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Developing Nuclear Forensics Signatures and National Nuclear Forensics Libraries for the African Continent: A Case Review for South Africa

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Abstract

Nuclear terrorism has led to the development of National Nuclear Forensics Libraries (NNFL) from signatures by each Member State of the International Atomic Energy Agency (IAEA). The objective of this Review is to highlight the need for Africa States especially South Africa to set-up their own Nuclear Forensic Laboratories that will apply available techniques to develop NNFL for their nuclear material. An overview of some applicable techniques is given as well as a few demonstrative results.

Keywords: Uranium products; Nuclear terrorism; Nuclear forensics signatures; Nuclear forensics libraries; ICP-MS; LA-ICP-MS; Gamma spectrometry

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Introduction

Many countries in Africa have resources such as gold, uranium, coal and gas, not to mention the agricultural land. While most of these countries are capable of utilizing these resources to the benefit of their citizens, it is not so with uranium deposits. Most African countries export the uranium for further processing into fuel for the nuclear reactor. Namibia has (42 uranium Mines), Nigeria (2), Egypt (5), Algeria (6), Chad (1), Botswana (9), Cameroon (2), DRC (9), Malawi (3), Central African Republic (5), Tunisia (1), Senegal (10), Zambia (10), Tanzania (10), South Africa (71) and Zimbabwe (1) [1]. All these countries have to observe the Non-Proliferation Treaty [2,3] which aims at safeguarding nuclear material and prevent nuclear terrorism due to illicit trafficking of the material. South Africa has around 71 uranium mines mainly located on the Witwatersrand Supergroup [4] **(Figure 1)** where a lot of gold/uranium mining has been going on for over 130 years [5]. Before September 1991 South Africa was capable of processing and enriching its own uranium [6,7] and she was making nuclear bombs [6,8]. She was forced to stop her nuclear programme in 1991 and all the nuclear materials stoke pile needs accounting and control. This need arose due to rising nuclear security concerns about the safety and proliferation of the nuclear materials [9,10] and possible diversion for illicit purposes by nuclear terrorists [11,12]. Each nation should have a National Nuclear Programme aimed at characterization of seized nuclear or radioactive material to determine its chemical and isotopic composition and physical parameters which form signatures of the origin of the interdicted radiological nuclear material. Such a database is lacking in all the African countries. No African country has a developed nuclear forensics library and South Africa is only starting, but does not yet have a fully functional nuclear forensics laboratory.

The aim of this Research Review is to highlight some of the techniques that have been used for developing nuclear forensics libraries and it is hoped that African nations can apply some of these techniques in developing their NNFL from the nuclear forensics signatures as required by the IAEA for each Member Sate [3]. In this work we then present some results that have been done from a uranium mine in Carletonville South Africa as an example.

The case of South Africa

There is therefore a need for South Africa and all the African countries to develop nuclear Forensic signatures and NNFL for their nuclear stoke pile (uranium mines, uranium material, yellow cake (U_3O_8), Nuclear Reactor fuel and spent fuel).

A nuclear forensics Library of all nuclear material in South Africa is vital for identifying and retribution of any interdicted nuclear

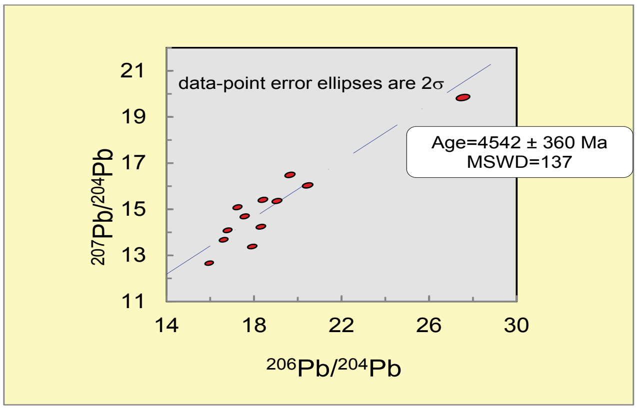

Figure 1 Pb-Pb isochron plot for Pb isotopic ratios from this work.

material from any African country. South Africa is the most likely route for nuclear material trafficking due to its vast transport network.

The Nuclear Forensic Laboratory (NFL)

Using South Africa as an example again, there should be a Nuclear Forensics Laboratory setup with full instrumentation, National Institute of Standards and Technology (NIST) calibration standards and Nuclear Scientists (some of whom can be trained at the Center for Applied Radiation Science and Technology (CARST), North-West University (Mafikeng). The first samples analyzed in such a Laboratory are the uranium ore samples from the national mines. Each country (e.g., Zimbabwe and Namibia) can start at this front end of the Nuclear Fuel Cycle (NFC). For South Africa and Namibia which can process the ore into uranium metal and further into yellow cake, the NFL can analyze such samples to build a data base of signatures at different stages of the NFC.

Forensic signatures

Nuclear forensic signatures can be obtained from the following categories of data:

- Rare Earth Elements (REE) of the periodic table as these exhibit consistent patterns under varying geochemical conditions [13,14]. This becomes a signature (or reflection) of the geochemical conditions of the mine.
- Trace element compositions show the impurities for each uranium processing [15].
- The U-Pb isotope composition [15,16].
- Concordia age dating of the samples [17,18].

Some of the Instruments used for geo-chronometric analysis of intercepted nuclear materials from a nuclear facility include: the LA ICP-MS or laser-ablation micro-sampling (LAM-ICP- MS), ICP-MS [14,19-21], as well as Gamma Spectrometry [22].

Materials and Methods

Study area

Geology of the mining site

The Witwatersrand Supergroup in South Africa has one of the largest gold and uranium deposits in the world. Although many studies have researched onto the mineralogy, geochemistry and chronology of this Reef [4,14,15,23], few studies have looked at the developing nuclear forensics signatures for the 72 uranium mines. The sampling site falls within the Carletonville goldfield which is part of the so called B-Reef or Witwatersrand Supergroup. The uraninite (UO_{2x}) deposits [24], here are unconformity in nature lying on the sedimentary succession of the Witwatersrand Supergroup, with an estimated age of about 2.59 Ga [4]. Gold (and uranium) mining uses the underground mining techniques as the mines are each estimated to be more than 2 Km deep. A full description of the different type's uranium deposits in this area and the mechanisms thereof is given by Fuchs [4].

The study area, sample collection, preparation and analysis on the Inductively Coupled Plasma Mass Spectrometer (ICP-MS), and by gamma spectrometry is described in our other articles [25,26] and the authors cannot give further details due to confidentiality agreements.

Results for Carletonville REE Patterns and U-Pb Isotopic Ratio

REE signatures

In **Figure 2**, the intensities of the REE/C1-Chondrite normalized decrease with the ascending order of atomic number for both tailing dams. Studies conducted by Asai and Limbeck [13], reported a directly proportional relationship between REE atomic number and intensity or integrated counts which is opposite of this work. This can be due to additional interferences or elemental fractionation from the ICP-MS. The result of our study is dominated by LREE, which gives a signature for this mine. There is enrichment in the LREE and a depletion of the HREE for this mine [15].

Conclusion

The results presented here demonstrate that South Africa and all other African countries have the capability to develop their own nuclear forensic signatures to account for nuclear materials [27,28].

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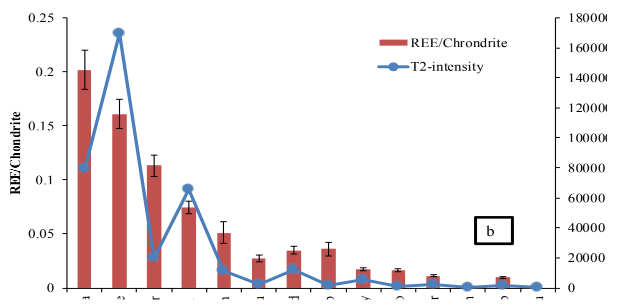

Figure 2 REE/Chondrite *vs.* REE and intensities.

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