposit were uraninite, beta-uranophane, and a mixture of sooty uranium and nenadkevite. The major non-metallic mineral was albite. Secondary non-metallic minerals included chlorite, riebeckite, aegirine, hematite, carbonate, and epidote.

Our observations and those found in [2, 7] confirmed that aegirine, riebeckite, chlorite, and epidote were widespread among the dark colored minerals from the Michurins'ke deposit, while phlogopite was more typical for the ore albitites from the Central deposit. Uranium oxides and nenadkevite were typical for the ores from the Michurins'ke deposit. These minerals rarely appeared in the Central deposit where brannerite was commonly found. In contrast, the Vatutins'ke deposit ores were fine-grained albitites formed on metasomatic orthogneisses. Radiometric counting data was collected for select isotopes from ores at the SE "Vostgok" laboratory (Table 1).

Table 1: Average activities in representative uranium ore samples (Ci/kg)

Deposit	$^{226}Ra \times 10^{-7}$	$^{230}Th \times 10^{-7}$	$^{210}Pb \times 10^{-7}$	$^{210}Po \times 10^{-7}$	$U_b/10^{-7}$	Ci/kg
Michurins'ke	3,88	3,04	4,37	3,62	81,56	5,44
Central	2,94	1,85	3,17	2,13	5,78	3,91
Vatutins'ke	10,47	8,72	11,04	9,38	225,00	15,19

These data showed that the ores of the Vatutins'ke deposit had high Ra, Th, Pb, Po and U contents compared to the Central and Michurins'ke deposit ores, which had 2-10 times lower contents of these elements.

4. Conclusion

The development of information technologies has promoted the creation and improvement of specialized databases that provide information about the location, quantity and quality of mineral resources and their current associated components, as well as the geological, hydrogeological, mining, economic and other characteristics of the mineral resources in the country. It is important to create databases to document the origin, movement, and storage of radioactive and nuclear materials. The ability to identify characteristic features of these materials is critical for any country that deals with radioactive and nuclear materials in its territory.

The study of ore samples from operating uranium deposits is considered a starting point for the identification of specific uranium ore characteristics that are indicative of their place of origin. This allows for the identification of nuclear material sources and helps to prevent their unlawful spread.

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В статі розглянуто проблему несанкціонованого обігу ядерних матеріалів. Проаналізовано статистичні дані МАГАТЕ щодо обігу ядерних матеріалів в світі за період з 1993 по 2012 рр. Проаналізовано уранові руди з діючих родовищ України з точки зору їхніх атрибутивних ознак для ідентифікації ядерних матеріалів для завдань ядерної криміналістики.

Ключові слова: ідентифікаційні ознаки; несанкціонований обіг; уранові руди; радіоактивні матеріали; ядерна криміналістика.

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Рассмотрена проблема несанкционированного обращения ядерных материалов. Проанализированы статистические данные МАГАТЭ по обороту ядерных материалов в мире за период с 1993 по 2012 гг. Проанализированы урановые руды из действующих месторождений Украины с точки зрения их атрибутивных признаков для идентификации ядерных материалов для задач ядерной криминалистики.

Ключевые слова: идентификационные признаки; несанкционированный оборот; урановые руды; радиоактивные материалы; ядерная криминалистика.

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