Contribution ID: **16** Type: **Poster**

Forensics Detection of Nuclear Materials by Machine Learning Microphotonic Techniques

Nuclear security is one of the greatest challenges facing the world today. Detecting criminal/unauthorized acts involving nuclear and other radioactive material out of regulatory control is a priority in nuclear security. In nuclear forensics detection of nuclear materials to determine whether the sample is nuclear, its isotopics and corresponding enrichment are the key aspects to collect information about the samples and other (suspicious) trace evidences; identify sample type(s); and categorize them normally using traditional radiation detectors and spectrometers. However these techniques are neither the only ones suitable for the task nor do they lack limitations especially with regard to rapid analysis. For nuclear forensics to be an effective "deterrence" against nuclear security threats, techniques for direct rapid analysis of nuclear and radioactive materials (NRM) are required.

A synergy is achieved by combining machine learning and microphotonics based techniques namely laser based spectrometry and spectral imaging to elucidate more comprehensively the isotopic, molecular and elemental composition, as well as microstructure of nuclear materials (each step in the fuel cycle creates and/or modifies these nuclear forensic (NF) signatures).

We will in this talk describe our work (photonics-based spectral imaging and microanalytical method developments for nuclear forensics in support of nuclear security) where we exploit laser induced breakdown spectroscopy (LIBS) spectral/imaging and confocal laser Raman spectromicroscopy towards this goal. The work focuses on the methods that answer questions that may be asked when nuclear material is seized by Law Enforcement. The techniques have further utility in responding to anthropogenic environmental releases of nuclear and radioactive materials and illicit trafficking activities of such materials in our region, as well as analyzing activities related to radiological dispersal devices (RDD) and improvised nuclear devices (IND).

While LIBS reveals the atomic (and sometimes molecular and isotopic) signatures of micro-plasma obtained from the ablated samples, laser Raman microspectroscopy reveals the molecular configuration as well as structure and morphology of the materials. Machine learning is used in combination to extract subtle information from the complex multivariate spectra/images and to perform data dimensionality reduction as well as exploratory modeling. Key advantages of this approach are: small samples ⊠⊠⊠⊠⊠g) can be evaluated with minimal or no sample preparation; and samples can be remotely analyzed rapidly ⊠⊠-seconds – ideal for radioactive samples). Especially microanalytical capability for micro-size samples is a powerful tool for monitoring undeclared nuclear activity, verifying nuclear safeguards, responding to nuclear anthropogenic releases, and analyzing materials from radiological crime scenes.

We have used LIBS coupled with machine learning to determine trace Y, Rb, Zr, Sr and Te in nuclear glass. These elements often coexist with uranium in post irradiation nuclear wastes. The biggest attraction of the developed analytical approach is that the protocol may be integrated into a suitable software interface and installed in a handheld LIBS system to provide on-site, real-time, stand-off and direct rapid analysis of fission products (FP) in post irradiated materials of nuclear origin and detonation events since only tiny glass debris (⊠ 1 mm) and tiny (≤ 2 µl) can provide reliable nuclear forensic signatures. We also exploited machine learning enabled LIBS in air and at atmospheric pressure utilizing weak uranium lines to predicted uranium concentration in uranium-bearing mineral ores between 103 - 837 ppm. The developed method in conjunction with principal component analysis (PCA) successfully assigned the samples to their origin. Size - resolved (Ø: 2.5 µm, 4.5 µm) analysis of individual aerosols from a mimic uranium mine atmosphere has been undertaken in the context of in-field nuclear forensics, using laser Raman spectromicroscopy (LRS), method that is suitable for forensic analysis of uranium-bearing nuclear materials and hot aerosols in the atmosphere. The concentration of uranium ranged 50-200 ppb, being more enriched in the larger compared to the smaller size fraction.

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Session Classification: Poster Session 3

Track Classification: 1. Nuclear Forensics Capability Building: Initiation and Sustainability: 1.2 New Technologies, R&D and Signature Research in Nuclear Forensics