JOINT SAMPLE ANALYSIS ON SELECTED URANIUM ORE CONCENTRATES

AND NUCLEAR FORENSICS LIBRARY EXERCISE

Ruth Kips[1], Rachel Lindvall[1], Naomi Marks[1], Viktor Gluchschenko[2],
Ayako Okubo[3], Yoshiki Kimura[3], Ogawa Jumpei[3], Evá Kovács-Széles[4], Csaba Tobi[4]

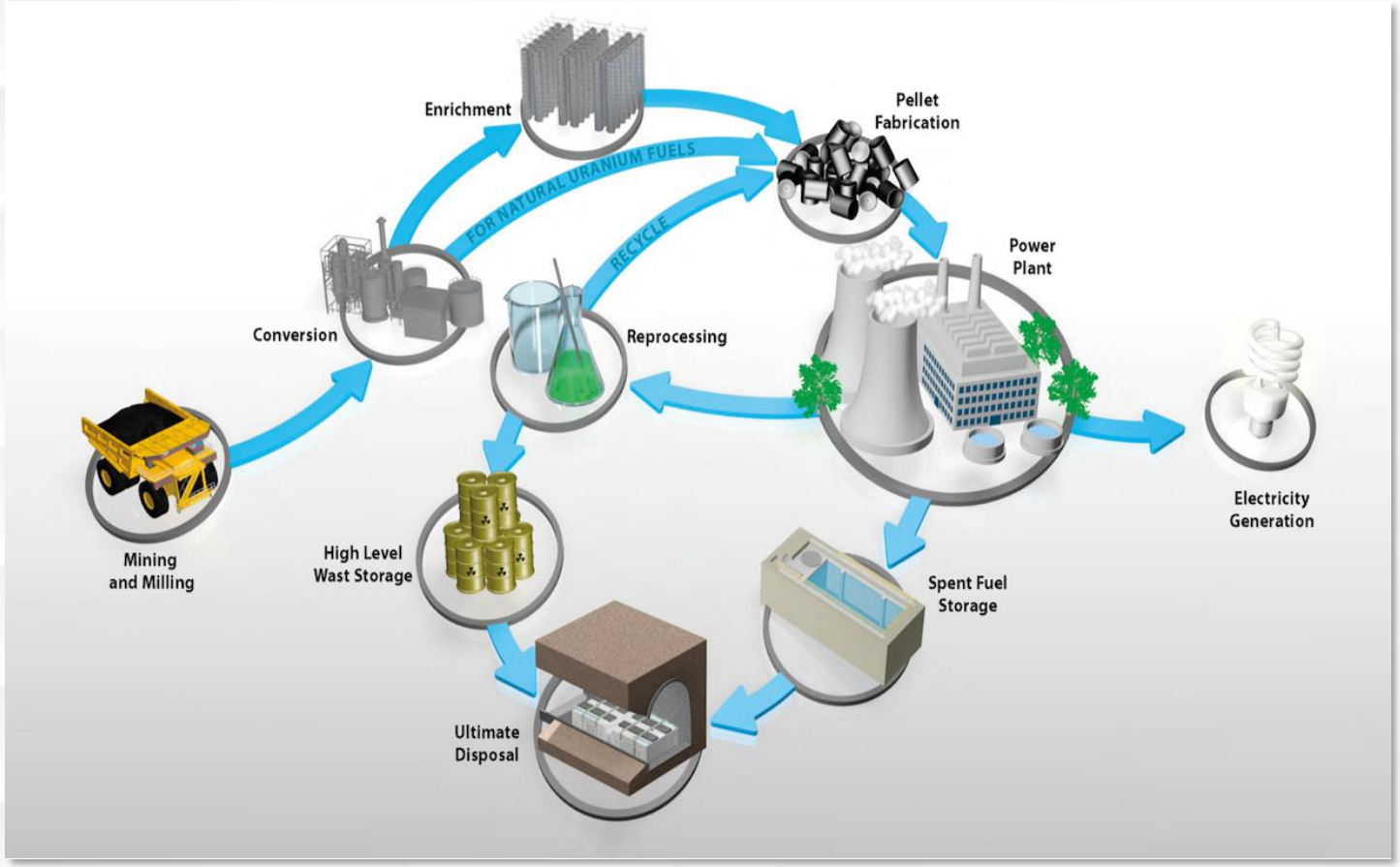
[1]Lawrence Livermore National Laboratory, USA
[2]Institute of Nuclear Physics, Kazakhstan
[3]Japan Atomic Energy Agency, Japan
[4]Centre for Energy Research, Hungary

LLNL-PRES-799527

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

Lawrence Livermore National Laboratory

Analysis of UOCs for Nuclear Forensics



NEWS

Black market for nuclear material endures

AP

Published 7:06 a.m. ET Dec. 10, 2012 | **Updated 8:40 a.m. ET Dec. 10, 2012**

This undated handout photo provided by the Georgia Interior Ministry shows bottles containing one kilogram (2.2 pounds) of yellowcake uranium. Police said they seized the nuclear material from a group of five in Samtredia, Georgia on April 5, 2012. *AP Photo/Georgia Interior Ministry*

BATUMI, Georgia (AP) — On the gritty side of this casino resort town near the Turkish border, three men in a hotel suite gathered in secret to talk about a deal for radioactive material.

The Georgian seller offered cesium, a byproduct of nuclear reactors that terrorists can use to arm a dirty bomb with the power to kill. But one of the Turkish men

The threats of nuclear proliferation and terrorism call for international cooperation to prevent, detect and respond to incidents involving material outside of regulatory control (MORC)

Joint Sample Analysis Overview

Participating Laboratories:

- **Kazakhstan**: Institute of Nuclear Physics (INP)
- **Japan**: Japan Atomic Energy Agency (JAEA)
- **Hungary**: Centre for Energy Research (MTA-EK)
- **US**: Lawrence Livermore National Laboratory (LLNL)

Analysis material:

- LLNL shipped a **set of 6 UOC samples** to the other participating laboratories
- All participating laboratories were not sample limited for their analyses

Why UOCs?

- Kazakhstan is a major producer of UOC and this type of material is of interest from a technological, industrial and nuclear forensics perspective
- Commercially available natural uranium product, relatively easy to ship

Exercise Objectives

1. Treat samples like actual nuclear forensics samples

2. Use existing laboratory capabilities for nuclear forensics analysis of 5 known UOC samples

3. Compare characteristics “unknown” sample with known sample set

4. Share best practices for obtaining, interpreting and reporting data

UOC Sample Set

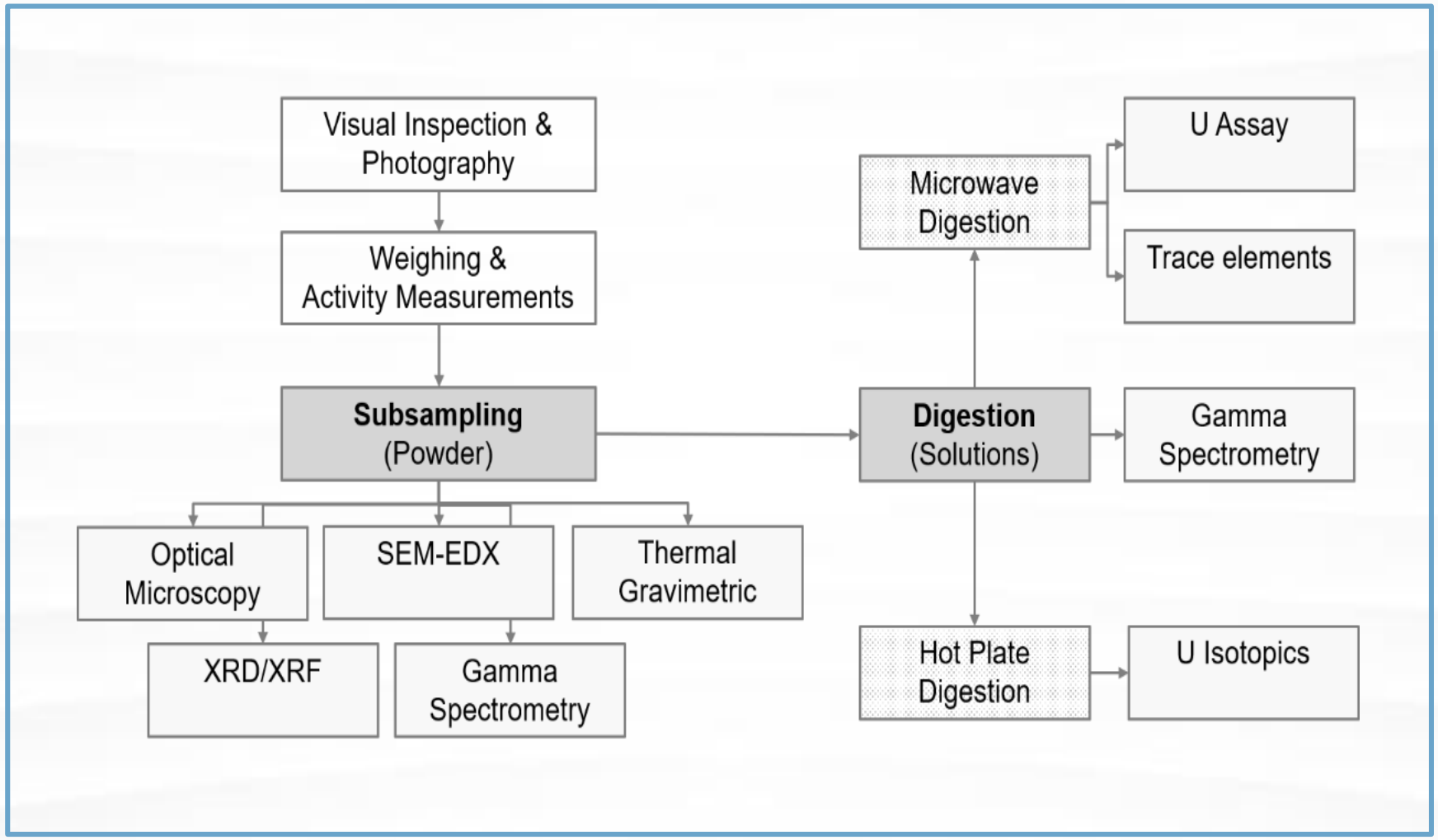
- Do samples have the same material properties?
- Is a sample consistent with materials information contained in a database or library?
- Is the sample consistent with material from a particular origin?

CUP-2 reference material

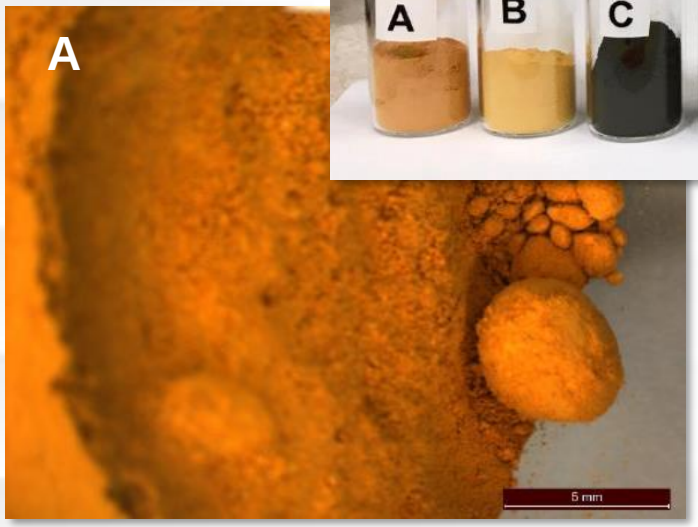
“Known” UOC samples (A-E)

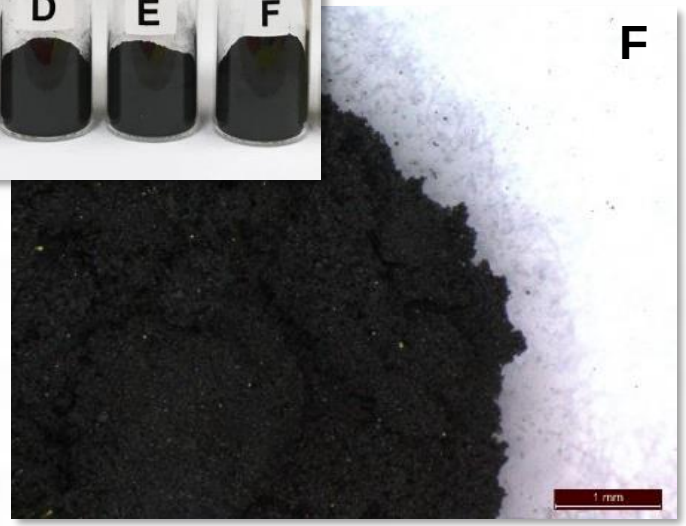
“Unknown” UOC sample (F)

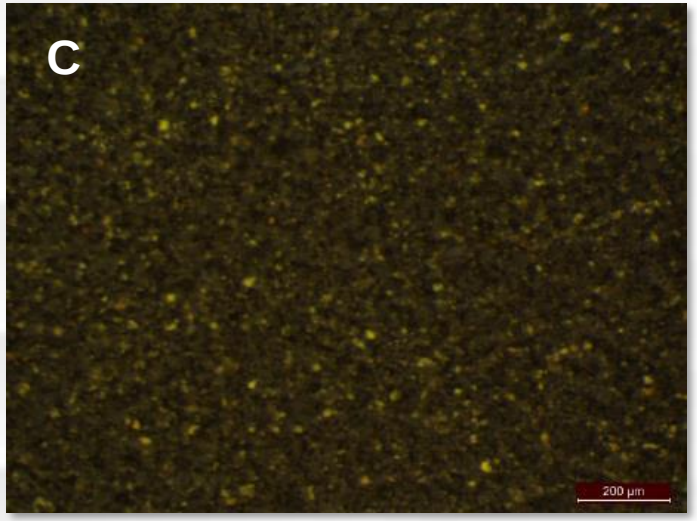
Example of an Analytical Plan

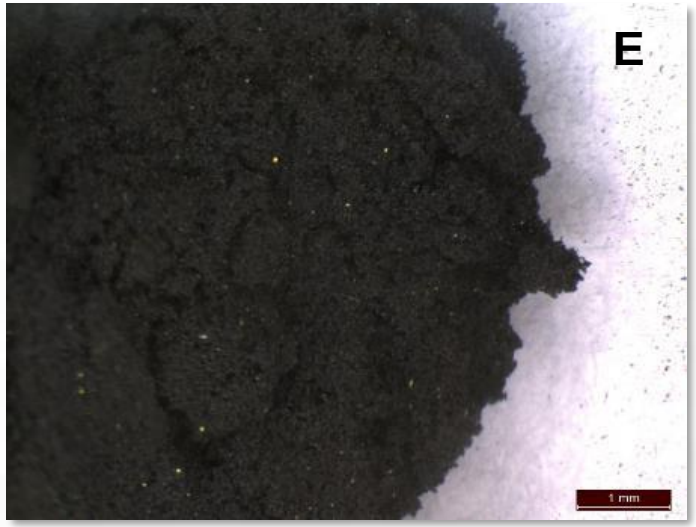


Selected Results: Light Microscopy and X-Ray Diffraction

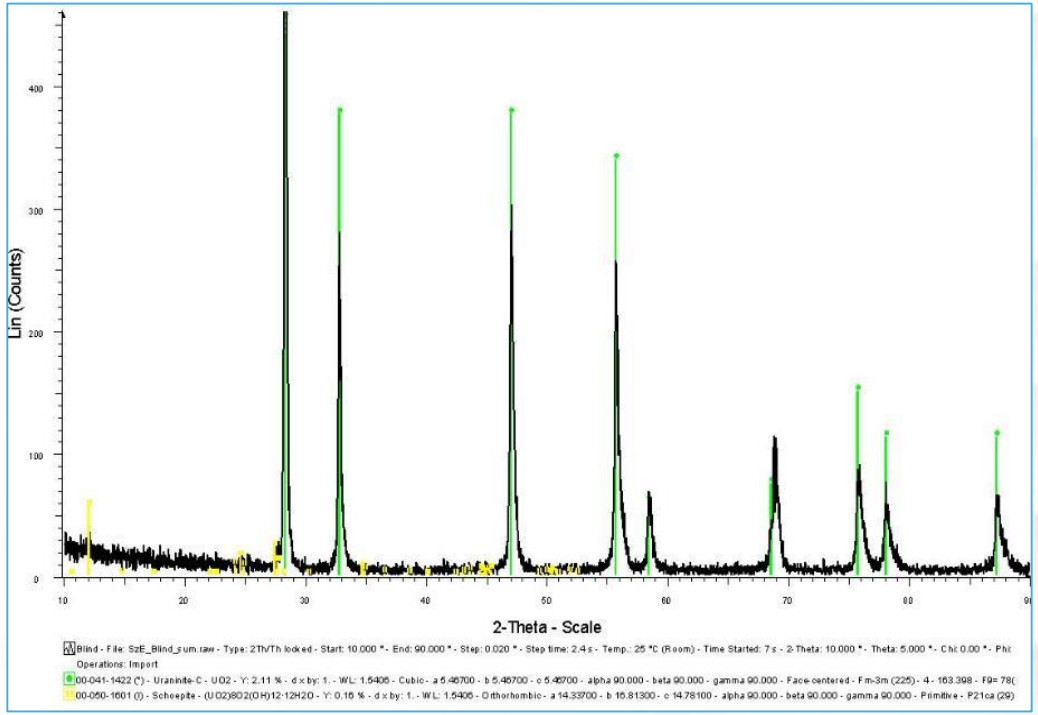




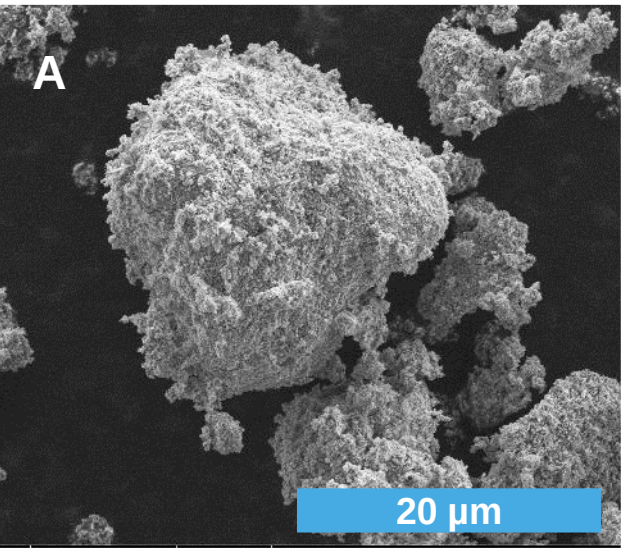


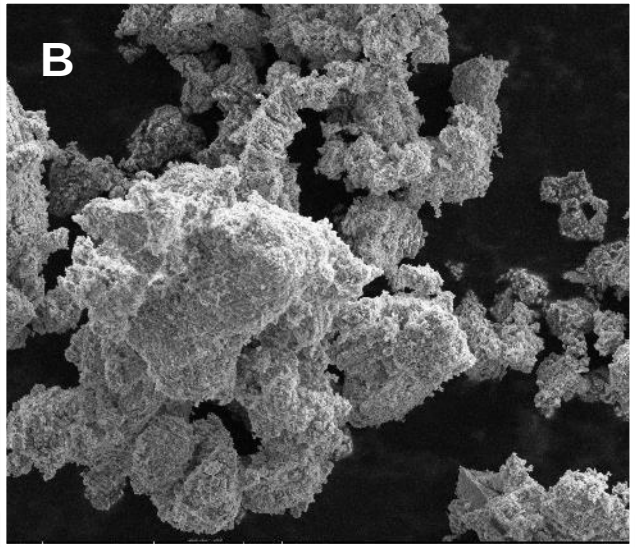


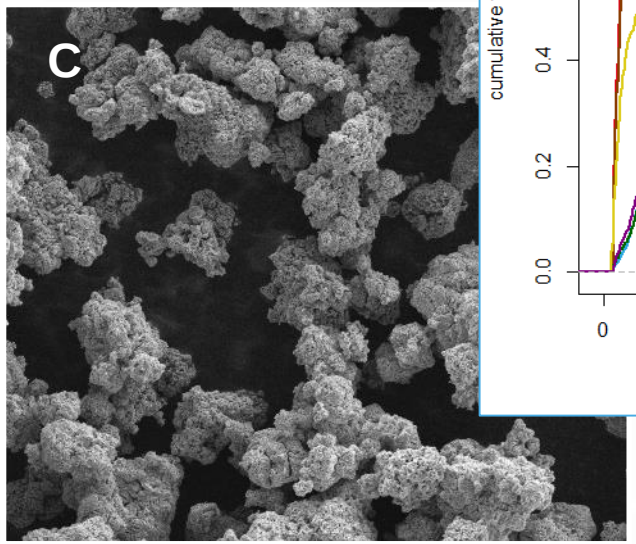
- **Need for method to quantify sample color**
- Optical microscopy identified multiple phases
- Significant differences in XRD spectra (multiple phases, spectral matching)
- Blind sample identified as UO_2 by all labs

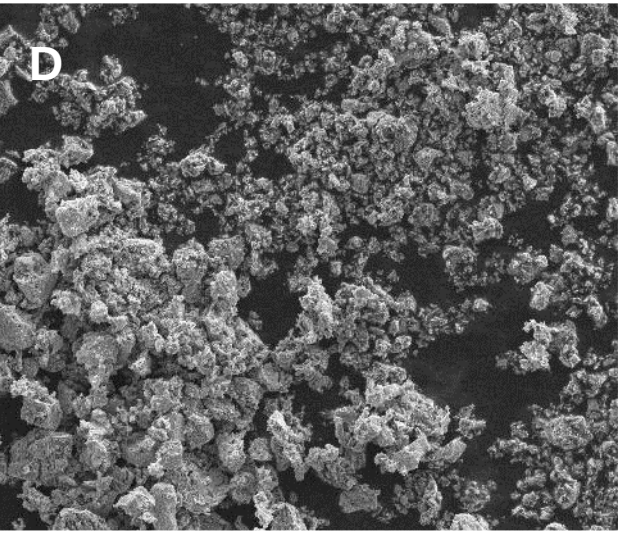


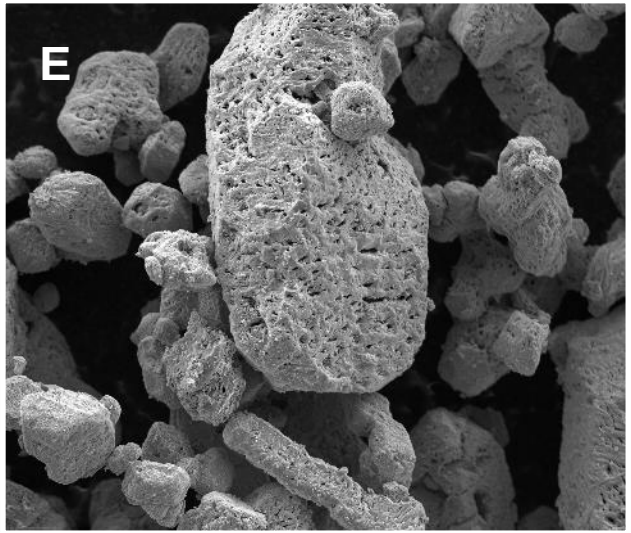
Selected Results: Electron Microscopy

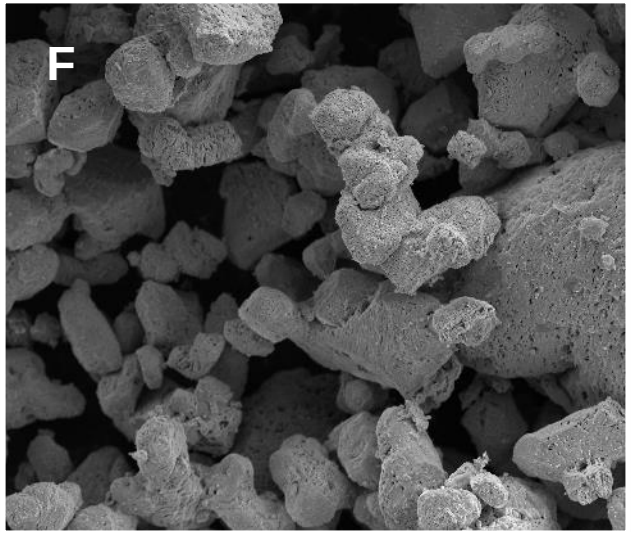


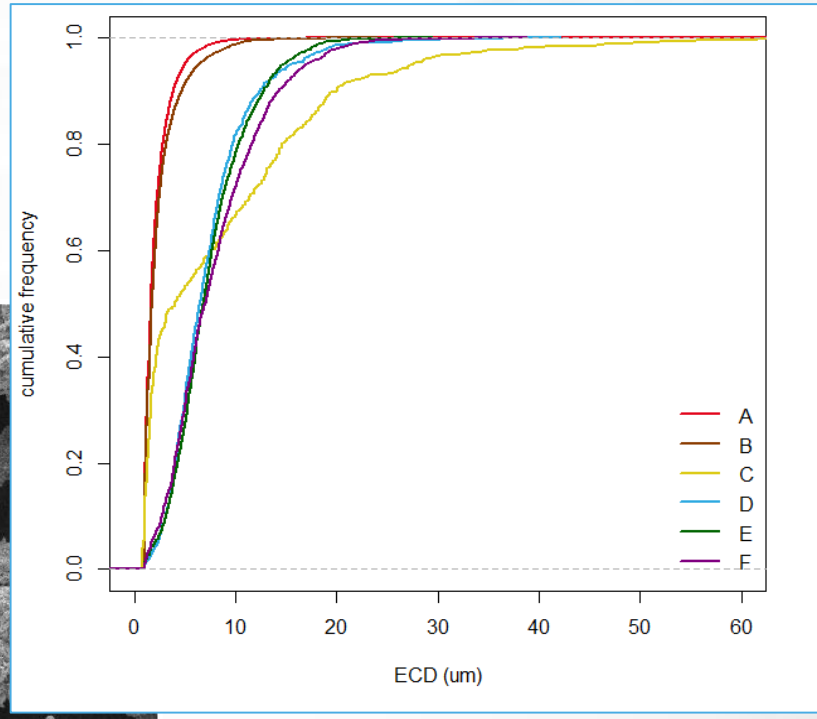






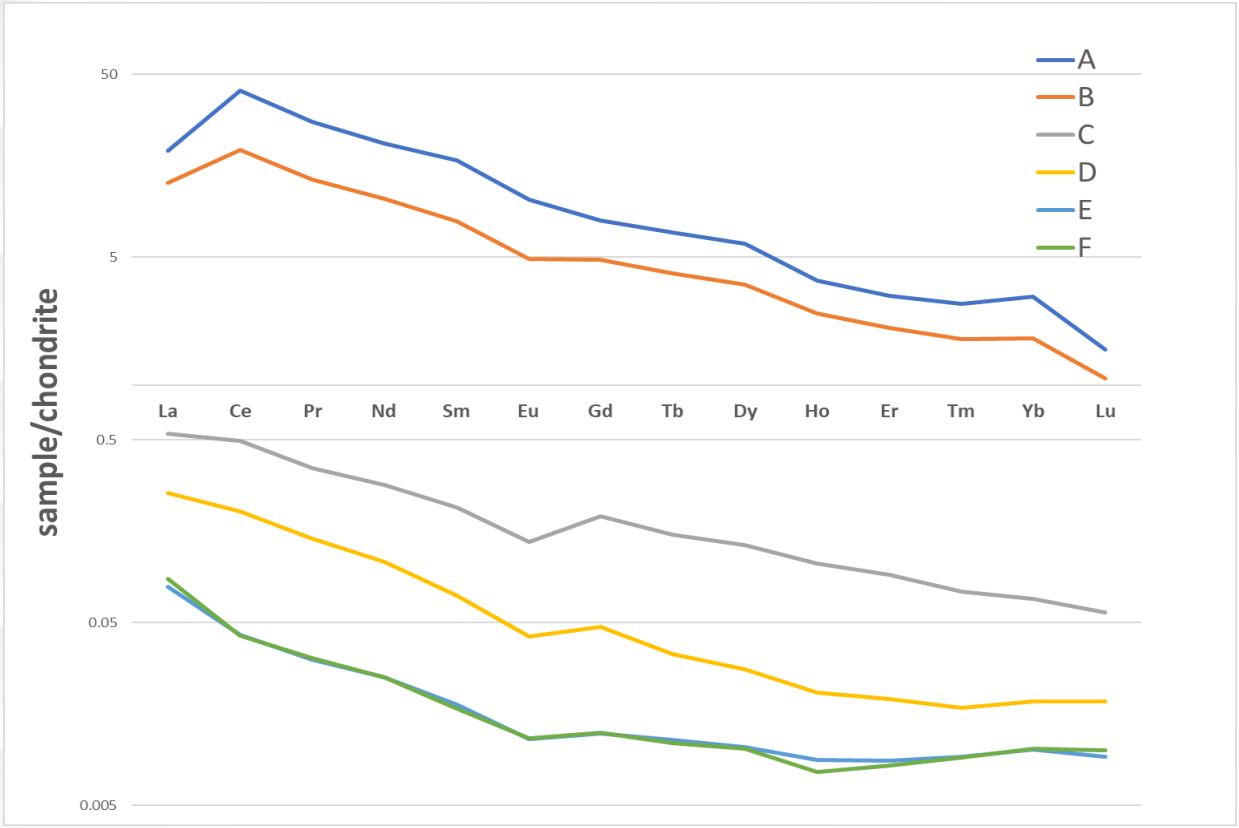


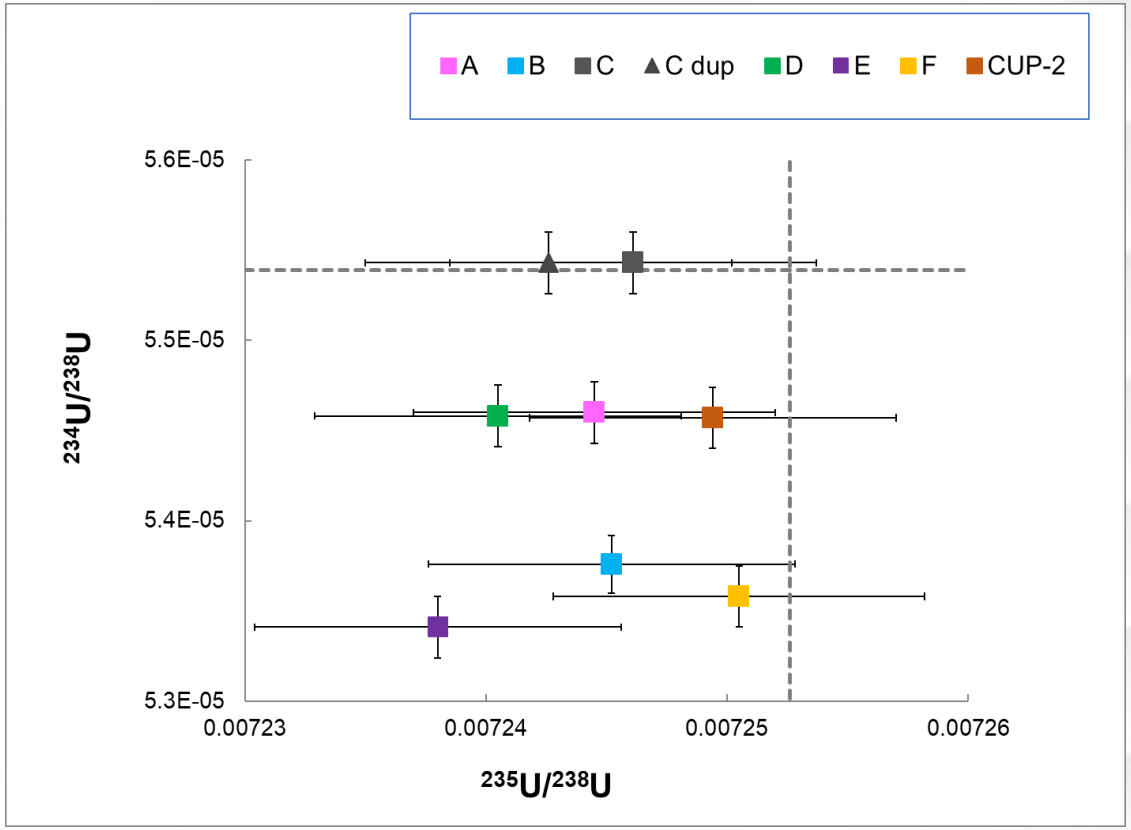




- **All UOC materials showed high degree of agglomeration**
- Samples D - F similar elemental composition, less impurities than A - C
- Samples E – F similar morphology
- Quantification through particle size distribution

Selected Results: Mass Spectrometry





- **The $^{235}U/^{238}U$ measurements with fully propagated uncertainty do not have the precision necessary to differentiate between the samples**
  - $^{234}U/^{238}U$ ratios are sufficiently variable to distinguish differences amongst the samples.
- The samples are depleted in $(^{234}U)/(^{238}U)$ relative to secular equilibrium except for Sample C, which had $(^{234}U)/(^{238}U)$ within uncertainty of secular equilibrium
- **Sample F (blind)** within uncertainty of Sample B and Sample E
- $^{236}U/\ ^{238}U$ was below the detection limit (4.4 ppb) for all samples

Application of the Graded Decision Framework

Nuclear Forensic Conclusion	Situation
Consistent	p > 0.05
Inconsistent with medium confidence	0.001 < p ≤ 0.05
Inconsistent with high confidence	p ≤ 0.001
Not assessed	Not enough information is available to make the necessary comparison, e.g., sufficient material characterization of a sample was not possible.

$$\zeta = \frac{(A - B)}{\sqrt{\left(u_{c,A}{}^2 + u_{c,B}{}^2\right)}}$$

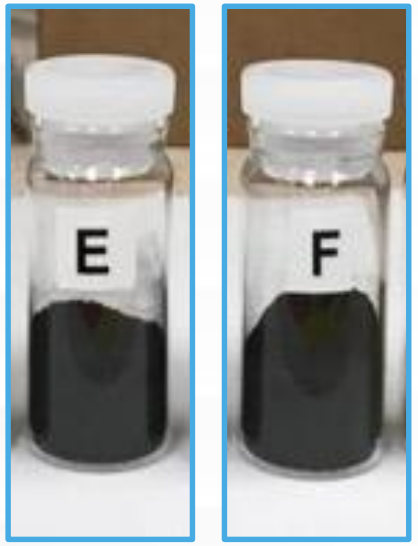
$$p = 2(1 - \Phi)$$

	Sample A	$U_{c,A}$ uncertainty	Sample B	$U_{c,B}$ uncertainty	Zeta score	P value
U (g/g)	0.882	0.004	0.878	0.004	0.707	0.479

Application of the Graded Decision Framework

Consistent
100% of Analytes

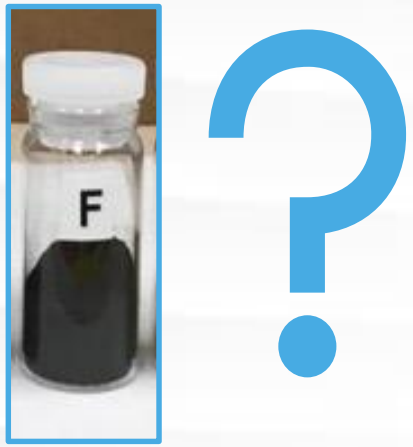
Inconsistent
0% of Analytes



Increasing p-value
(increasing probability of consistency)

Sb Cu 235U/238U Rb % Moisture Zr Mn 234U/238U Be Zn Mg La Ge Sc Ho Se As Cs V Pb Co Nb Fe Ba Mo Tl Ti 236U/238U Lu Cr Ni B Li Er Tb W Ta Sm Bi Th Sn Sr K Pr Ca Hf Y Ce Ga Re Na Cd Eu Gd Dy Al U Assay (%) Yb Tm Ag Nd

Application of the Graded Decision Framework



?

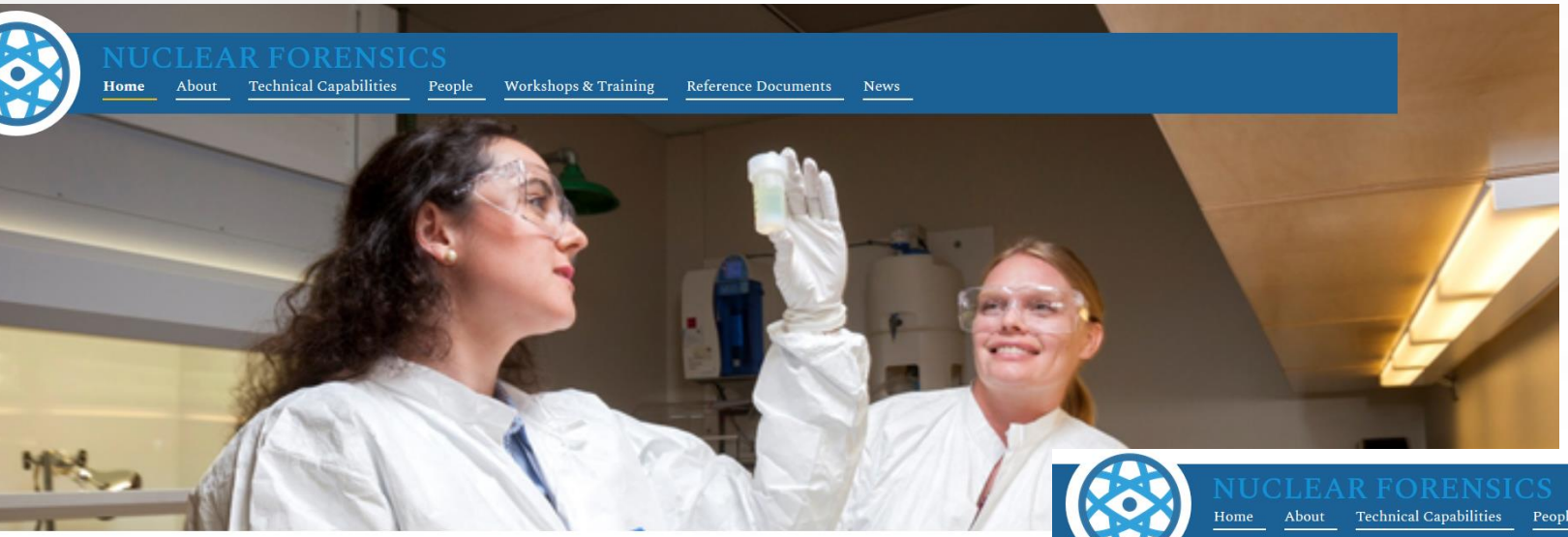
- If we know for certain that Sample F is from the same original sample as one of the five samples of known provenance, then based on the GDF, Sample F is most likely derived from the same original sample as Sample E.
- Based on the GDF, it is possible to rule out Sample D as a match, because the slightly more than half of the analytes are inconsistent, and key signature analytes are inconsistent.

Conclusions

The results presented by the different laboratories during the October 2019 data review meeting largely agreed with one another:

- Despite significant differences in XRD and XRF results, all laboratories concluded that, based on the physical characterization of the samples, in combination with several other non-destructive measurements, the blind sample (sample F) was similar to samples D and E
- Further destructive analysis of impurities indicated the blind sample was similar to sample E with high confidence
- The development and exercising of the UOC component of the NNFL will be an important next step in the assembly of a comprehensive library capturing important nuclear and radioactive materials in Kazakhstan.

Want to Know More?



Check out our new Nuclear Forensics Website: www.nuclear-forensics.org

Nuclear forensic science –or nuclear forensics– aims to answer questions about nuclear or other radioactive material by revealing links among:

People

Places

Events

Joint UOC analysis

The Institute of Nuclear Physics (INP) in Almaty, Kazakhstan, hosted a data review meeting on 15-17 October 2019 to discuss the outcomes of the recent nuclear forensics joint sample analysis between INP, the Japan Atomic Energy Agency (JAEA), the Hungarian Academy of Sciences (MTA-EK) and Lawrence Livermore National Laboratory (LLNL). The objective of the joint sample analysis was for the participating laboratories to 1) exercise their nuclear forensics capabilities by analyzing a set of uranium ore concentrates (UOC) according to a nuclear forensics analytical plan developed by each participating laboratory, and 2) determine whether an additional "blind" sample was similar to any of the other UOC samples in the set. During this 2.5-day meeting with close to 30 participants, the four laboratories described their analyses and presented their findings, which largely agreed with each other. Due to the success of the exercise, the nuclear forensics group at INP will use the outcomes and results of the joint sample analysis for a new scenario-based table-top exercise as part of the upcoming IAEA regional nuclear forensics workshop that will be held at INP in December 2019. The results of the exercise will also be presented at the IAEA's International Conference on Nuclear Security (ICONS) in February 2020 at IAEA Headquarters in Vienna, and a joint publication is in preparation. The data review meetings were held at INP's Nuclear Security Training Center (NSTC) and were concluded with lab tours of INP's nuclear forensics laboratories, as well as a visit to the VVR-K reactor and medical isotope production facility. Representatives from the Committee of Atomic and Energy Supervision and Control of the Ministry of Energy (CAESC), the National Nuclear Center Kurchatov (NNC), the Institute of High Technology (IHT) and Kazatomprom were invited as observers to the meeting.

LAWRENCE LIVERMORE NATIONAL LAB
NUCLEAR FORENSICS

LLNL-PRES-799527

Questions?

NSDD Partnership
Working Together to Prevent Nuclear Trafficking
The Office of Nuclear Smuggling Detection and Deterrence

mta E

NNSA
National Nuclear Security Administration

JAEA

LAWRENCE LIVERMORE NATIONAL LAB
NUCLEAR FORENSICS

Thank you ☺