STRENGTHENING INTERNATIONAL NUCLEAR FORENSIC CAPABILITIES THROUGH COLLABORATIVE SCIENCE IN UKRAINE

Kim B. Knight[1], Eileen S. Vergino[1], Olexander Gaidar[2], Dmytri V. Kutniy[3], Georgii V. Lysychenko[4], Igor A. Malyuk[2], Anton A. Valter[5]

1: Livermore National Laboratory, USA; 2: Institute for Nuclear Research, Ukraine; 3: Kharkov Institute of Physics and Technology, Ukraine; 4: Institute for Environmental Geochemistry, Ukraine; 5: Institute of Applied Physics, Ukraine

ABSTRACT

Globally, the production, transport and storage of nuclear materials have led to serious concerns over illegal trafficking of such materials. Ukraine stands at one of the geographical crossroads of such activities, and contains the largest uranium ore reserves in Europe. Moreover, Ukraine retains significant waste from Soviet-era uranium production and enrichment activities, as well as radioactive materials accumulated from the Chernobyl catastrophe. Lawrence Livermore National Laboratories (LLNL), with support through NA-242, has initiated multiple cooperative efforts within Ukraine, engaging some of the best Ukrainian scientists and institutions in nuclear forensic science. Nuclear forensics serves as a vehicle for scientific collaborations between the Ukrainian and United States governments, strengthening the response and core capabilities of Ukraine, who is also taking an active role as the regional leader in nuclear forensics, and additionally contributing to further engagements between respective governments. These collaborations are being supported through the Department of Energy, NA-242 GIPP (Global Initiatives for Proliferation Prevention) and CBM (Confidence Building Measures) programs, and serve to enhance nuclear forensics capabilities for Ukraine and neighboring countries, as well as in the United States.

INTRODUCTION

Ukraine stands at a geographical and geopolitical crossroads for illicit trafficking of nuclear materials, possessing the largest uranium ore reserves in Europe, as well as retaining significant waste from Soviet-era uranium production and enrichment activities, and radioactive materials accumulated from the Chernobyl catastrophe. Additionally, Ukraine supports a large uranium mining industry founded on a diverse set of geological settings and employing multiple uranium mining technologies, from open-pit to leach field mining. According to the illicit trafficking database maintained by the International Atomic Energy Agency (IAEA) [1,2], over the past two decades, more than one thousand cases have been confirmed by States Points of Contact, about 25% of which involved nuclear materials. Interdictions on nuclear materials, including samples consistent with origins in the former Soviet Union [3], suggests a real threat of illicit trafficking of nuclear materials in Ukraine, and highlights the need for the development of a nuclear forensics infrastructure including analytical methods, technologies and material databases. Most research regarding the identification of specific characteristics of uranium ore and related materials for addressing nuclear forensics was, until recently, considered classified by the Ukrainian and previous governments.

Nuclear forensics is the analysis of intercepted illicit nuclear or radioactive material and any associated material to provide evidence for nuclear attribution [4]. The goal of nuclear analysis is to identify forensic indicators in interdicted nuclear and radiological samples or the surrounding environment, *e.g.*, the container or transport vehicle. These indicators arise from known relationships between material characteristics and process history. Thus, nuclear forensic analysis includes the characterization of the material and correlation with its production history. Attribution, interpretation and legal prosecution based on evidence and material properties draws a broad range of scientific, forensic and nuclear technology knowledge and expertise. This expertise can be most effective in combination with reference databases of characteristic material properties (signatures), which represent a powerful tool to be used for guiding a nuclear forensic study and interpretation of analytical results. The construction of such nuclear data and sample libraries, as well as the need for international cooperation, established best practices and data exchange in the areas of nuclear forensics and nuclear security areas are recognized as being of vital importance to combat nuclear terrorism and illicit trafficking of nuclear and radiological materials.

In 2010-2011, LLNL and Ukraine worked to initiate several projects in nuclear forensics to be pursued through Ukrainian and United States-based technical collaborations derived from existing capabilities, current needs and scientific interests of both parties. These projects include 1) participation and training through regional nuclear forensic workshops, 2) analytical quality assurance and cooperation through the development and co-analysis of relevant standard reference materials, 3) analytical and capacity building for nuclear forensics through nuclear forensic research, and 4) sample collection and data collection towards populating a national Ukrainian database for nuclear forensics. These collaborations are being supported through the Department of Energy, NA-242 GIPP (Global Initiatives for Proliferation Prevention) and CBM (Confidence Building Measures) programs, and serve to enhance nuclear forensics capabilities for Ukraine and neighboring countries, as well as in the United States.

Collaborative projects in the area of nuclear forensic research support the goals of the Nuclear Security Summit [5] by developing Ukraine as a regional lead in forensic capabilities, with other neighboring countries such as Georgia, Azerbaijan, Uzbekistan and Moldova acting in a supporting role to conduct basic forensic analyses. Broad objectives include working with Ukraine to build capacity for domestic nuclear forensic analysis and interpretation, as well as development of Ukraine as a regional leader in nuclear forensic capabilities, supporting neighboring countries with only basic nuclear forensic analytical capacity. These activities also expand Ukrainian nuclear forensic expertise, lay the foundations for a nuclear materials database, and establish the relationships and robust scientific basis necessary for cooperative analysis of materials of nuclear forensic interest between the United States and Ukraine.

COLLABORATIVE NUCLEAR FORENSIC SCIENCE WITHIN UKRAINE

Collaborations in nuclear forensic science provide an excellent avenue for establishing, from the ground up, scientific relationships that realize a foundation for larger scale exchange, and confirm, in the event of serious cases of nuclear materials interdictions, that expertise and practiced protocols are in place for the proper handling of evidence and, as needed, data and/or sample exchange. This includes ensuring appropriate use of new and innovative technologies to prevent and combat illicit nuclear trafficking, establishing, demonstrating and sharing of best practices, and enhancing cooperation among relevant local, national, regional and international bodies.

Success in establishing a strong international nuclear forensics collaboration requires 1) an understanding the technical people, skills and instrumentation already in country; 2) the creation of projects of mutual interest and benefit; 3) the development and sustenance of working relationships between scientists and other involved parties; and 4) mechanisms for the transfer and monitoring of funding and deliverables. In Ukraine, and in the development and execution of the collaborative projects presented here, the existence of the Science & Technology Center in Ukraine (STCU) has greatly facilitated efforts in all of these areas. The STCU provides a simplified and accountable framework for the transfer and monitoring of funding provided for these projects, and is a mechanism for supporting scientific collaboration between regional neighbors including Georgia, Ukraine, Azerbaijan and Moldova. The scope of the STCU is considerably larger than only that of nuclear forensics (a Targeted Initiative topic for them), and they have a proven track record for ensuring the logistical flow of collaborative projects such as those discussed here.

Collaborative projects in nuclear forensics were developed with Ukraine through a broad call for proposals, with assistance through the STCU to ensure that potential collaborators were made aware of the call, and to facilitate proposal submission according to the guidelines of the proposals. From these initial proposals, several were selected to be further developed for potential funding, having interest and mutual benefits to the United States, Ukraine and the international community, and were pursued for funding through the Department of Energy, NA-242. A brief description of these four projects is provided below. These projects encompass a collaborative team of six institutes within Ukraine, including the participation of over 100 Ukrainian scientists, as well as participation from three regional partners, and are additionally supported by Ukraine and the National Academy of Science of Ukraine. Lawrence Livermore National Laboratory serves as the technical advisor and scientific collaborator to these projects in the United States.

The first project is a two year project focusing on training in nuclear forensics coordination and response aimed on the creation of an infrastructure for regional cooperation in nuclear forensics through establishment of a network of the nuclear forensic laboratories encompassing national expert laboratories in Georgia, Moldova and Azerbaijan, possessing core capabilities in detection and analysis, with central regional nuclear forensic experts laboratory in Ukraine, having advanced analytical and interpretation capabilities. This project will follow on and compliment funding and efforts through the European Union providing infrastructure support including in-country establishment and operation of 'mobile laboratory' equipment for forensic interdictions.

Ukraine has an established training center, the George Kusmycz Training Centre (GKTZ), which was created at the Institute for Nuclear Research in Kiev, Ukraine as a result of collaborative efforts between the United States, the European Commission and the government of Ukraine. The GKTC has been designated by the Ukrainian Government to provide material protection, control, accounting training and methodological assistance to nuclear facilities and nuclear specialists. Leveraging over ten years of experience in coordinating and carrying out training in these areas, the GKTC forms a strong cornerstone of this project. Regional training and outreach will begin to consolidate and enhance assets for nuclear materials interdiction, analysis and interpretation, and will inform nuclear interdiction model action plans. Other outcomes of this project include demonstrating simple, yet critical proof-of-concept details, such as planning and executing a means of sample transfer and tracking between analytical laboratories within Ukraine, as well as with regional partners and the United States.

Fig. 1: Scientific and logistical discussions at the George Kusmycz Training Centre, Institute for Nuclear Research, Kiev including participation from LLNL and the STCU in 2011.

A second, two year project, centered at the Kharkov Institute for Physics and Technology (KIPT), focuses on development and enhancement of non-destructive analytical capacity. Non-destructive analysis often forms the fundamental backbone of material characterization of nuclear materials, from initial detection in the field, to decisions for material handing and transport, and also in higher level laboratory characterizations of the isotopic and elemental composition. This project focuses on development of modern X-ray fluorescence (XRF) capabilities, a non-destructive technique for characterizing elemental compositions of materials, and also on the development and certification of analytical standards for gamma spectrometry analysis of various morphologies and chemical forms of uranium to determine U-assay (concentration by mass) and the level of ^{235}U enrichment. Aliquots of the developed and characterized standards, their pedigree and their certified values, as well as the related methodology will be supplied to the United States, and materials will be co-analyzed between the Ukrainians and LLNL, establishing an analytical baseline between the labs for non-destructive analysis. This project leverages considerable existing experience in materials handling and metallurgy at KIPT, and builds their existing non-destructive analytical capabilities towards nuclear forensics application, while filling the a need for the creation of additional certified standards for these techniques. This project also provides infrastructure and capacity (XRF) to be utilized across all four proposed projects, and to serve as a cornerstone capability for nuclear forensic analysis, forming the basis for direct comparisons and calibration between KIPT and LLNL of select materials.

The Institute for Nuclear Research (INR) in Kiev leads the third, two year project, which also engages the Kharkov Institute of Physics and Technology, the Institute of Applied Physics in Sumy, and the Institute of Environmental Geochemistry in Kiev. This project transitions existing analytical expertise towards nuclear forensics application through research to identify and measures forensic signatures in nuclear materials. In the frame of this project, using a set of validated and optimized analytical techniques, we will determine a variety of physical, elemental, isotopic and microstructural characteristics for a comprehensive set of uranium bearing materials. Uranium ores, ore concentrated and intermediate products will be studied to retrieve regional and technology specific signatures, as well study of the addition, transfer and modification of chemical impurities and isotopic signatures during the uranium purification processes utilized in Ukraine. Enriched uranium materials of known origins will be studied to relate the known material origins to material properties and characteristics determined in the course of the study. Finally, uranium-bearing materials of unknown origin seized from illicit trafficking in Ukraine will be characterized to attempt to establish their origin by querying the ITU's nuclear material database and other resources.

This project develops a significant nuclear forensics analytical capability and accomplishes several additional broad goals. First, this will be first time these four key Ukrainian institutions will be working together to transfer nuclear materials, to exchange data and communicate methodologies and error assessments, and to unify the strengths of each institution with regard to nuclear forensics capabilities and response for Ukrainian interdicted materials. Such relationships are essential in the development of a cohesive, rapid and effective response in the event of nuclear materials interdictions. Secondly, this project practices and explores analytical capabilities, and will serve to provide a practical assessment of analytical strengths and weaknesses, which can guide follow-on work and collaboration. Finally, the basic research may illustrate nuclear materials signatures worthy of additional study. Other outcomes of this project include establishment of simple, yet vital protocols, such as those for planning and executing sample transfer and tracking between analytical laboratories within the Ukraine, as well as to external partners.

The final project in this suite initiates the process of compiling existing data on uranium ores, ore concentrates and related materials, including existing samples, for development of the national nuclear forensics database. This project involves the Institute for Environmental Geochemistry, Kiev and the Institute of Applied Physics, Sumy. In 2001 the Institute for Nuclear Research (INR) signed an agreement with the Institute for Transuranium Elements (ITU) on the use of their nuclear material database and permit information requests from the ITU's database on a case-by-case basis as required by nuclear forensic investigations. Respective data querying and information exchange procedures have been developed and tested through TACIS programs (Technical Assistance to Commonwealth of Independent States). In addition, data on the properties of INR's nuclear research reactor fuel and nuclear materials seized from illicit trafficking were appended to the ITU's nuclear material database. There is growing interest in the extension of the nuclear fuel databases through the addition of data on characteristics of uranium bearing materials, such as uranium ores and uranium ore concentrates, that appear at the front end of the nuclear fuel cycle. Importantly, this project initiates the process of compiling existing data on uranium ores and related materials, including existing samples, providing nuclear materials source information for a national nuclear forensics database. This project also targets collection of a new suite of samples, which will be preliminarily characterized, aliquoted and transferred to collaborating laboratories for additional research (leveraging the previously discussed projects). Collection of U ore samples, intermediate products and U-ore concentrates from primary Ukrainian deposits is a first for the purpose of nuclear forensic research and database development.

These projects will move forward under the sponsorship of NA-242's Global Initiatives for Proliferation Prevention and Confidence Building Measures programs, complimented by and coordinated with concurrent efforts through the European Union, as well as with internal support from Ukraine and the National Academy of Science of Ukraine. Each project has an associated time line with stated deliverables and milestones to guide progress and define success. With any endeavor of this scale, however, it is inevitable that minor changes and modifications will become necessary as these projects progress (particularly over the lifetimes of the 2-year projects). Project progress and success will be monitored through close communications, including visits between the technical lead laboratory (LLNL) and the participating Ukrainian institutions, such that the focus and objectives of each project can be achieved within the agreed to framework. In the scope of these projects, the presentation and publication of resultant findings in peer reviewed journals and meetings is anticipated and encouraged.

BENEFITS FOR NATIONAL AND INTERNATIONAL SECURITY

We have developed collaborative projects which enhance the capacity of Ukraine in the field of nuclear forensics analysis and interpretation, encourage cooperative communications amongst participating research institutions in the nuclear forensics field, increase regional participation in global nuclear forensics efforts, and establish sample exchange and analytical collaboration on samples of interest between the Ukraine and the United States. These projects additionally benefit from the regional interests of other international partners such as the European Union and Canada. Communications between these additional external organizations ensures that these cooperative efforts leverage one another's strengths, rather than resulting in duplication or inefficient overlaps.

This work directly supports the Nuclear Security Summit (Washington, 2010) communiqué [5], which recognized the need for cooperation among States to effectively prevent and respond to illicit trafficking, including agreeing to share information and expertise in relevant areas such as nuclear detection and nuclear forensics. The broad objectives of these collaborations include building up Ukraine's capacity for nuclear forensic analysis and interpretation, as well as development of Ukraine as a regional leader in nuclear forensic capabilities, and build regional (Georgia, Ukraine, Azerbaijan and Moldova) country capabilities to respond appropriately to cases of nuclear smuggling. Of highest priority are building Ukraine's capacity for nuclear forensic analytical response and supporting their efforts to develop a national database characterizing uranium sources. Lawrence Livermore National Laboratory, the technical lead laboratory for the United States, additionally benefits in these collaborations through additional opportunities to place practical nuclear forensics into practice with new samples of interest, the delivery of new analytical standards, the opportunity to participate in comprehensive sampling of one front-end fuel cycle process, and enriching scientific exchange.

These collaborations would be neither possible nor successful without a strong technical component anchored in laboratory-to-laboratory and scientist-to-scientist discussions. The skills to handle, analyze and interpret interdicted nuclear materials are inherently technical issues, and are best understood and improved upon through a science-based engagement. In the building and vetting of these projects, institutional visits and scientific discussions were essential to establishing the practical fit between institutions, people, and science to create a synergistic foundation.

Direct engagement of scientific effort to evolve projects of mutual interest is key to the development of collaborative efforts with the potential for a lasting positive impact. Indeed, one metric for success with respect to international collaborations in nuclear forensics is the potential long term impact of the proposed work. In our case, the scale of the projects and participants is substantial, aimed towards bringing together disparate resources at different organizations towards the common goals mentioned above. Meeting of near-term milestones and deliverables will serve to advise how best to move forward in nuclear forensic collaboration with Ukraine, and the continued engagement of Ukraine in international nuclear forensics such as the International Technical Working Group appears highly likely. The long term impacts of these collaborations stem from their coordinated establishment of a solid base for nuclear forensics, including an assessment of existing data and materials, and a readiness to participate in further sample exchange and implementation of best practices.

Any effort to maintain and improve regional capabilities in Ukraine and neighboring areas in the long term will require sustained internal diligence and innovation (and infrastructure). Real success will be for Ukraine to fully support nuclear forensics detection, response and research, through active participation. As an older generation of scientists translates skills into nuclear forensics applications, they have also begun to train and engage the interests of the younger generation. This transfer of interest and awareness of nuclear forensic science to upcoming researchers and future institutional leaders is essential to a long term metric of success. The presence of funding and modern, versatile instrumentation can assure that the skills and interest in nuclear forensics will not become stagnant or lost, but instead continue to develop, be shared, and contribute to the international community.

Following completion of these projects, additional efforts to consider include developing a comprehensive national nuclear data and materials library, encouraging round robin participation and further cooperative analytical work, and supporting the exchange of graduate and post-doctoral researchers for jointly supervised research and training. For the present, establishment of a scientific relationship and technical foundation for nuclear forensic collaboration between the United States and Ukraine is a significant and positive step forwards for Ukrainian, American and international security interests. We look forward reporting on our progress.

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