CMX-6 Data Review Meeting – Day 1

4th – 6th June 2019
Warsaw, Poland

Jon Schwantes Pacific Northwest National Laboratory, Richland, Washington, USA
Olivia Marsden AWE, Aldermaston, UK

Welcome to CMX-6 DRM

- **Welcome-**
  - Institute of Nuclear Chemistry and Technology, Warsaw, Poland
- **Venue information**

Data Review Meeting Overview

- Day 1
  - Welcome and introductions
  - 24 hour report results
- Day 2
  - 1 week report results
  - Introduction to 2 month report results
  - DRM evening dinner
- Day 3
  - 2 month report results
  - Reveal/backstory
  - Lessons learned and future exercises
  - CMX-6 after action report schedule
  - Close out

Background

- 6th Collaborative Materials Exercise (CMX-6)
  - 1999-2000 Pu Oxide Powder, Round Robin 1
  - 2000-2002 HEU Powder, Round Robin 2
  - 2009-2010 HEU Metal, Round Robin 3
  - 2014-2015 LEU pellets and powder, CMX-4
  - 2016-2017 LEU pellets, theoretical injects, CMX-5

- Goal of CMX’s:

  …to improve international Technical Nuclear Forensics capabilities, cooperation, and communication between practitioners through the discovery, development, and sharing of best practices

ITWG Exercise Philosophy

- Each Laboratory's results are held in confidence
- A summary of exercise results is published (AAR- After Action Report)
- Uses "real world" samples – not reference materials
- Scenario based exercises with reporting times balancing the needs of the investigation with the limitations of methodologies
- Designed to target questions of both a (1) legal and (2) national security nature
  1. Is the material radioactive? Dangerous? LEU? HEU? Illegal to possess?
  2. Can we identify the origin? Can we include or exclude it from other materials?
- Use the Graded Decision Framework to accurately communicate exercise results

Benefits of participating in CM exercises

- **Put the lab capability into practice**
- **Utilise different techniques to answer questions that may be asked when nuclear material is seized by law enforcement agencies**
- **Compare results to other laboratories (although NOT a proficiency test)**
- **Exchange information on nuclear forensics with other laboratories**

CMX-6 Participant Statistics

- **Congratulations!!! You are all part of the largest Collaborative Materials Exercise in the 24 year history of the ITWG**

- **Sixth Collaborative Materials Exercise (CMX-6)**
  - **22** laboratories will have completed the exercise plus one virtual participation

  - Round Robin 1 (**RR1**), **6** participating laboratories
  - Round Robin 2 (**RR2**), **10** participating laboratories
  - Round Robin 3 (**RR3**), **9** participating laboratories
  - Collaborative Materials Exercise 4 (**CMX-4**), **16** participating laboratories
  - Collaborative Materials Exercise 5 (**CMX-5**), **20** participating laboratories

Caveats & Assumptions for CMX-6

- **CMX-6 is the 4th consecutive "paired comparison" exercise**
  - Supporting technical comparisons without the need for a NF Library
- **It is assumed that all participating laboratories have a satisfactory Quality Control and Quality Assurance program**
- **Exercise materials used:**
  - Have well known process history and laboratory analysis, but are not *"certified"* materials (when possible, mean values of all CMX-6 laboratory results are provided to illustrate consensus answers)
  - CMX-6 has a conventional forensics part of the exercise (not included since RR2)

Purpose of CMX-6

- **Improve TNF tools and best practices**
- **Assist labs to develop new and improve existing TNF capabilities**
- **Enhance decision making process by optimizing the ITWG Graded Decision Framework (GDF)**
- **Emphasize the utility of Group Inclusion/Exclusion (GIE) decisions related to TNF evaluations**
- **Address questions of both legal and National Security nature**

Ground Rules for CMX-6

- **Technical Learning Experience / not a performance test**
  - ITWG is not a governing body and does not have the "right answer"
  - Our job is to facilitate a discussion about best practices
- **Data Review Meeting is open to only participants or persons that have helped facilitate the exercise.**
- **All meeting discussions are to be held in confidence and not shared outside of this community**
- **Individual data points will be referenced using the code name for that laboratory at all times.**
- **Meeting participants are asked to refrain from references to data in a way that may divulge the identity of laboratories other than their own**

Participant Introductions

- Name
- Country
- ITWG exercises experience
- What was your lab hoping to gain from participation?

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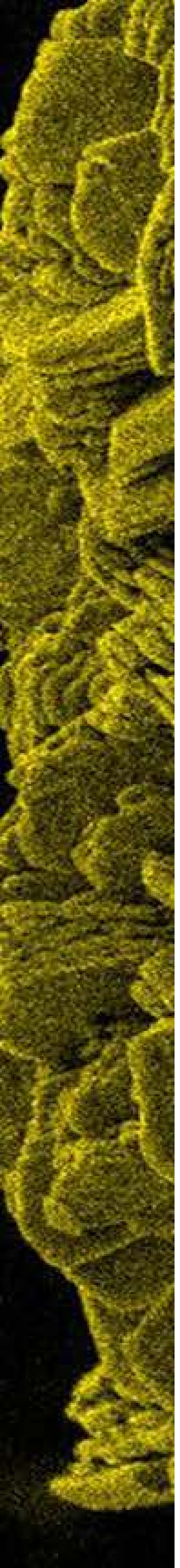
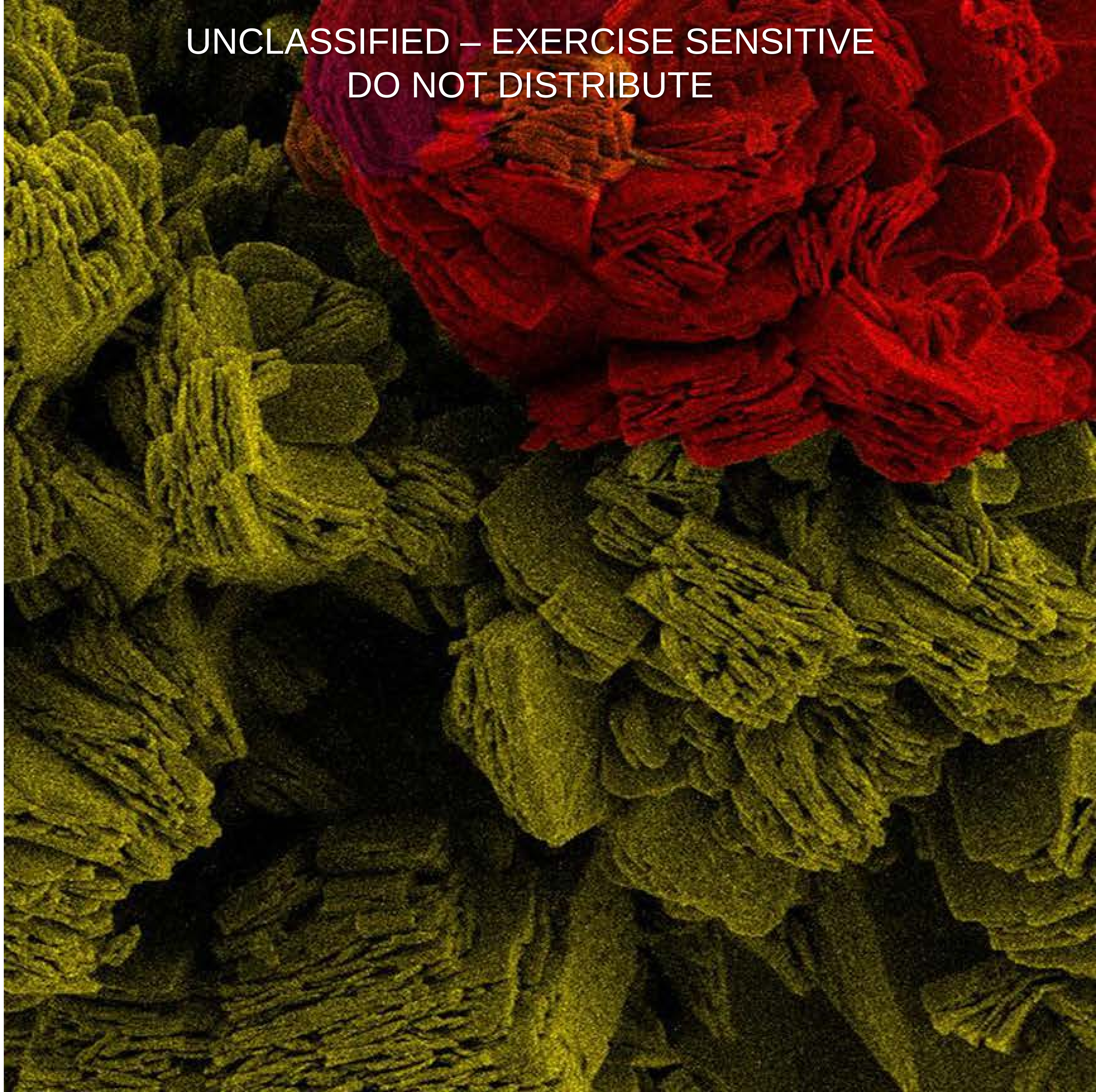


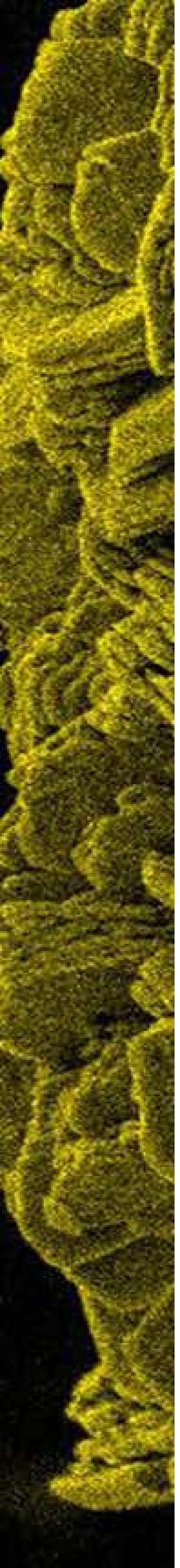


Operation Celestial Skónis

6th Collaborative Materials Exercise (CMX-6) of the Nuclear Forensics International Technical Working Group (ITWG)

Jon Schwantes & Olivia Marsden

Co-Chairs ETG, ITWG



Background

20 years of Materials Exercises

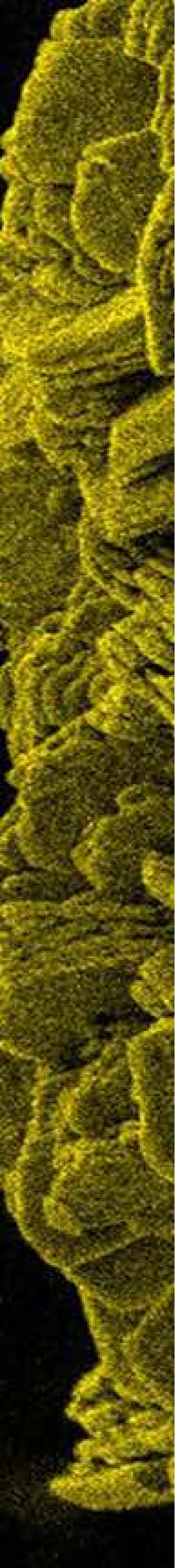
- 1999-2000 Pu Oxide Powder, RR1 (6)
- 2000-2002 HEU Powder, RR2 (10)
- 2009-2010 HEU Metal, RR3/CMX-3 (9)
- 2014-2015 LEU pellets and powder, CMX-4 (16)
- 2016-2017 LEU pellets, CMX-5 (20)
- 2018-2019 PuF_4 powder, Ce & DU Metal, CMX-6 (23)

Purpose:

…to improve international Technical Nuclear Forensics capabilities, cooperation, and communication between practitioners through the discovery, development, and sharing of best practices

Goal:

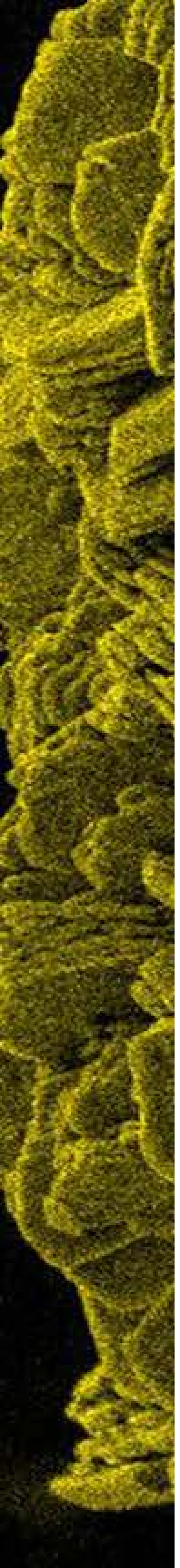
Evaluate the state of practice and identify emerging technologies



CMX-6 Participants

- 23 participants
- 19 shipped standard exercise materials
- 3 shipped exercise materials w/o Pu
- 1 virtual participant*

- Australia
- Azerbaijan
- Brazil*
- Canada
- France
- Germany
- European Commission
- Hungary-U
- Israel-U
- Japan-U
- Kazakhstan
- Korea
- Moldova
- Poland
- Romania
- Russia
- Singapore
- South Africa
- Sweden
- Switzerland
- UK
- Ukraine
- USA



Ground Rules / Design

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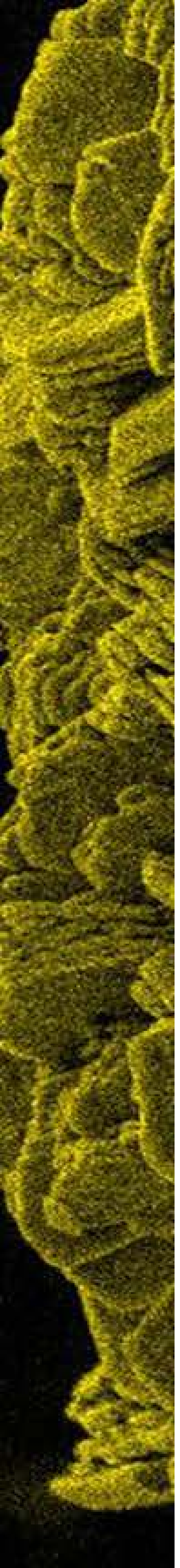
- Summary of exercise results is published
- Uses "real world" samples (i.e., not PT)
- Scenario based exercises with real-world reporting
- Designed to target questions of both a (1) legal and (2) national security nature
  - Is the material radioactive? Dangerous? LEU? HEU? Illegal to possess?
  - Can we identify the origin? Can we include or exclude it from other materials?

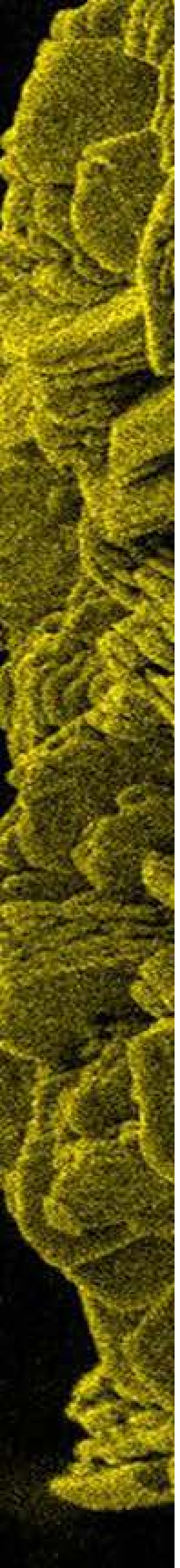
Key CMX-6 Design Features

- Include Traditional Forensics
- Utilize novel materials
- Blind receipt



Exercise Objectives

- Obj 1: Novel Materials
- Obj 2: NDA Categorization (24 hrs)
- Obj 3: 1-Week Characterization
- Obj 4: 2 Month Characterization
- Obj 5: Evaluation



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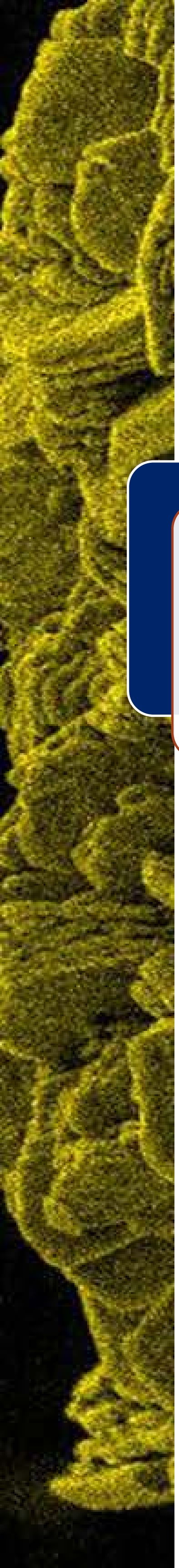
Performance Indicators

- Obj 1: Novel Materials
  - Cap 1.1: Receipt
    - PI 1.1.1: Paperwork
    - PI 1.1.2: Receipt of ES
  - Cap 1.2: Handling
    - Act 1.2.1: Radiological
      - PI 1.2.1.1: Visual Inspection
      - PI 1.2.1.2: Dose estimates
      - PI 1.2.1.3: Surface Contamination
    - Act 1.2.2: Ev. Inventory
      - PI 1.2.2.1: COC
      - PI 1.2.2.2: Photos
      - PI 1.2.2.3: Mass
      - PI 1.2.2.4: Dimensions
      - PI 1.2.2.3.5: Density
  - Cap 1.3: Comms
    - PI 1.3.1: Analytical Plan



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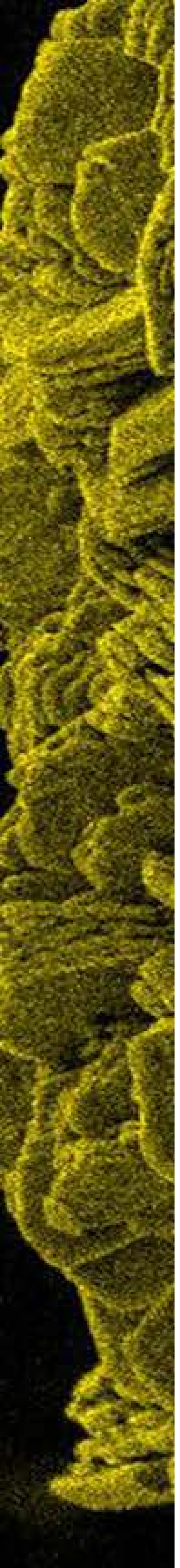
Performance Indicators

- Obj 2: NDA Categorization (24 hrs)
  - Cap 2.1: Isotopics
    - PI 2.1.1: Detect Pu in ES1 in 24 hrs
    - PI 2.1.2: Detect U in ES1 in 24 hrs
    - PI 2.1.3: Detect U in ES2 in 24 hrs
    - PI 2.1.4: Detect Pu in ES2 in 24 hrs
  - Cap 2.2: Elemental/Chemical
    - PI 2.2.1: ID Ce Metal in ES1 in 24 hrs
    - PI 2.2.2: ID trace in ES1 in 24 hrs
    - PI 2.2.3: ID U metal in ES2 in 24 hrs
    - PI 2.2.4: ID trace in ES2 in 24 hrs
  - Cap 2.3 Physical
    - PI 2.3.1: Microscopy of pipes
    - PI 2.3.2: Microscopy of ES's
  - Cap 2.4: Age Date
    - PI 2.4.1: U age
    - PI 2.4.2: Pu age
  - Cap 2.5: Traditional Forensics
    - Act 2.5.1: Fingerprinting
      - Task 2.5.1.1: Patent Prints
        - PI 2.5.1.1.1: Locate
        - PI 2.5.1.1.2: Image
      - Task 2.5.1.2: Latent Prints
        - PI 2.5.1.2.1: Develop
        - PI 2.5.1.2.2: Image
    - Act 2.5.2: Toolmarks
      - PI 2.5.2.1: Image and compare cut surfaces on pipes
      - PI 2.5.2.2: Image and compare cut surfaces on ES's

Purpose of the Data Review Meeting

- Opportunity to view your results relative to the community of results
- Please pay special attention to the results attributed to your lab:
  - Did we capture all of the important data you generated?
  - Is it accurate?
  - If either of these are not the case, please let me or Olivia know so we can correct this in the After Action Report



Case No. 52521, Sample ID: ES-1

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Inject 1 – 24 Hour Preliminary Report

- **On August 3, 2018, workers at Greene's Metal Recycling call health department after a shipment of scrap metal alarm their radiation detectors**
- **Health department confirms alarm, isolates radioactive material (~15cm metal pipe) and notifies Central Police. Pipe and contents are taken into custody**

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Case No. 52521, Sample ID: ES-2

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Inject 1 – 24 Hour Preliminary Report

- **On August 4, 2018, after a search by authorities of 6 metal foundries that contributed scrap to Greene's Recycling, recovered 31 additional pipe sections that were radioactive.**

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Inject 1 – 24 Hour Preliminary Report

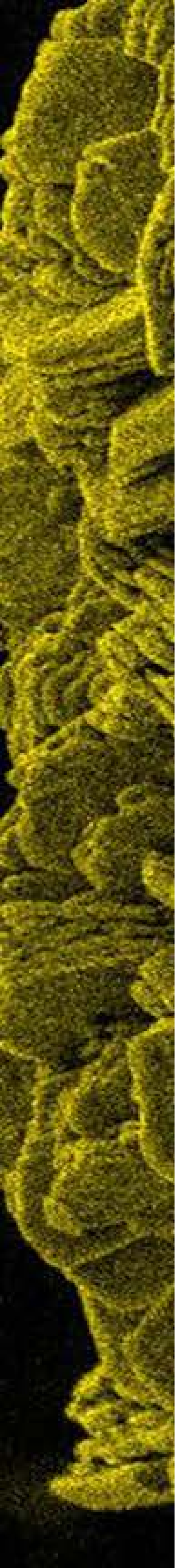
Authorities requested lab assistance to:

(1) Inventory evidence and conduct basic physical measurements

(2) Identify any potential traditional forensic evidence that might need to be processed

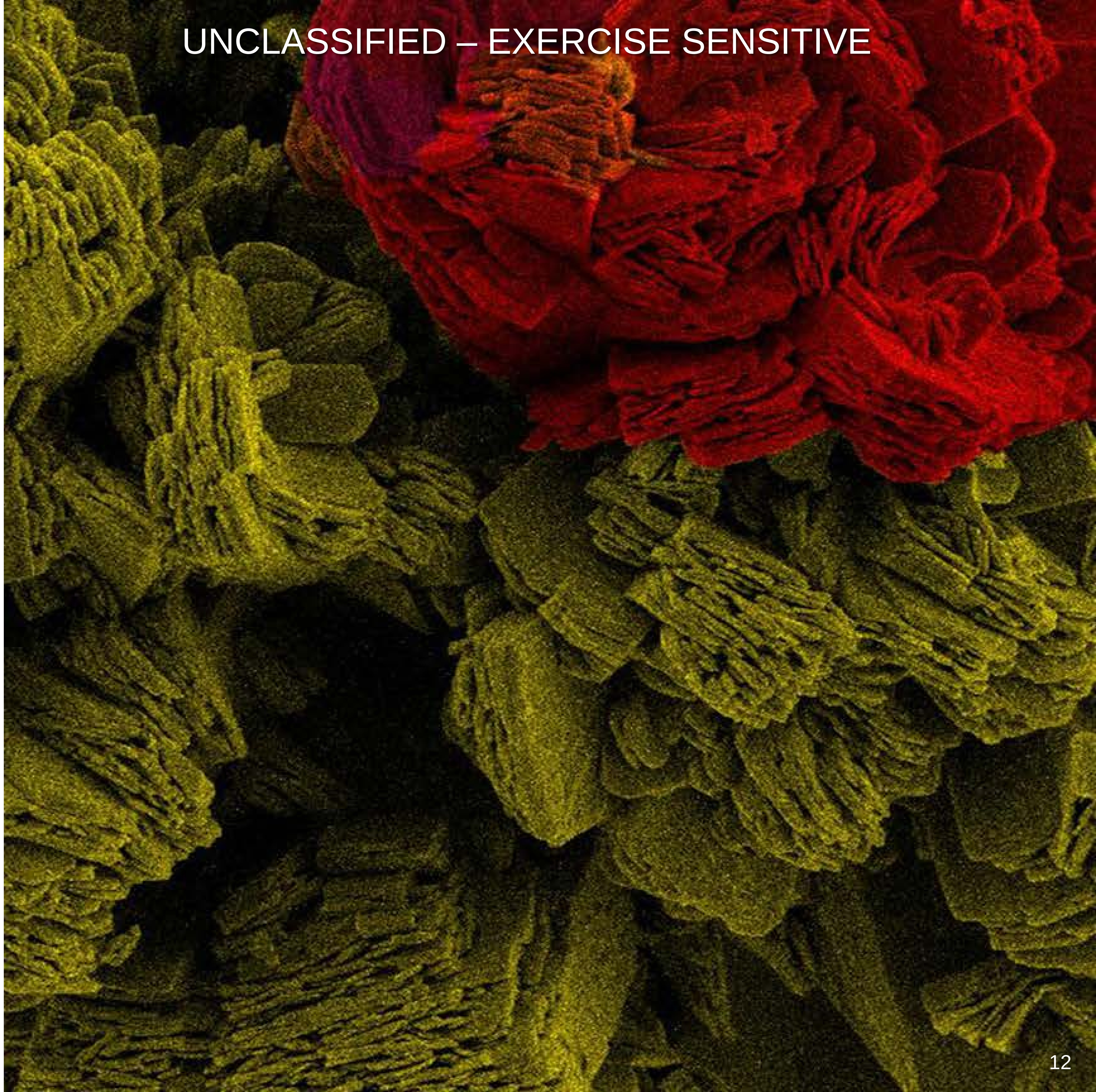
(3) Categorize radioactive items without (significantly) destroying any of the evidence

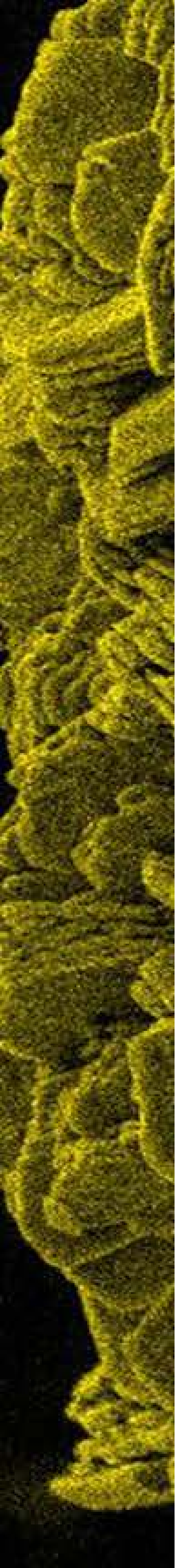
(4) Develop an analytical plan for the purpose of determining if ES-1 and ES-2 are related in any way



Pacific Northwest
NATIONAL LABORATORY

Thank you





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Laboratory Presentations – 24 Hours

TIME	TOPIC	Responsible
11:45 – 12:05 pm	24-hour report results	Azerbaijan
12:05 – 12:25 pm	24-hour report results	Ukraine
12:25 – 1:25 pm	Lunch	
1:25 – 1:45 pm	24-hour report results	Germany
1:45 – 2:05 pm	24-hour report results	Russia
2:05 – 2:20 pm	Break	
2:20 – 2:40 pm	Novel Methodologies in 24 hours - sample receipt / managing contamination	Hungary
2:40 – 3:00 pm	Novel Methodologies in 24 hours - sample receipt / managing contamination	Romania

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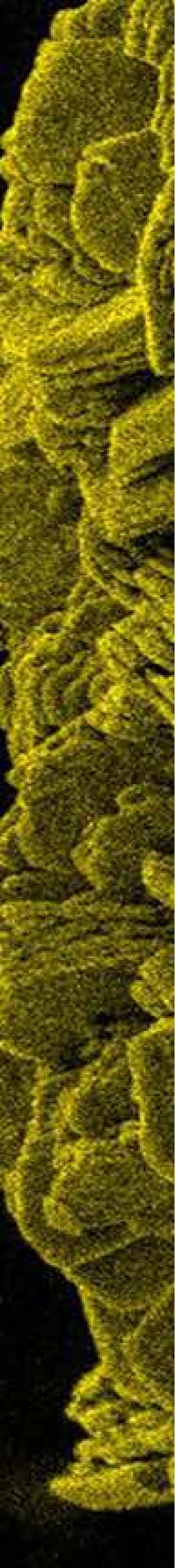
Summary of 24 Hour Reporting

Jon Schwantes & Olivia Marsden
Co-Chairs ETG, ITWG



24 Hour Reporting

- Summary of 24 Hour Analyses
  - Basic Physical Measurements
    - ✓ Mass uncertainties
    - ✓ Density Estimates
  - Trace Elements
  - Categorization – Isotopic Analyses
    - ✓ U isotopes
    - ✓ Pu & Am isotopes
    - ✓ Other
- Graded Decision Framework
- Notable Efforts
- Discussion: Lessons Learned

Purpose of the Data Review Meeting

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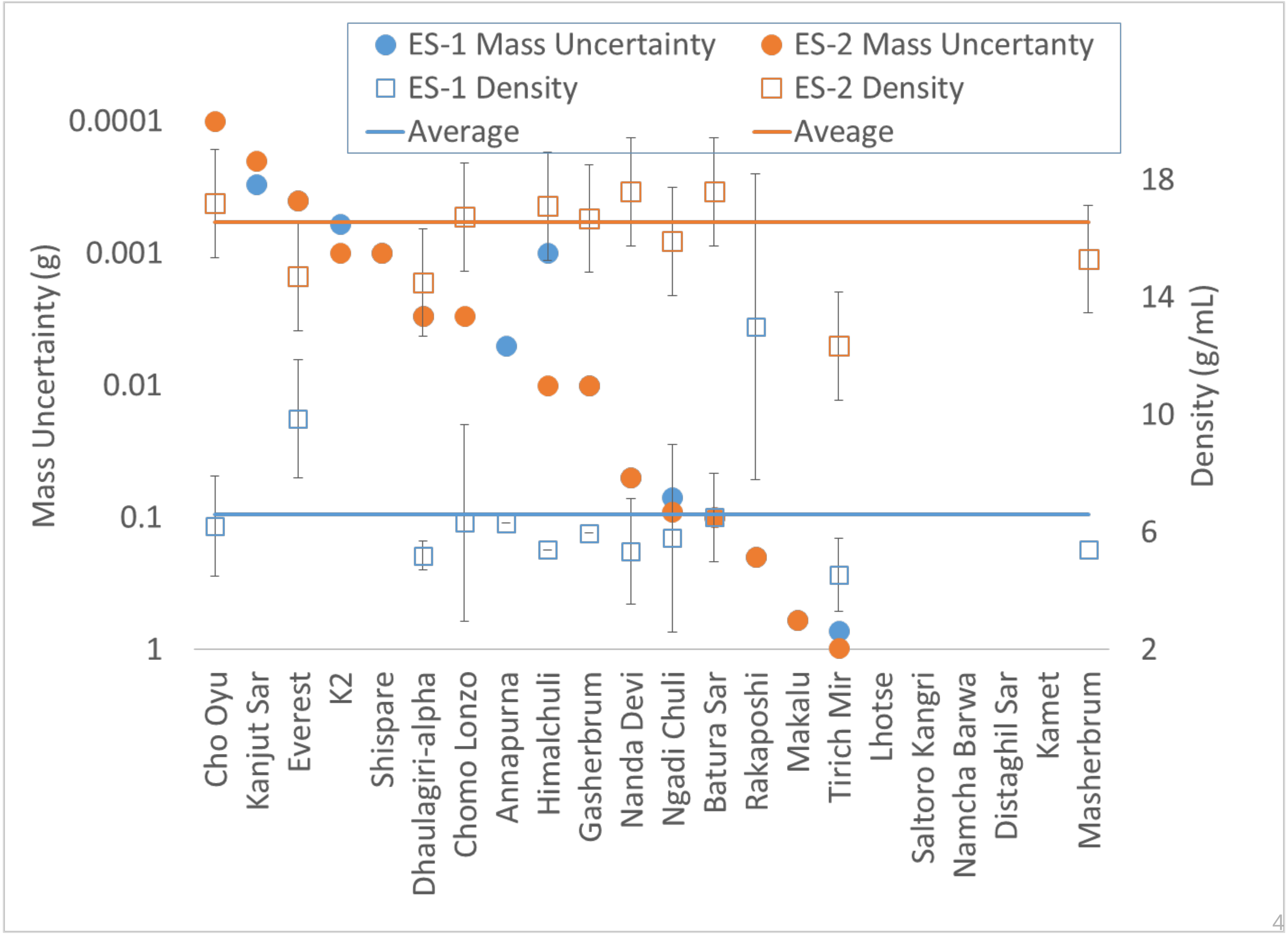
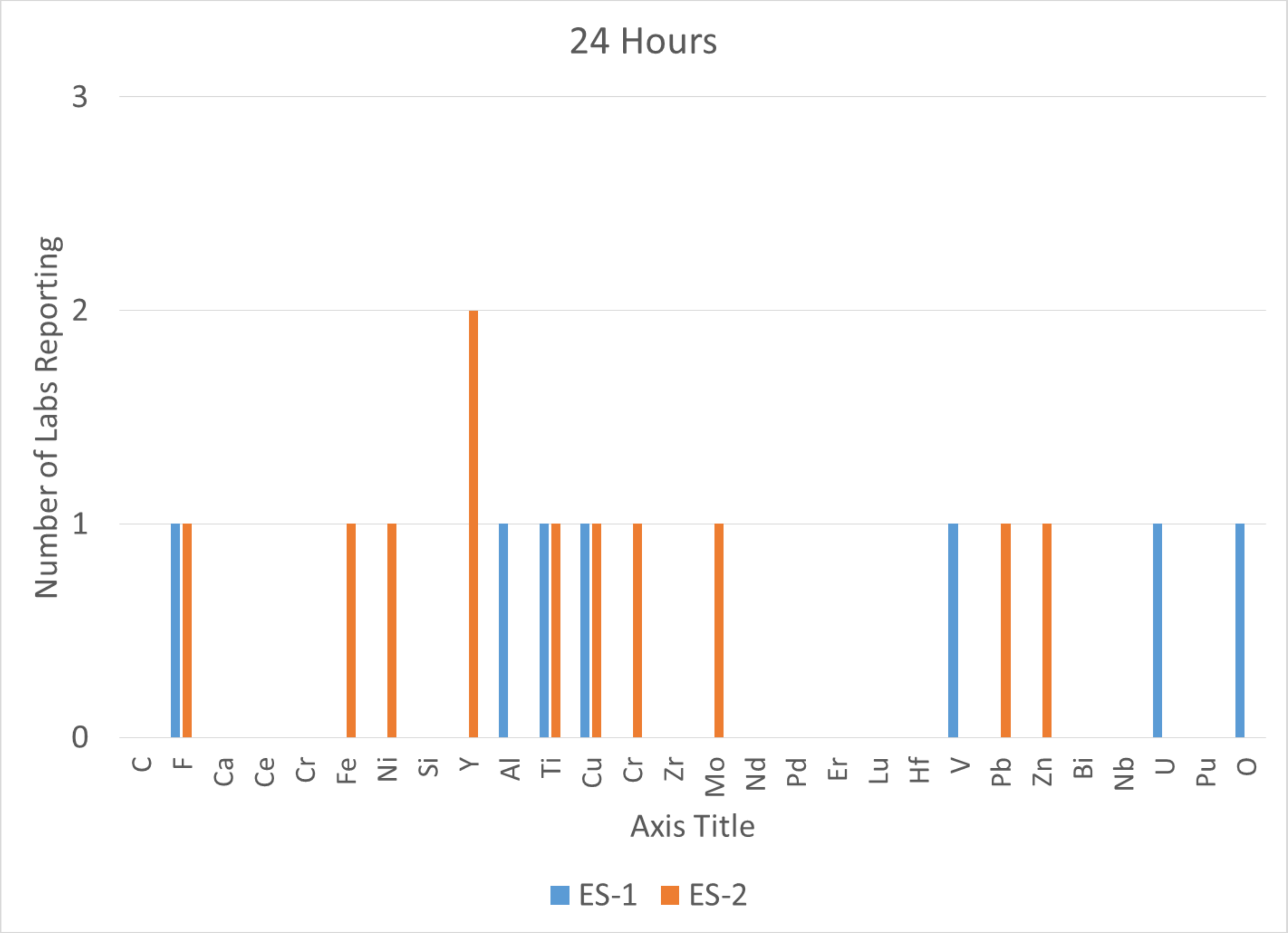
Comparison of Basic Physical Measurements

- 4 orders of magnitude difference in mass uncertainties
- Uncertainties of density measurement not correlated to mass uncertainty
- Complicated geometry (estimate of volume) likely drives density uncertainty
- All but 2 labs reported results in 24 hrs



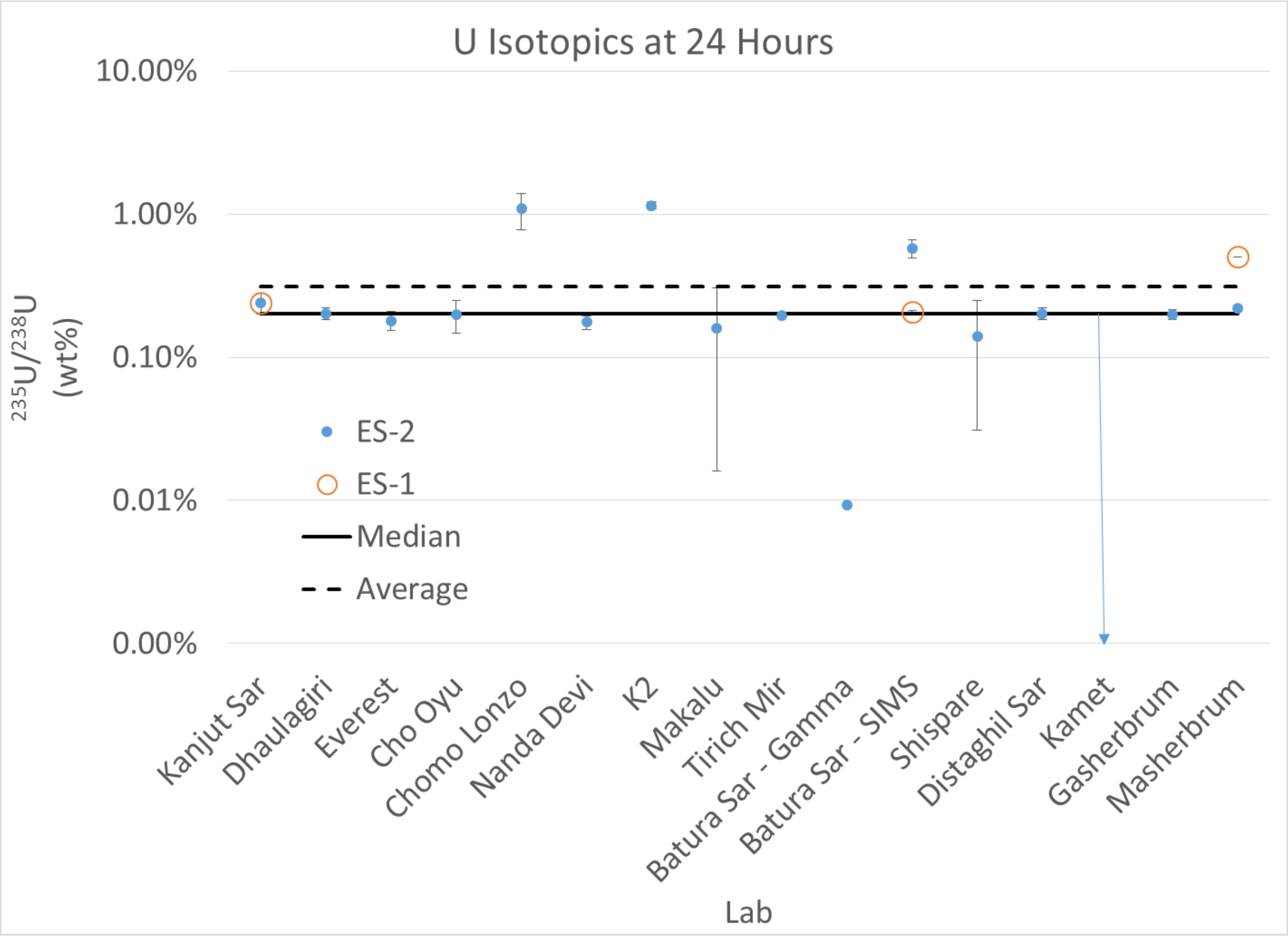
Trace Elements

- 7 labs reported trace elements in the first 24 hrs
- 6 used XRF, 1 used SEM-EDX
- Pipe
  - Makalu, Nanda Devi, Tirich Mir, Kamet-Gamma
- Ingots
  - Himalchuli, Tirich Mir, Masherbru,
  - Batura Sar - SEM-EDX
  - Gasherbram – X-ray ID of Ce via HPGe



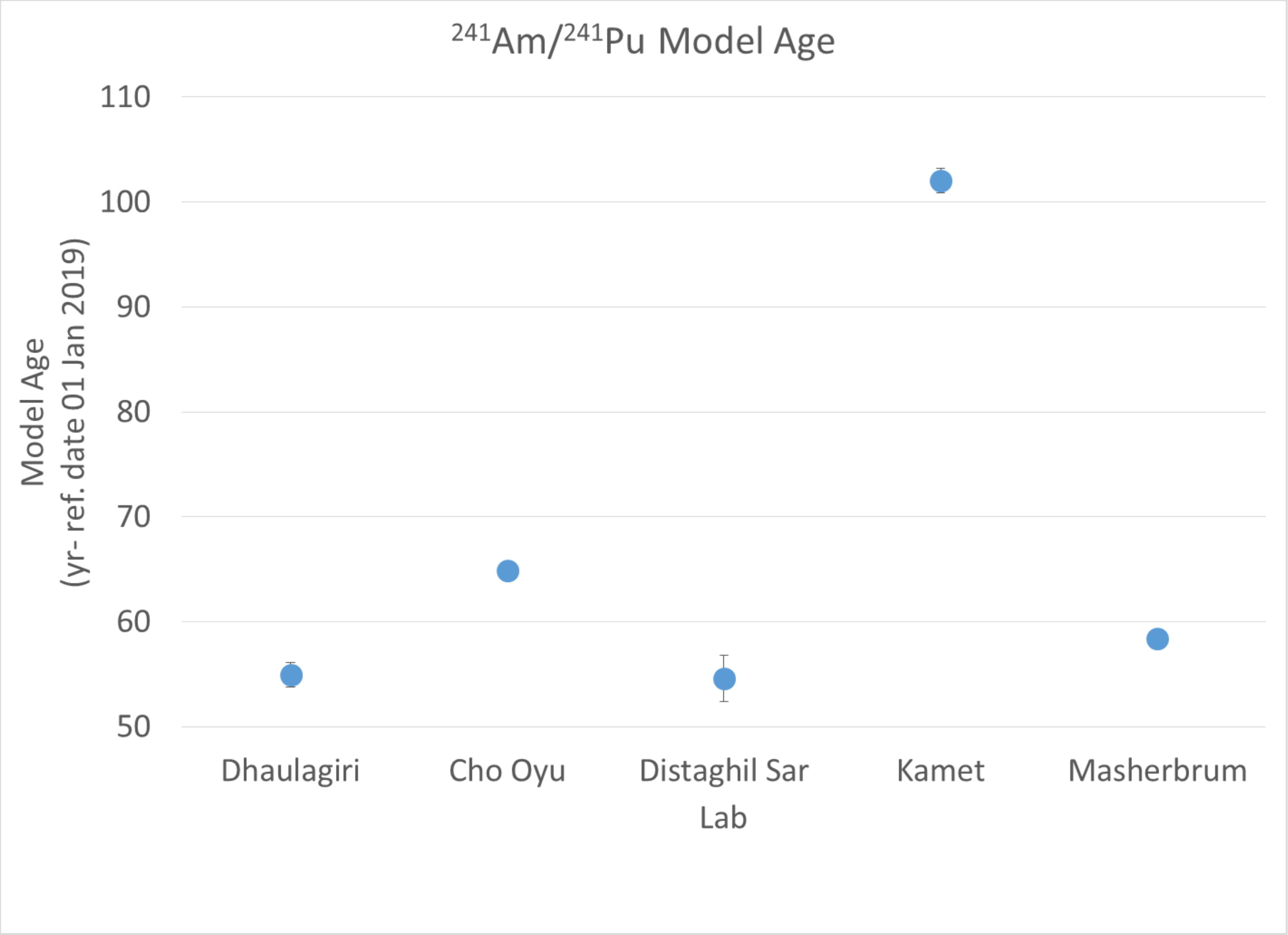
Uranium Isotopics at 24 hrs

- 6 labs detected U in ES-1
- 3 labs reported 235/238 ratios in ES-1
- All but 1 lab detected U in ES-2
- 16 labs reporting 235/238 ratios
- 1 of three labs show 235/238 ratios in ES-1 and ES-2 consistent with each other
- HPGe, 1xSIMS



Pu & Am Detection at 24 Hours

- 17 of the 20 labs received samples containing Pu
- Of those 17:
  - 13 detected Pu in ES-1
  - 7 detected Pu in ES-2
  - 13 detected ^{241}Am in ES-1
  - 12 detected ^{241}Am in ES-2
  - 5 labs reported model age
    - ✓ 2 of 5 were consistent with one another



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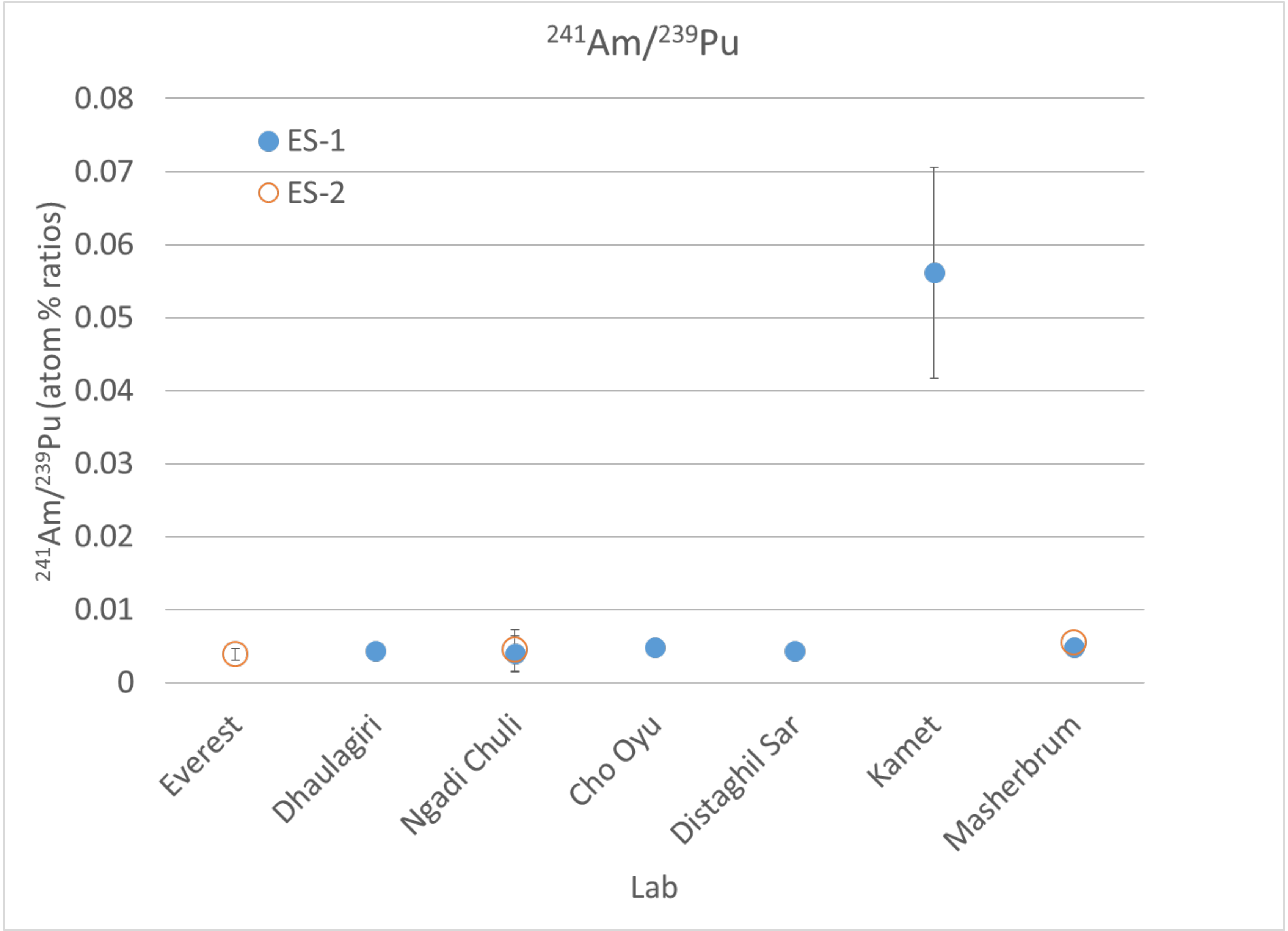
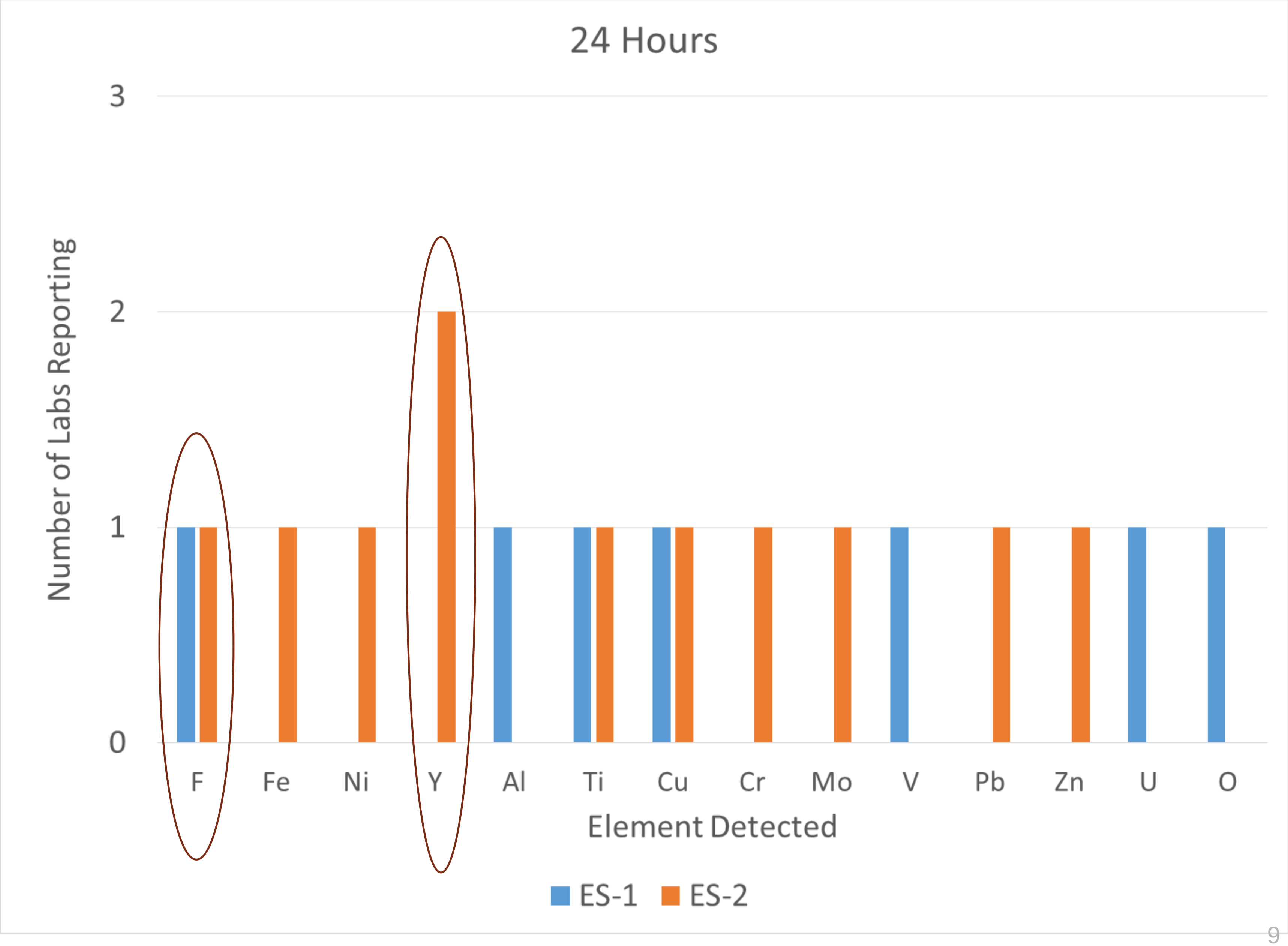
  - 7 detected Pu in ES-2
  - 13 detected ^{241}Am in ES-1
  - 12 detected ^{241}Am in ES-2
  - 6 labs reported ^{239}Pu/^{241}Am ratios for ES-1
  - 3 labs reported ^{239}Pu/^{241}Am ratios for ES-2
  - 2 labs reported ratios for both

- ES-1 and ES-2 consistent



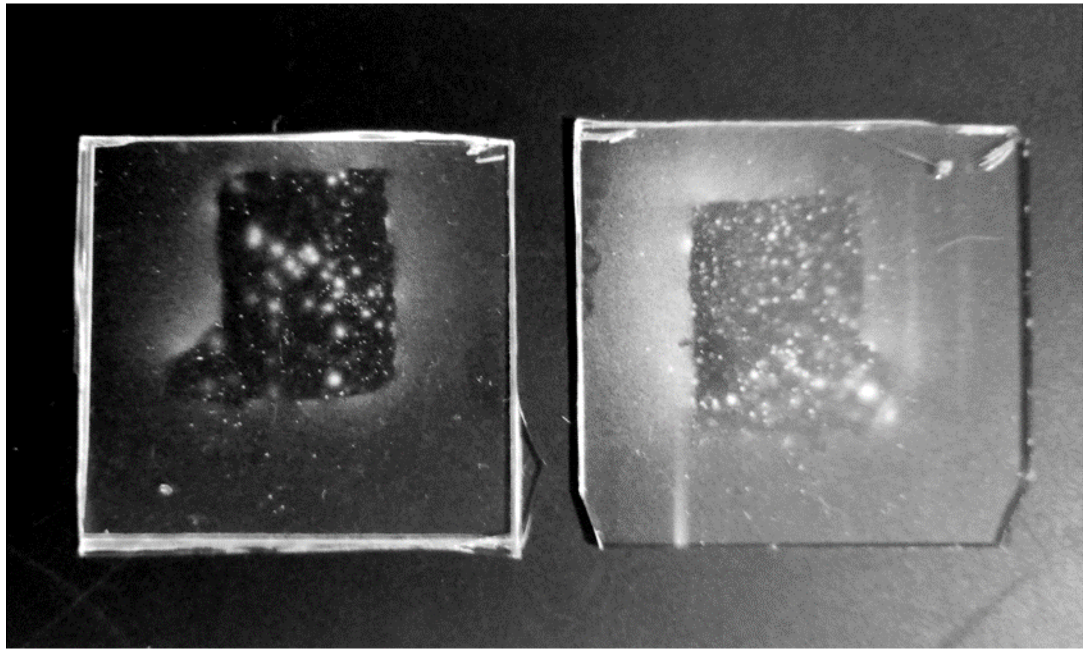
Notable Efforts in 24 Hours

- Chomo Lonzo and others – contamination control
- Batura Sar, Masherbrum & Tirich Mir
  - Detection of important trace contaminants (F, Y)
- Gasherbram – X-ray ID of Ce via HPGe

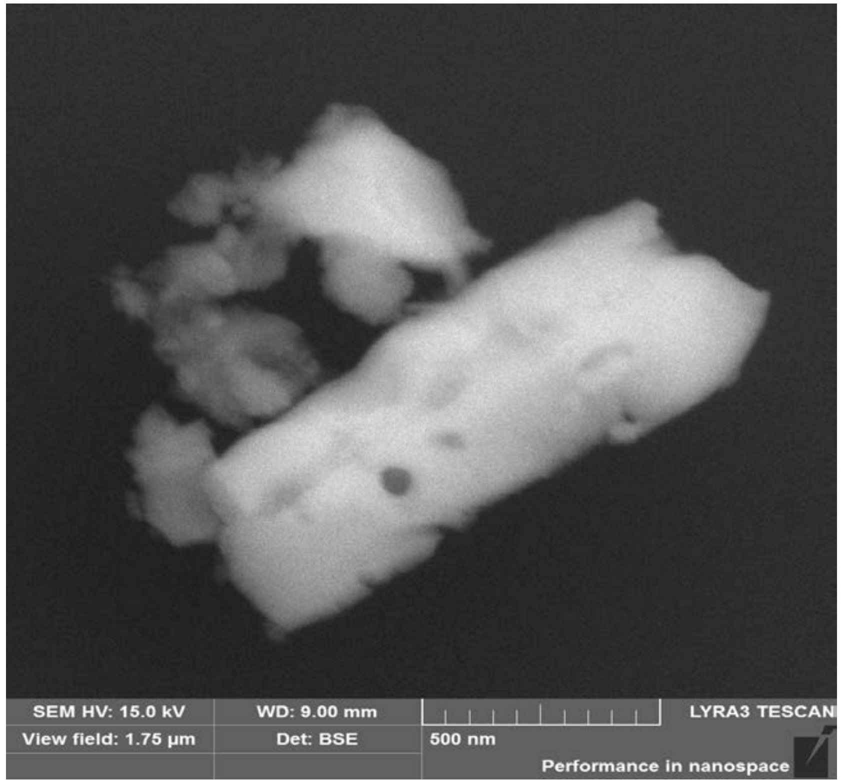


Notable Efforts in 24 Hours

- Batura Sar – alpha track, SEM and SIMS analysis at 24 hrs!
  - Detection of U contamination on Ce



ES-1 alpha-tracks over sample ES-1 (Batura Sar).



ES-1 Pu-containing particle. Approximate elemental composition: Pu - 80.2%, O - 11.3%, F - 6.6%, Ce - 1.5%, Al - 0.4%.

Notable Efforts in 24 Hours

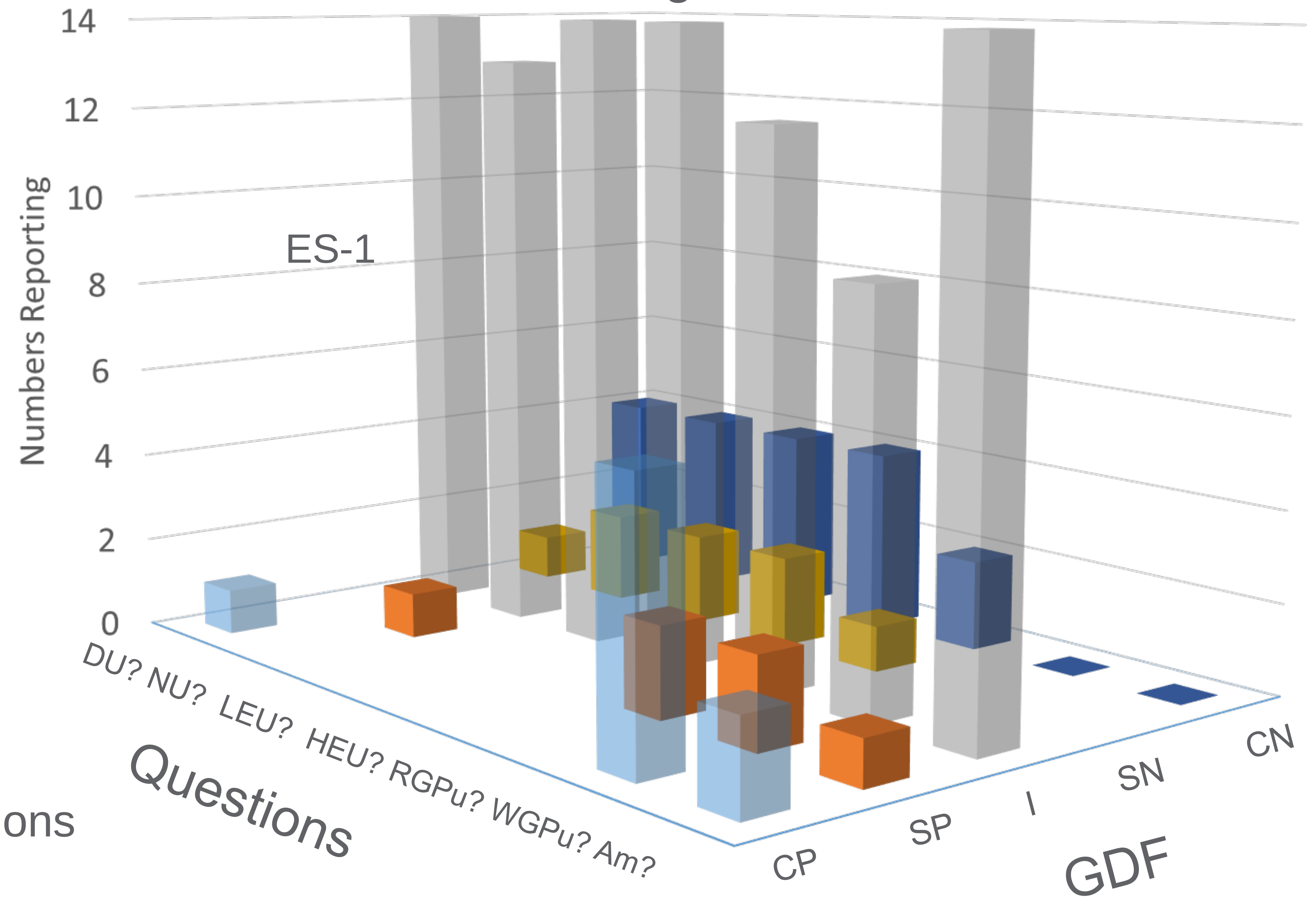
- Rakaposhi – detection of ^{22}Na

$$^{19}F(\alpha, n)^{22}Na$$

  - Alpha energy barrier for this reaction is ~5MeV…suggesting the presence of an element in fluoride form (e.g., Pu, but not U) that emits an alpha particle with an energy >5MeV
- Dhaulagiri, Cho Oyu, Kamet, Masherbrum - Pu age determination
- Everest, Ngadi Chuli, Masherbrum - Group Inclusion / Exclusion using $^{241}Am/^{239}Pu$
- Cho Oyo, 24 hour analysis of Pu by alpha spectrometry
- Gasherbrum, segregation of traditional evidence from radioactivity for analysis outside of radiochemical laboratory

Graded Decision Framework

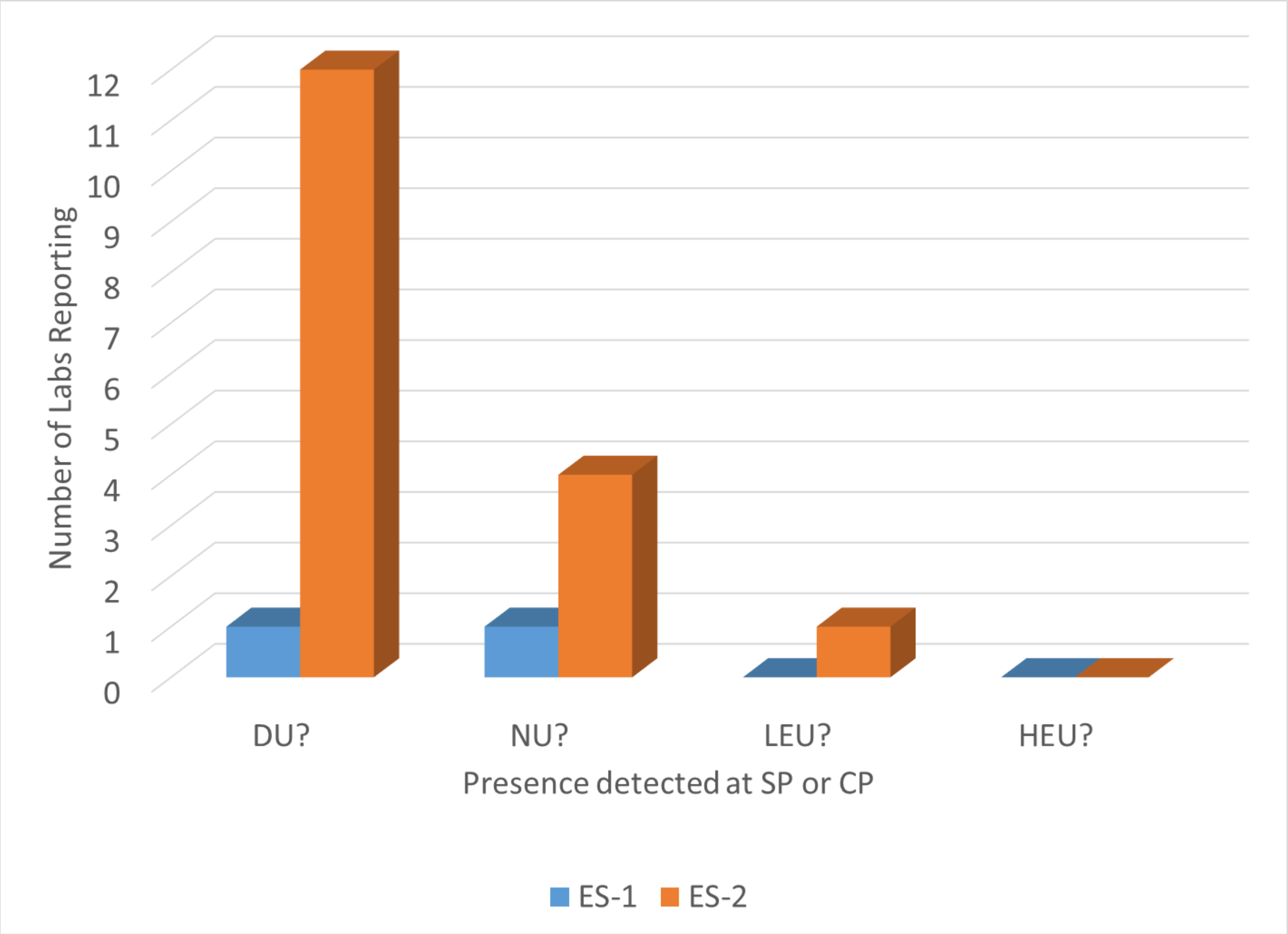
- Ratio of Conclusive Decisions to those labs not recording a decision for ES-1:
  - DU? – 5/14
  - NU? – 4/13
  - LEU? – 4/14
  - HEU? – 4/14
  - RGPu? – 2/12
  - WGPu? - 6/9
  - Am? - 2/14



*NR marked as I
*20 labs total for U questions
*17 labs total for Pu/Am questions

U Detection at 24 Hours

- 2 labs out of 20 identified DU or NU in ES-1 with SP or CP confidence
- 16 out of 20 identified ES-2 as DU or NU with SP or CP confidence



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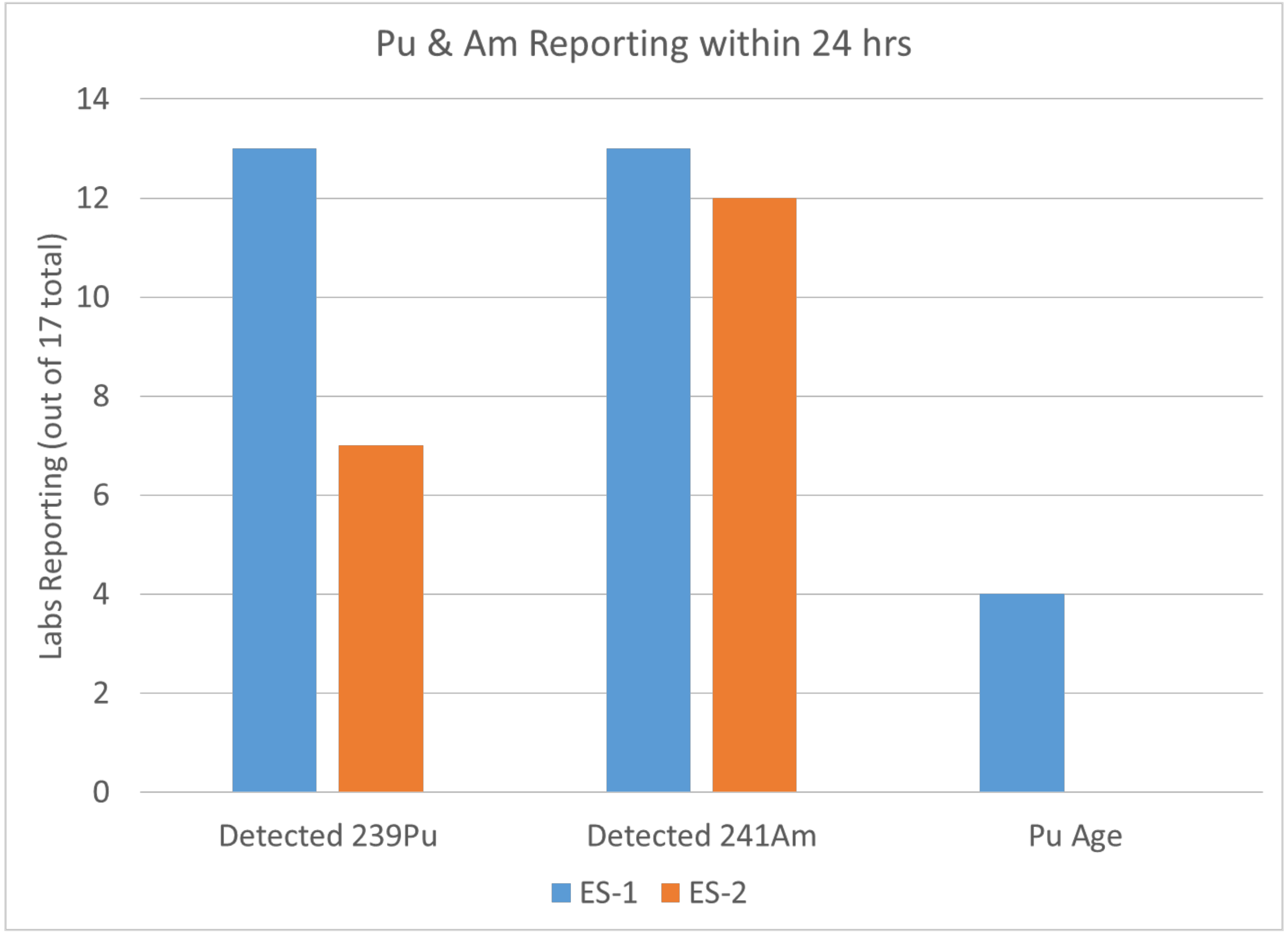

Discussion

- Exercise Objectives?
  - Primary Objectives – Novel Materials*, Traditional Forensics, Blind Receipt
  - General Objectives – Physical characteristics, Phase ID, Trace Elements, Isotopics, Particles, Evaluations at 24 hours, 1 week, 2 months?
  - Inject location (with samples)?
- Sample shipping / receipt?
  - Issues with packaging?
  - Issues with “Blind” receipt?
- Exercise Timing?
  - Every 2 years or every 3 years?
  - Time of year still ok? (we currently target the fall as the start of the exercise)
  - Timing of this exercise? / DRM?
- Other comments related to logistics and the first 24 hrs of play?
- Exercise Scenario? – save for discussion after 2 month reporting
- *Exercise Materials? – save for discussion after 2 month reporting

Discussion Cont'd

- Exercise Play in the First 24-Hours?
  - Was inject 1 appropriate for this scenario?
    - ✓ Issues with waiting on DA until after the 24-hr report?
  - What methodologies were used?
  - Which ones were useful? Were there any that were not useful?
  - Were there any methodologies you wanted to use but didn't?
  - Was there anything you would do differently in the first 24 hours knowing what you know now?
- Any other comments / Questions related to the first 24 hours of exercise play?

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Inject 2 & Introduction to 1-Week Report

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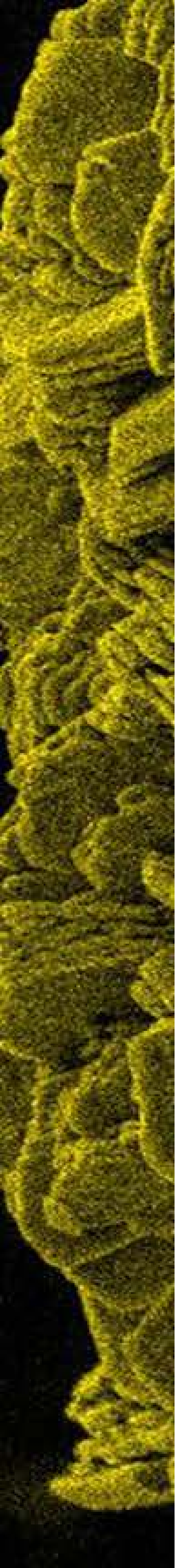
- Exercise Objectives / Performance Metrics for 1 Week Report
- Inject 2
- 1 Week schedule of presentations



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Exercise Objectives

- Obj 1: Novel Materials
- Obj 2: NDA Categorization (24 hrs)
- Obj 3: 1-Week Characterization
- Obj 4: 2 Month Characterization
- Obj 5: Evaluation

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Performance Indicators

- Obj 3: 1-Week Characterization
  - Cap 3.1: Isotopics
    - PI 3.1.1: Detect Pu in ES1 in 24 hrs
    - PI 3.1.2: Detect U in ES1 in 24 hrs
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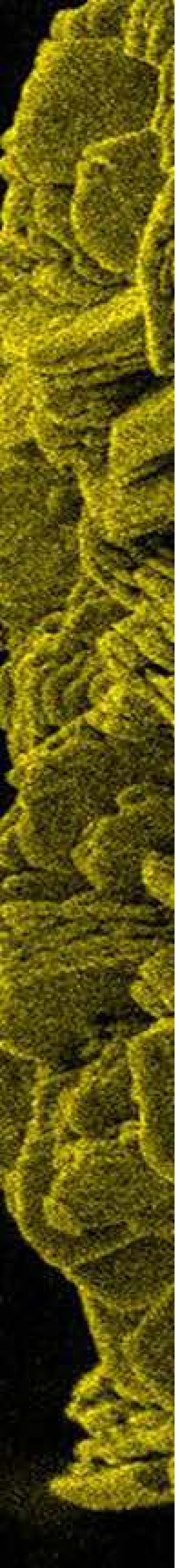

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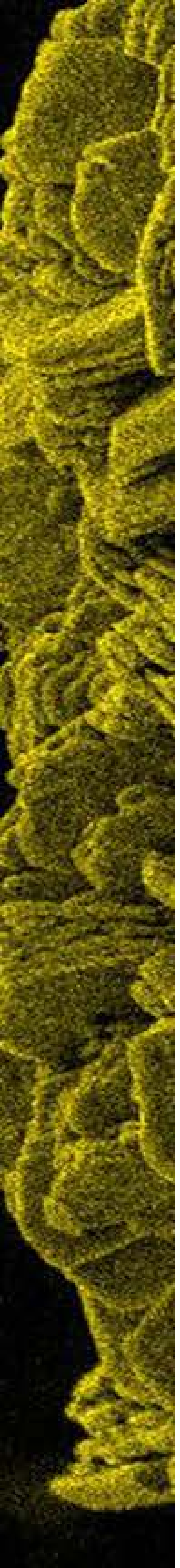
Inject 2 – 1-Week Preliminary Report

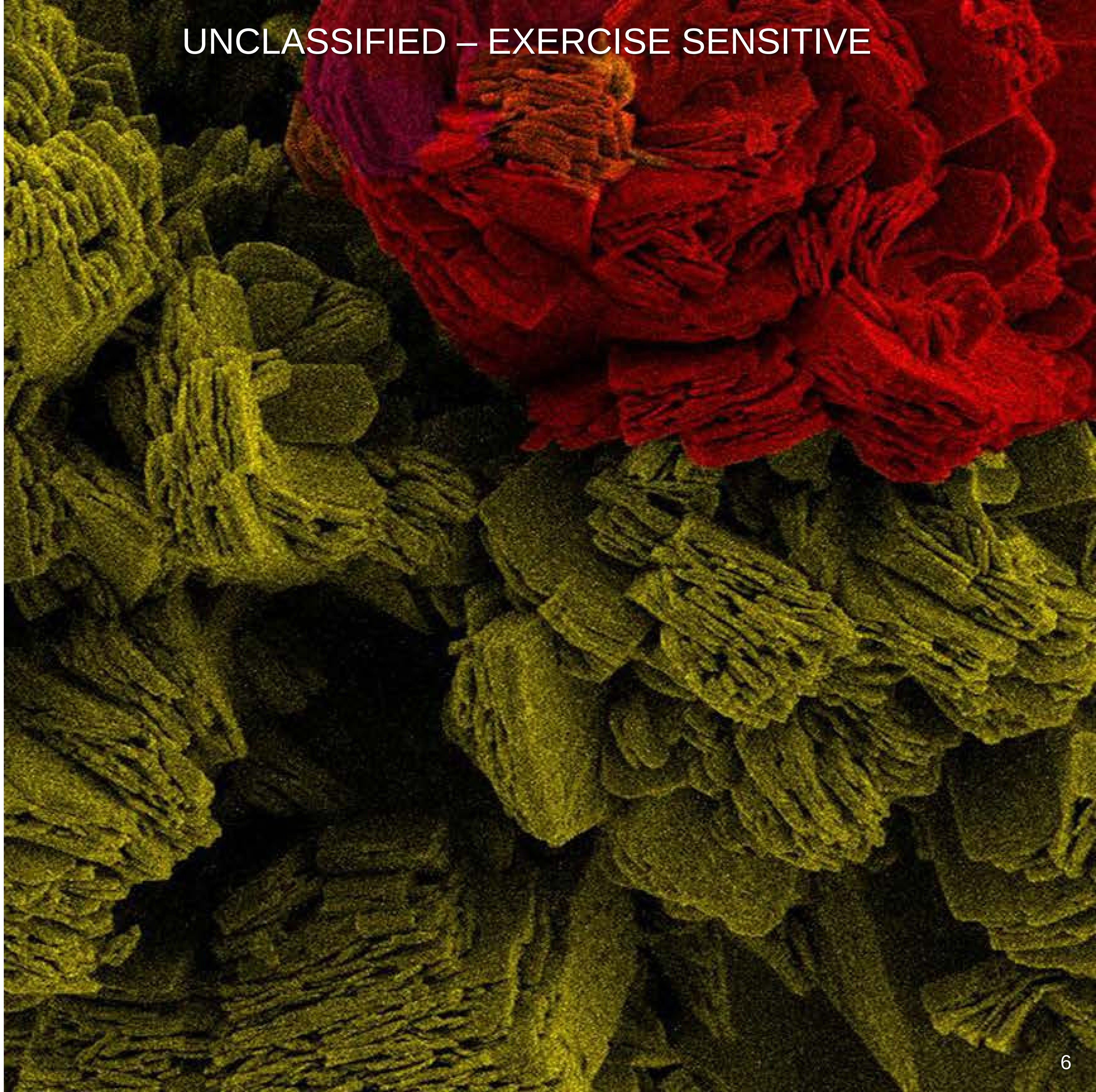
Lead investigator has received your 24 hour report and approved your Analytical Plan

1) **Proceed with your proposed analyses of ES-1 & ES-2**
2) **Using new or old version of the GDF, determine if the metal pipes associated with ES-1 and ES-2 consistent with one another?**
3) **Determine chemical composition / phase of ES-1**
4) **Determine chemical composition / phase of ES-2**
5) **Using new or old version of the GDF, determine if the radioactive ingots associated with ES-1 and ES-2 are consistent with one another?**
6) **Evaluate any other traditional or nuclear forensic evidence that may link ES-1 and ES-2 using either version of the GDF.**

Report all results to the LI within 6 days



Thank you



Laboratory Presentations – 1 Week

9:45 – 10:05 am	1-Week report results	Poland
10:05 – 10:25 am	1-Week report results	Sweden
10:25 – 10:45 am	Break	
10:45 – 11:05 am	1-Week report results (U Only)	Japan
11:05 – 11:25 am	1-Week report results	Singapore
11:25 – 11:45 pm	1-Week report results (U Only)	Israel
11:45 – 12:05 pm	1-Week report results (with focus on comparing GDF-A and GDF-B)	Korea
12:05 – 1:05 pm	Lunch	
1:05 – 1:25 pm	Novel Methodologies 1-Week – traditional forensics	Australia
1:25 – 1:45 pm	Novel Methodologies 1-Week – traditional forensics	JRC

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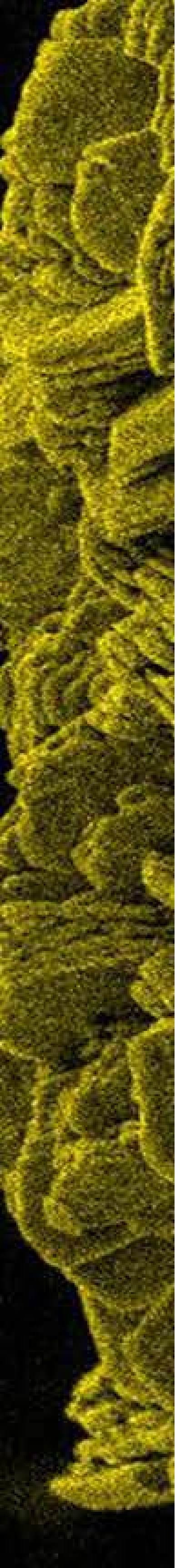
Summary of 1-Week Reporting

6th Collaborative Materials Exercise (CMX-6) of the Nuclear Forensics International Technical Working Group (ITWG)

Jon Schwantes & Olivia Marsden
Co-Chairs ETG, ITWG



1-Week Reporting

- Summary of 1-Week Analyses
  - Traditional Evidence
  - Physical Characterization
  - Phase ID
  - Chemical / Elemental Characterization
    - ✓ Bulk
    - ✓ Surface
  - Isotopic Characterization
    - ✓ Bulk
    - ✓ Surface
- Evaluation
  - Age Dating
  - Pedigree
  - Graded Decision Framework
- Notable Efforts
- Discussion: Lessons Learned

Purpose of the Data Review Meeting

- Opportunity to view your results relative to the community of results
- Please pay special attention to the results attributed to your lab:
  - Did we capture all of the important data you generated?
  - Is it accurate?
  - If either of these are not the case, please let me or Olivia know so we can correct this in the After Action Report

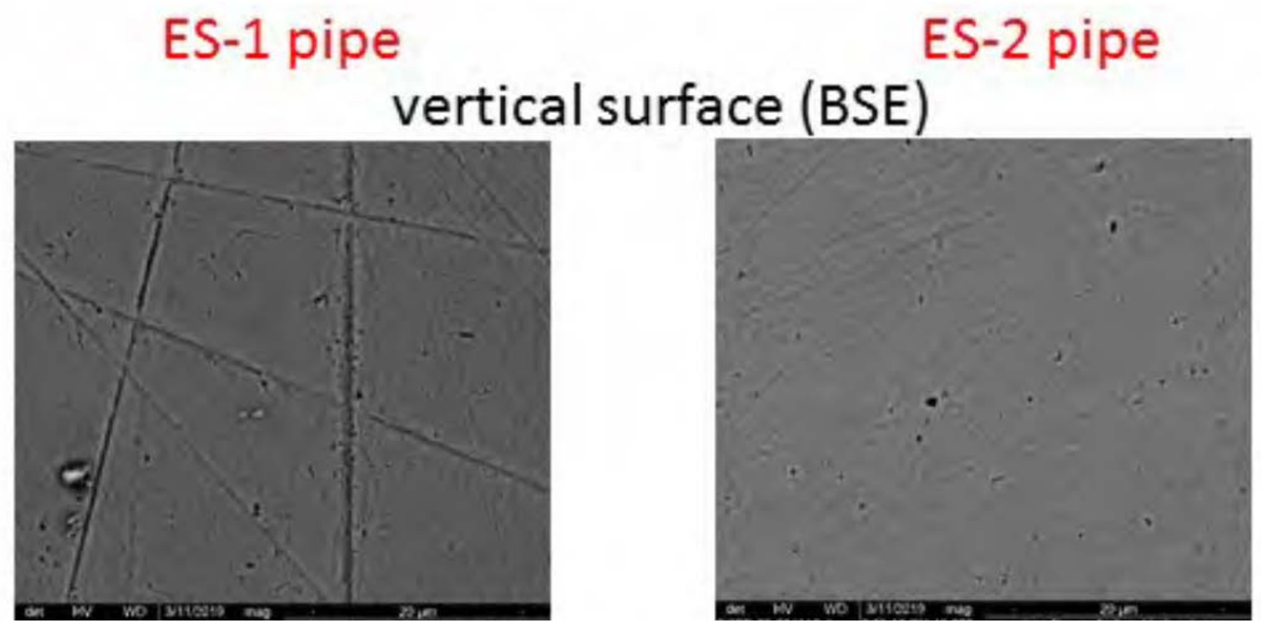
Traditional Evidence

- K2 performed fiber analysis of evidence recovered from ES-1
- 5 labs developed fingerprints in 1-week
- 6 labs compared tool marks on the pipes
- Cho and Masherbrum Oyo compared tool marks on ingots
- Rakaposhi compared tool marks on plastic bags

Image of fiber found on ES-1 processed by K2

Physical Measurements

- Optical & Electron Microscopies utilized extensively.
  - 6 labs reported OM results in 1 Week report
  - 9 labs reported SEM results in 1 week

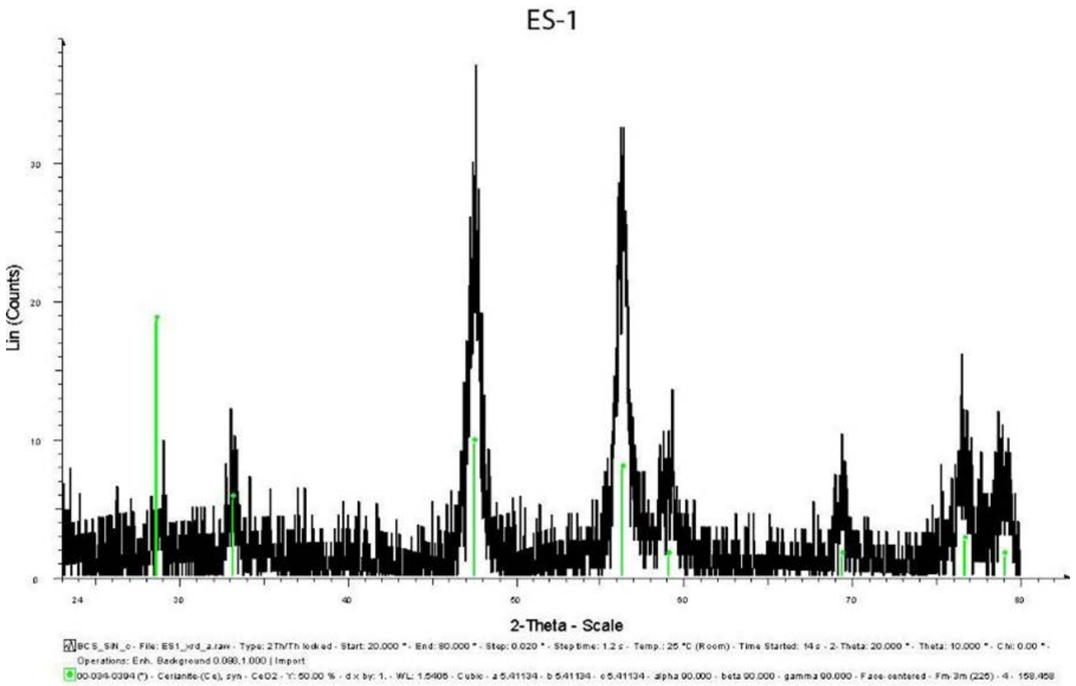


SEM images of ES-1 and ES-2 showing remnants of polishing (Masherbrum).

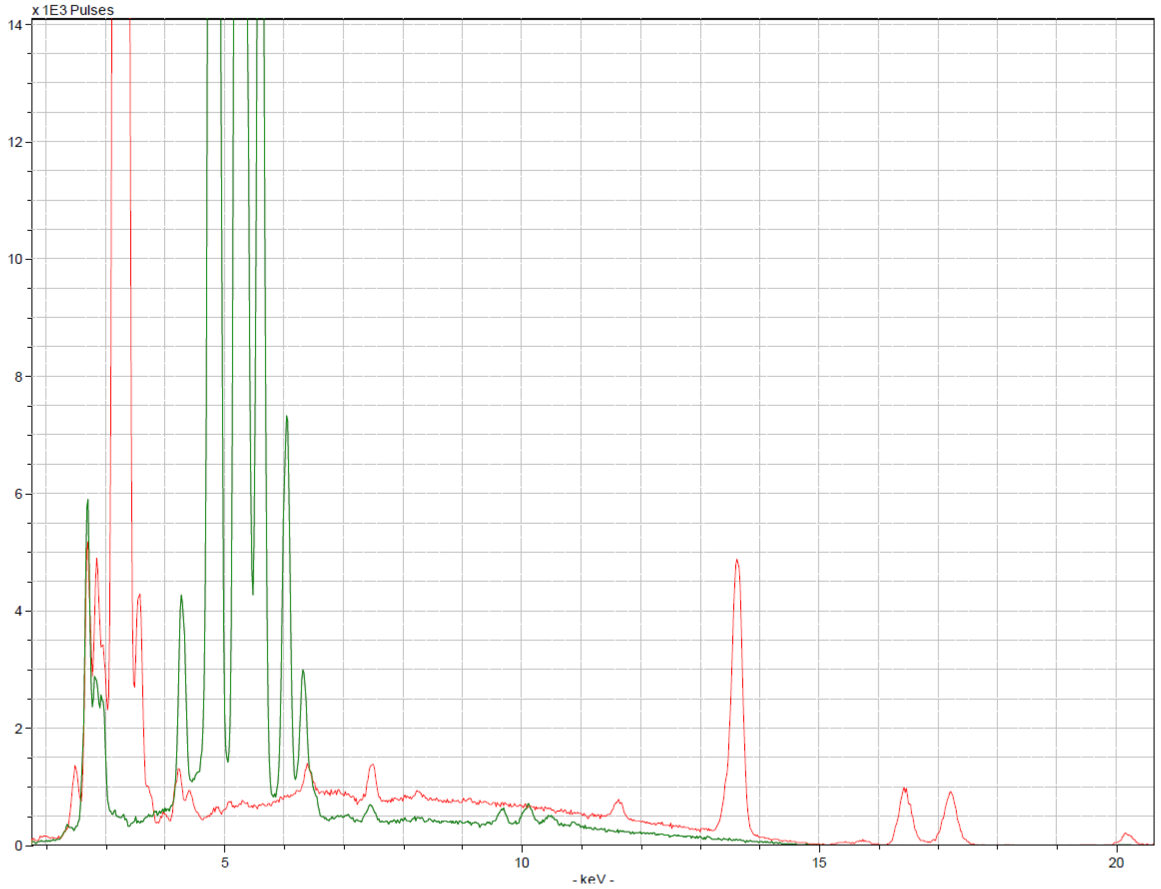
Digital optical microscope image of ES-1 (Cho Oyu).

Phase ID of Ingots

- Chomo Lonzo, Batura Sar, Rakaposhi and Annapurna evaluated phase of ingots with pXRD
- 7 labs used alternative means (Gamma spec, XRF, IR, SEM-EDX) to identify phase of ingots



XRD pattern of ES-1 reported by Chomo Lonzo



Comparison of XRF spectra from ES-1 and ES-2 by Kanjut Sar

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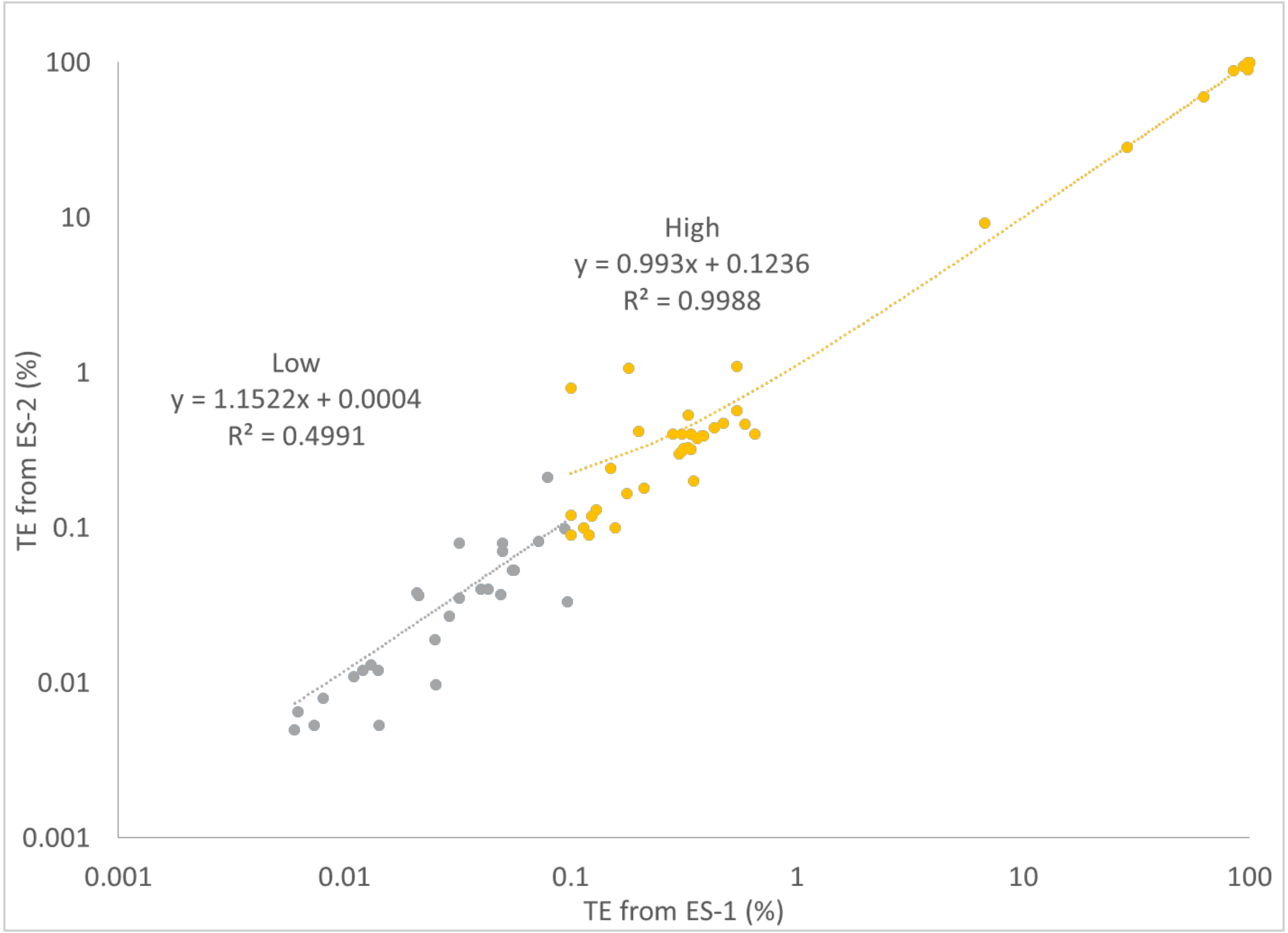
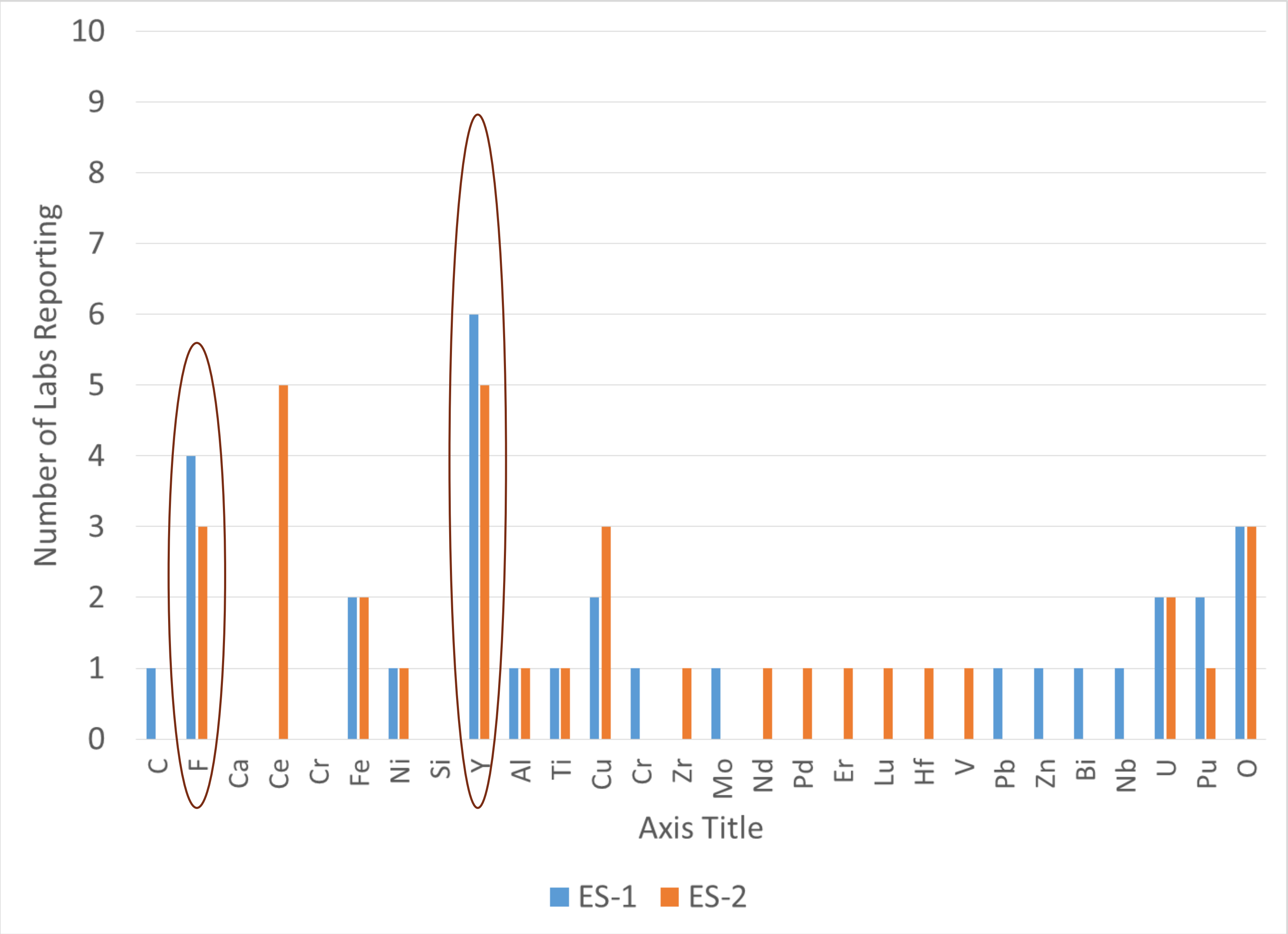
Trace Elements - bulk

- Good correlation between trace elements found in pipes
- Techniques applied: qICP-MS, SF-ICP-MS, ICP-OES
- Labs reporting values in 1 week: Nanda Devi, Batura Sar, K2, Kamet, Shispare, and Namcha Barwa



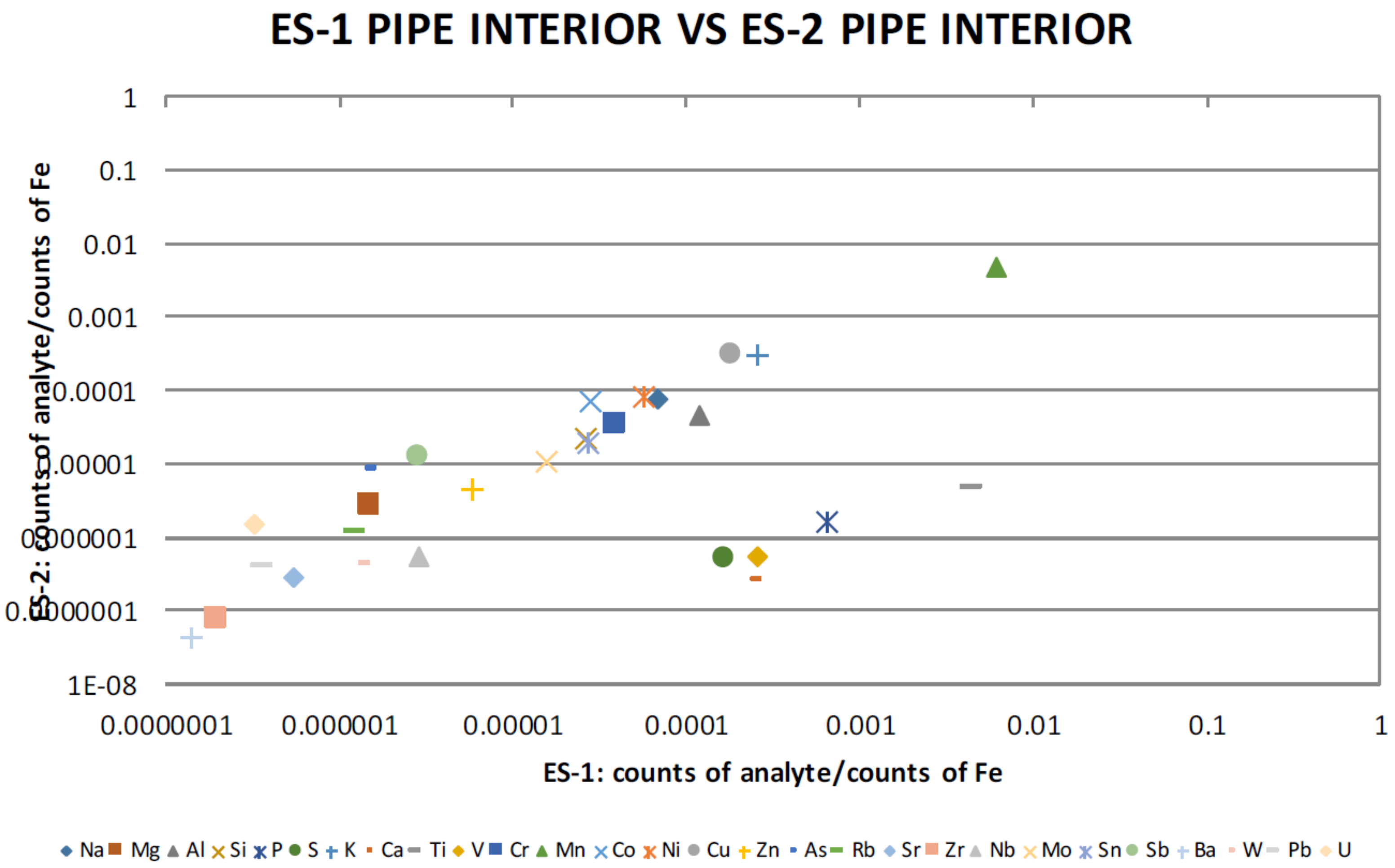
Trace Elements

- 13 labs reported trace elements within the first week
  - 3 surface techniques: 6xXRF, 4xSEM, and 1xLA-QQQ-ICP-MS
  - More labs identify presence of significant contaminants



Trace Elements

- Everest applied LA-QQQ-ICP-MS
  - Quantitative results of surface elemental analysis compared well with bulk analysis



Trace Elements

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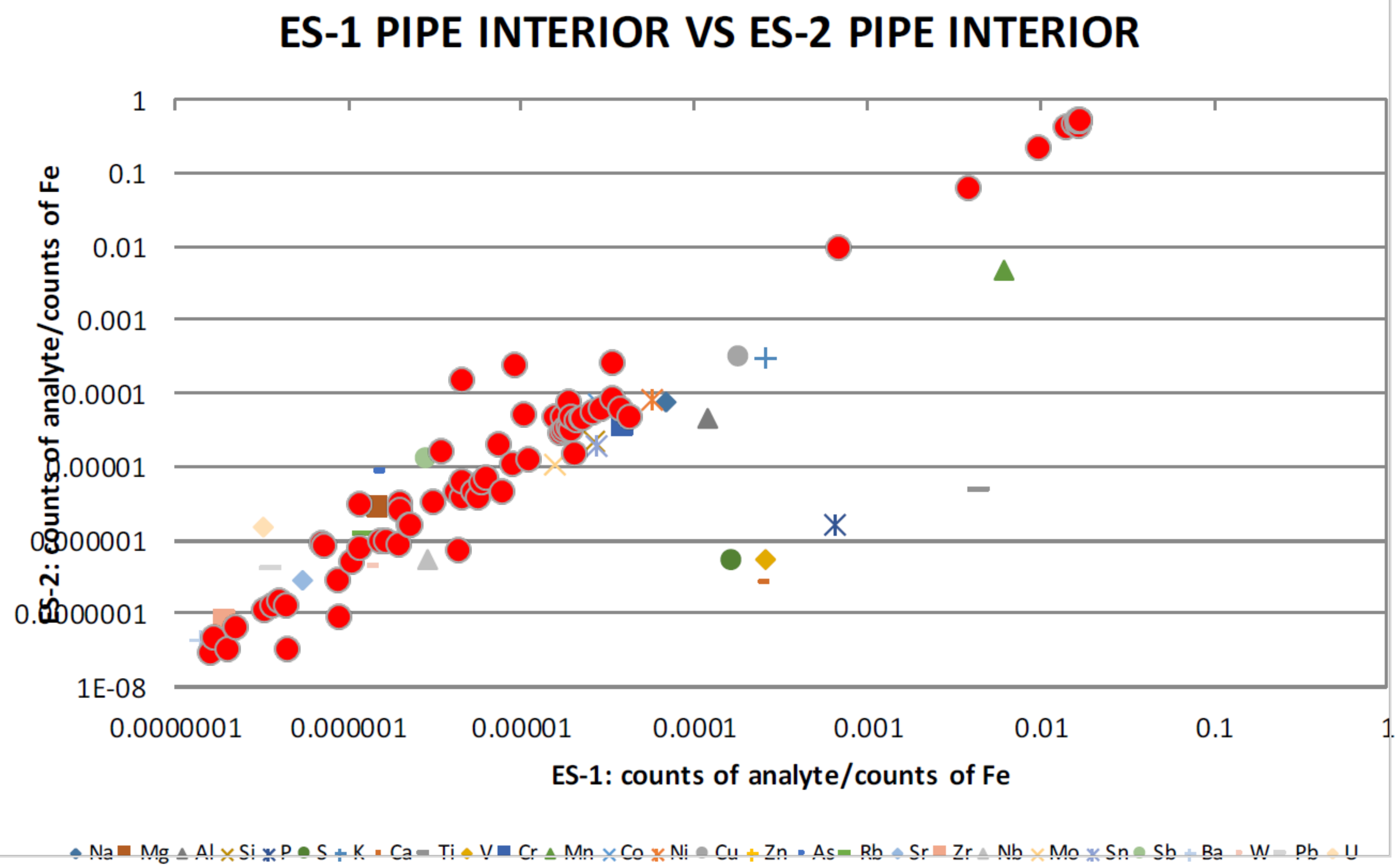
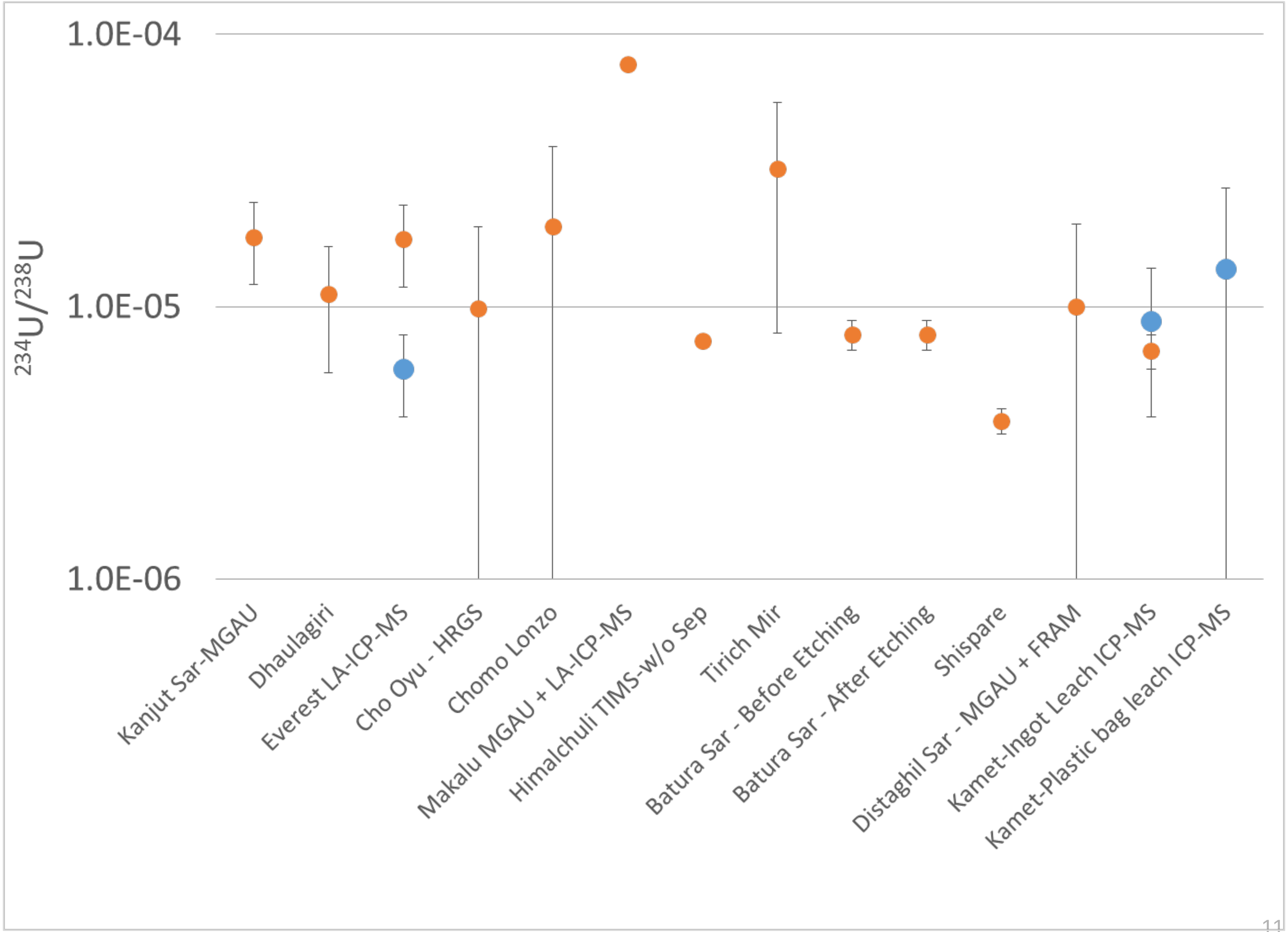


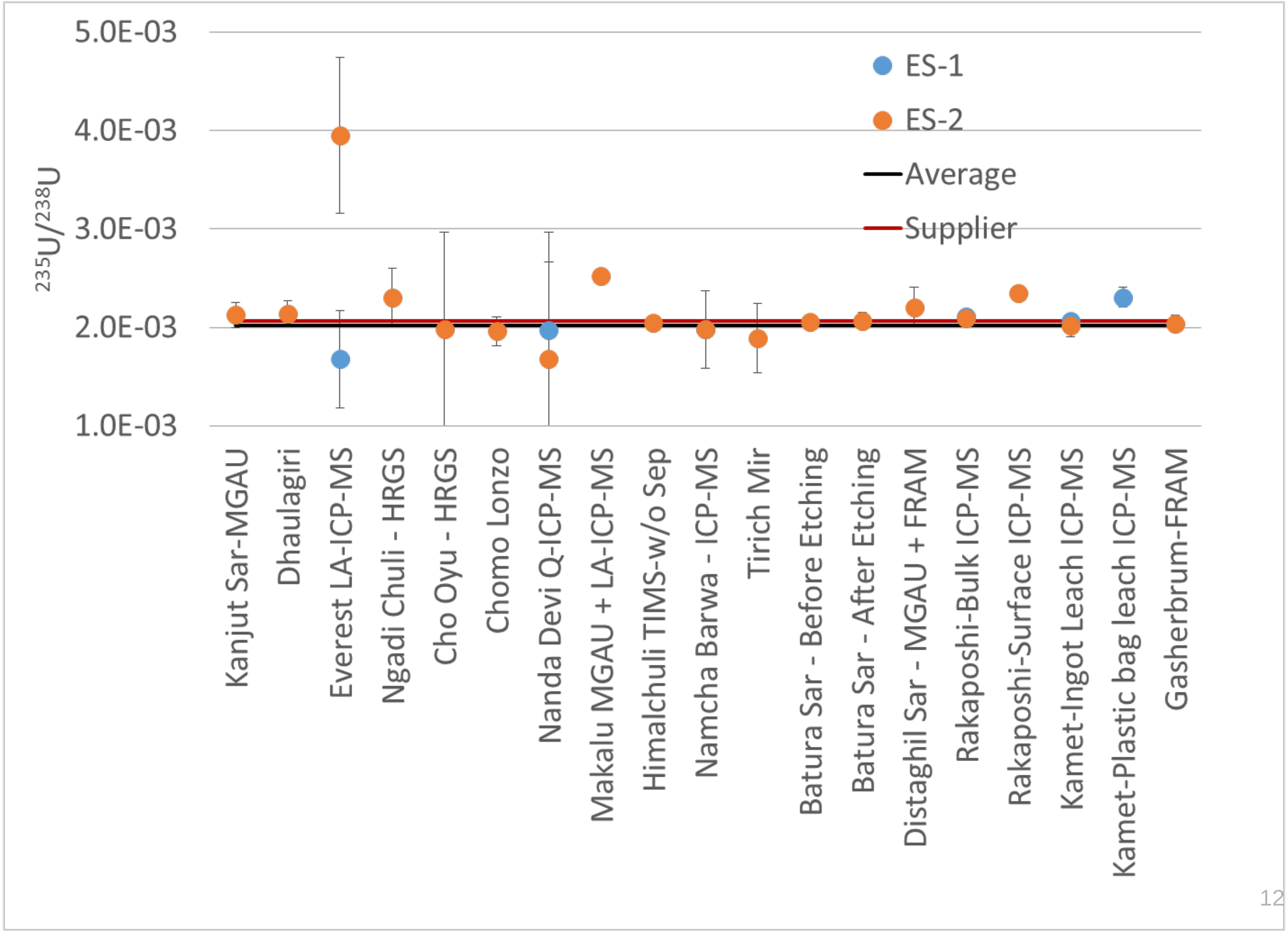
Uranium Isotopics in 1 Week

- 14 labs reporting 234/238 ratios for ES-2
- Everest and Kamet reported 234/238 ratios for ES-1
- Kamet shows consistency between ES-1 and ES-2
- Everest shows minor inconsistency between ES-1 and ES-2 using surface technique



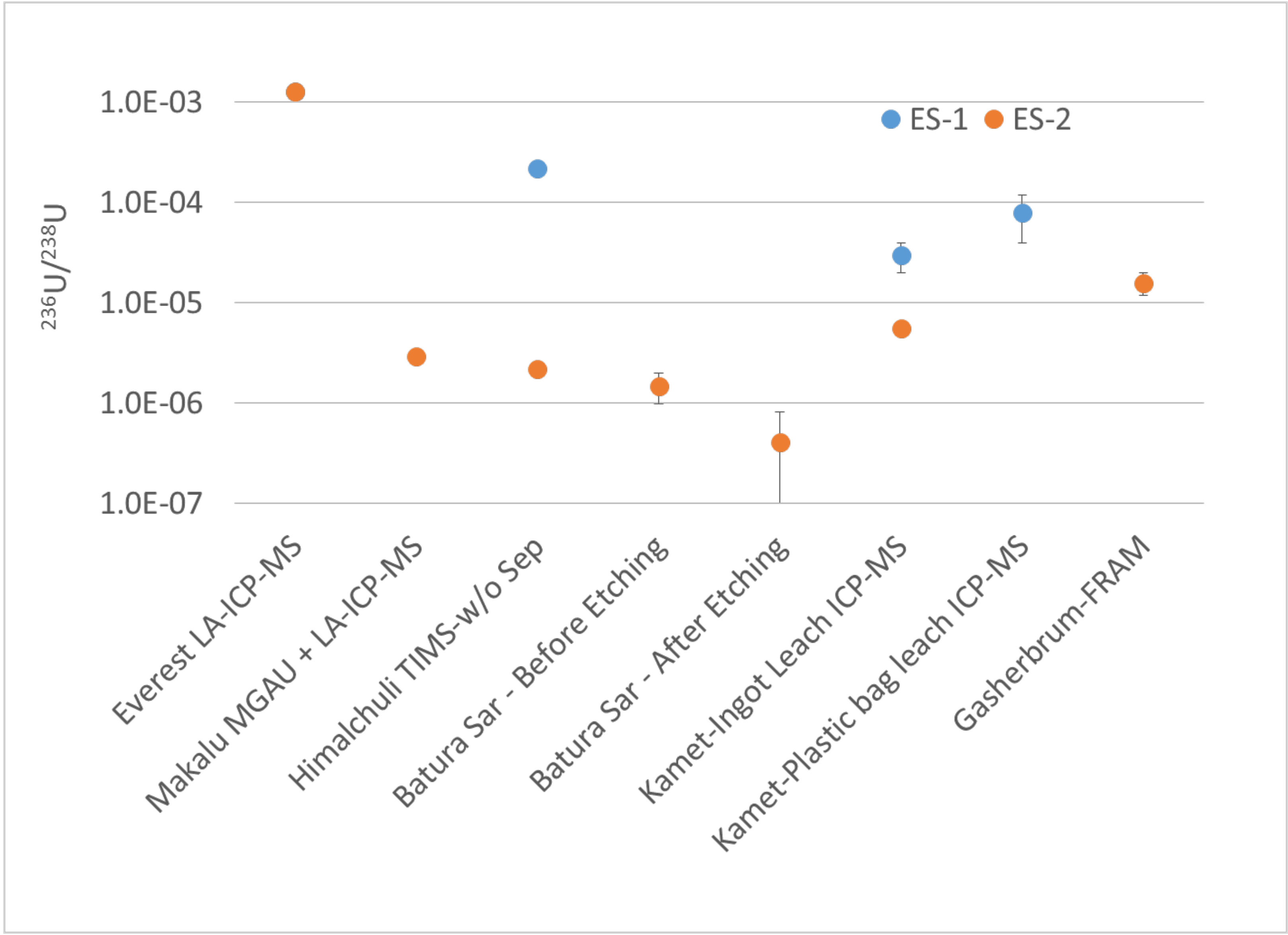
Uranium Isotopics in 1 Week

- 17 labs reporting 235/238 ratios for ES-2
- Everest, Nanda Devi, Kamet, and Annapurna reported 235/238 ratios in ES-1
- Most labs reporting values for both ES-1 and ES-2 show consistency between samples
- Most lab results consistent with supplier declaration

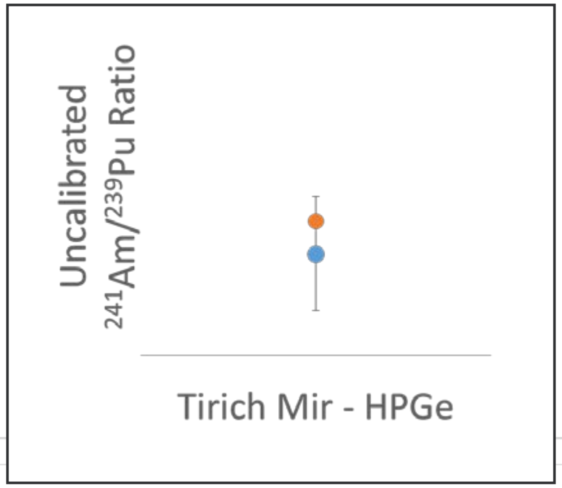


Uranium Isotopics in 1 Week

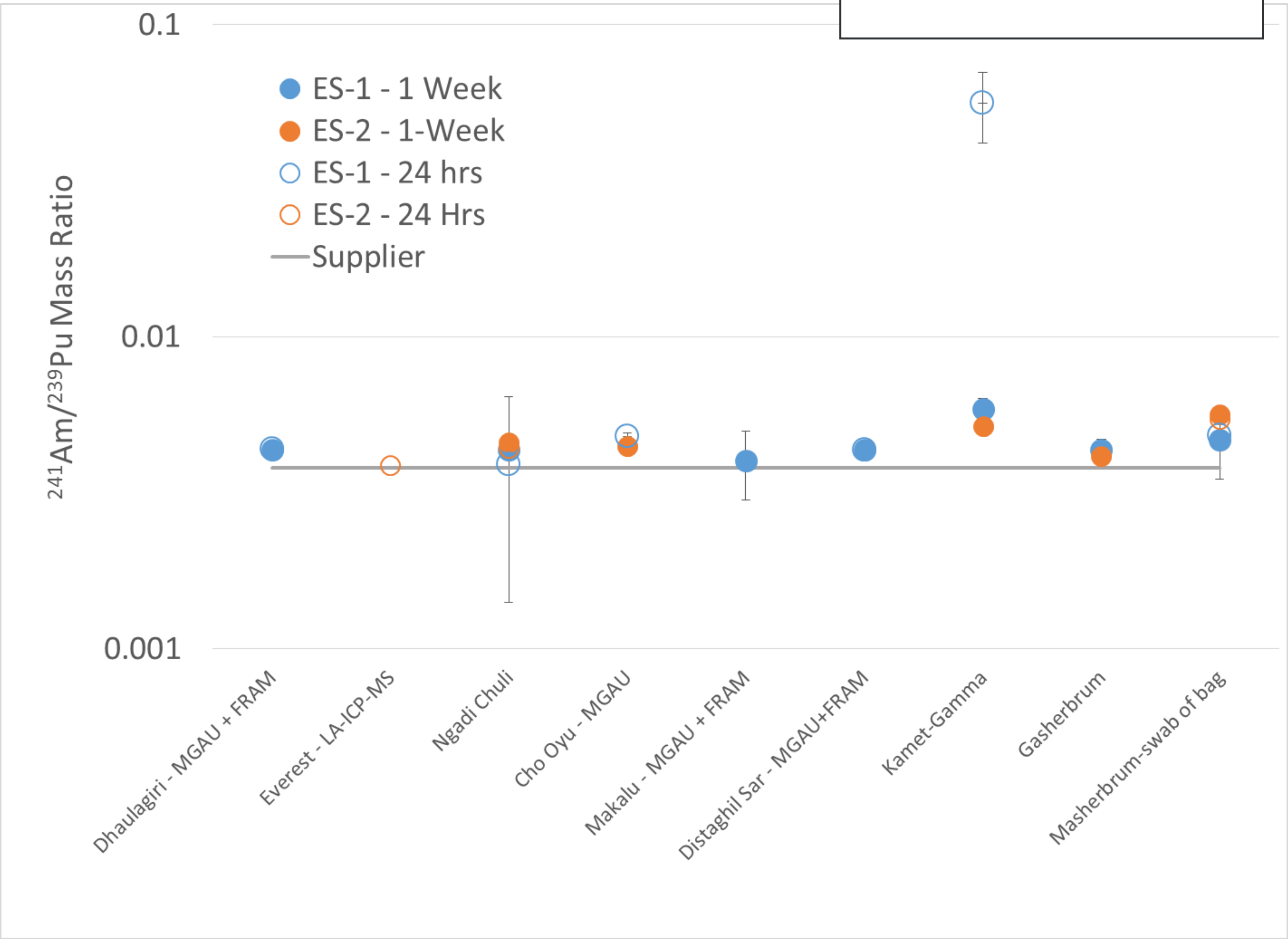
- Himalchuli and Kamet reported 236/238 ratios for ES-1 and ES-2
- Annapurna reported 236/238 ratios for ES-1
- Everest, Makalu, Batura Sar and Shispare reported 236/238 ratios for ES-2
- Large spread in data between labs
- No consistency observed between ES-1 and ES-2
- Excess U from Pu contamination may be to blame??



Pu & Am Detection at 1 Week

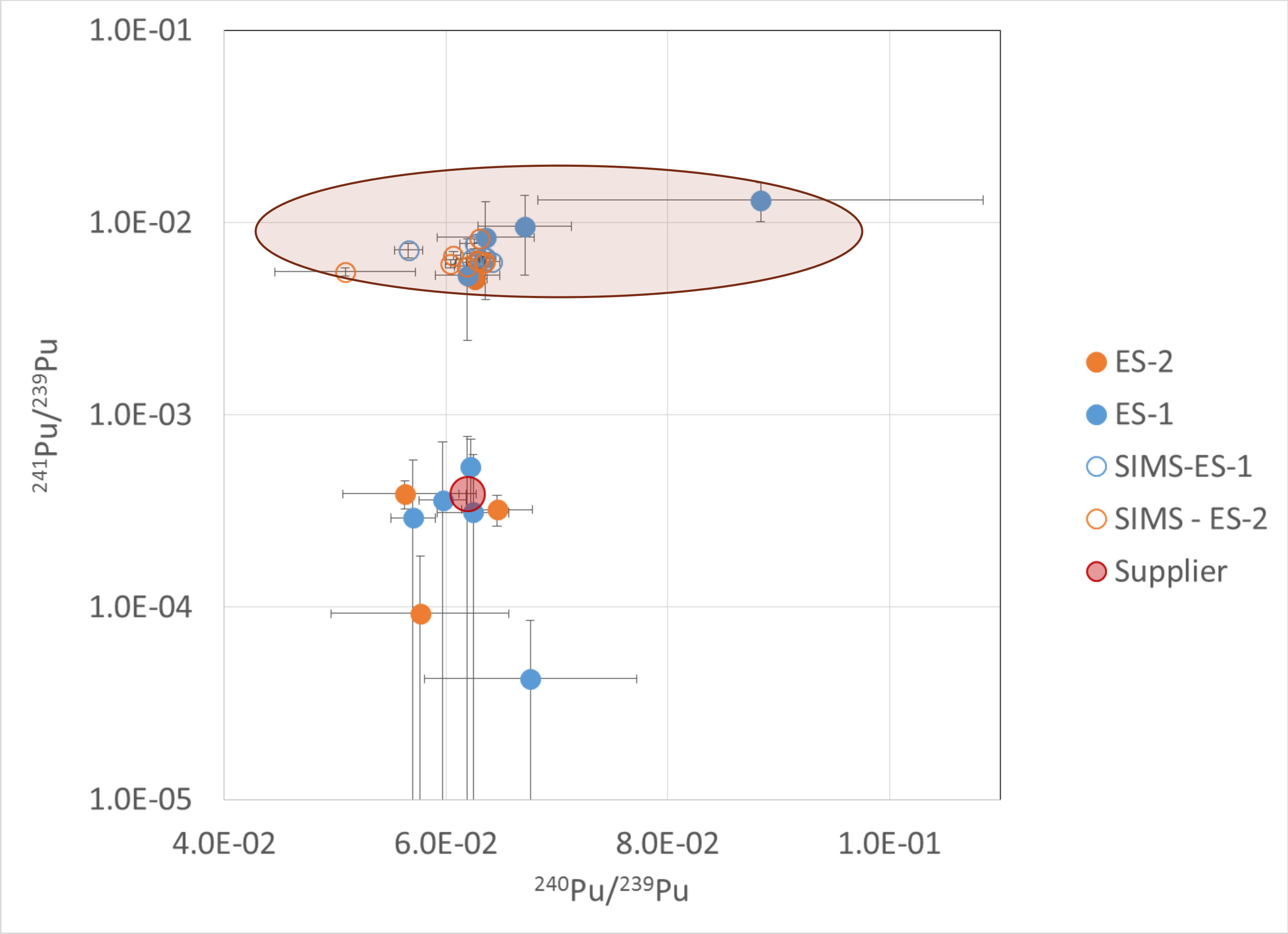


- 10 Labs reporting ^{241}Am & ^{239}Pu values for ES-1 and ES-2
- Ngadi Chuli, Cho Oyo, Kamet, Gasherbrum, and Masherbrum report values for both ES-1 and ES-2
- 5 out of 6 labs show consistency between ES-1 and ES-2 based on this ratio
- Most values consistent with supplier declarations



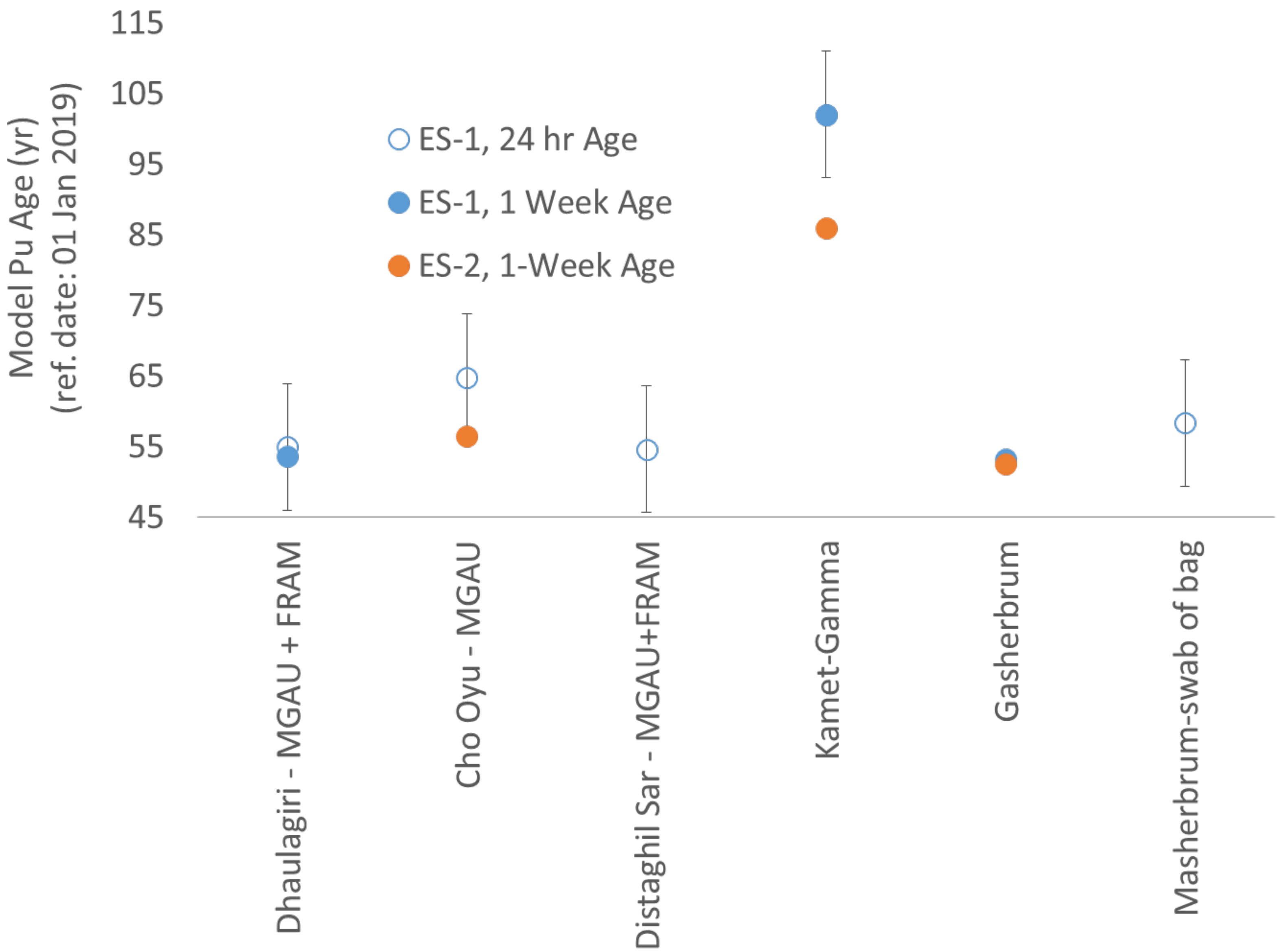
$^{240}Pu/^{239}Pu$ vs. $^{241}Pu/^{239}Pu$ at 1 Week

- 11 Labs reporting ^{241}Am & ^{239}Pu values for ES-1
- 11 Labs reporting ^{241}Am & ^{239}Pu values for ES-2
- Most values consistent with supplier declarations
- SIMS and “rapid” bulk MS methods not employing a separation step expected to be bias high due to isobaric interference with ^{241}Am



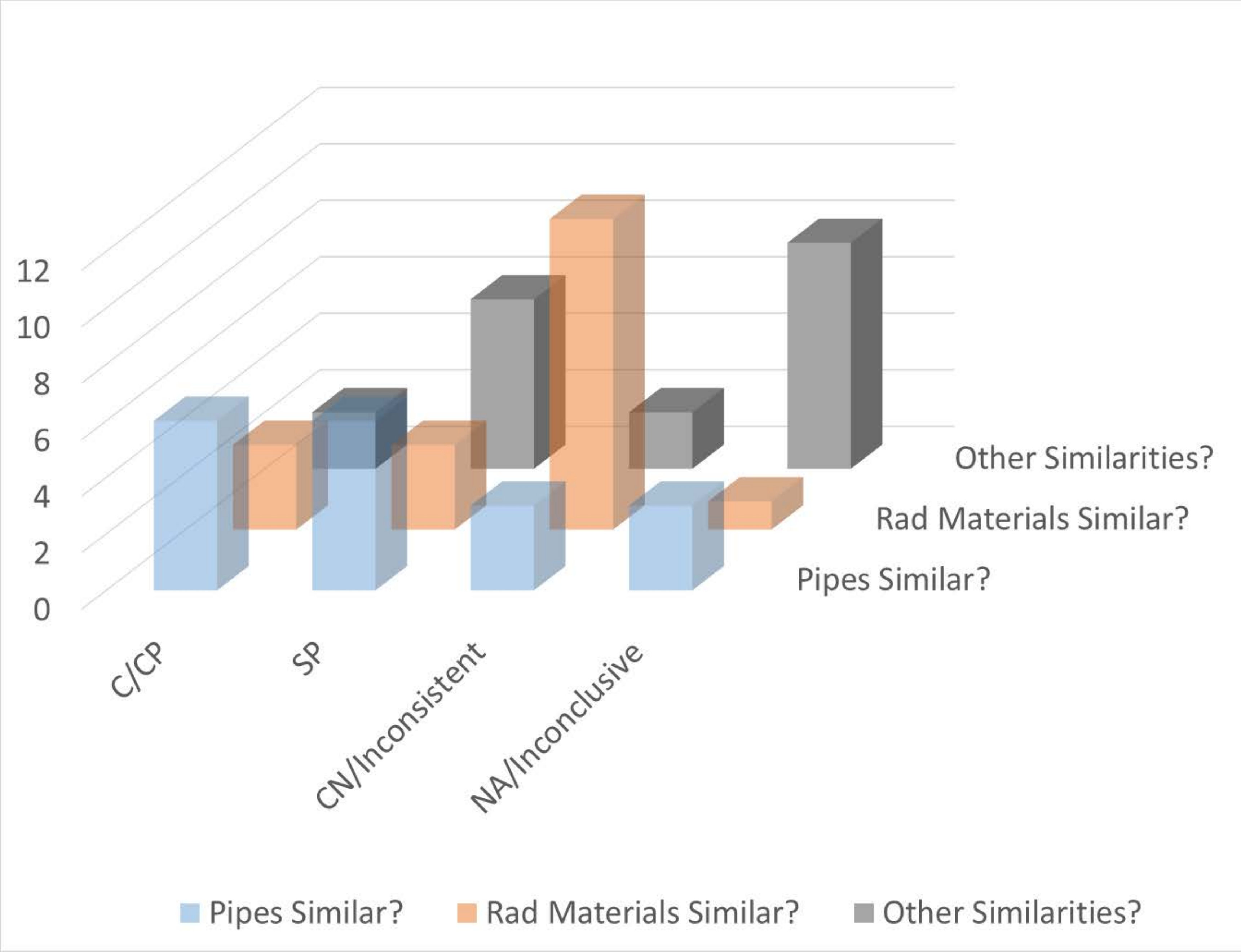
Evaluation – Model Age of Pu

- Dhaulagiri, Cho Oyo, Kamet, and Gasherbrum reported new estimates of Am/Pu model age
- Gasherbrum and Cho Oyo show consistency in Am/Pu model ages for ES-1 and ES-2



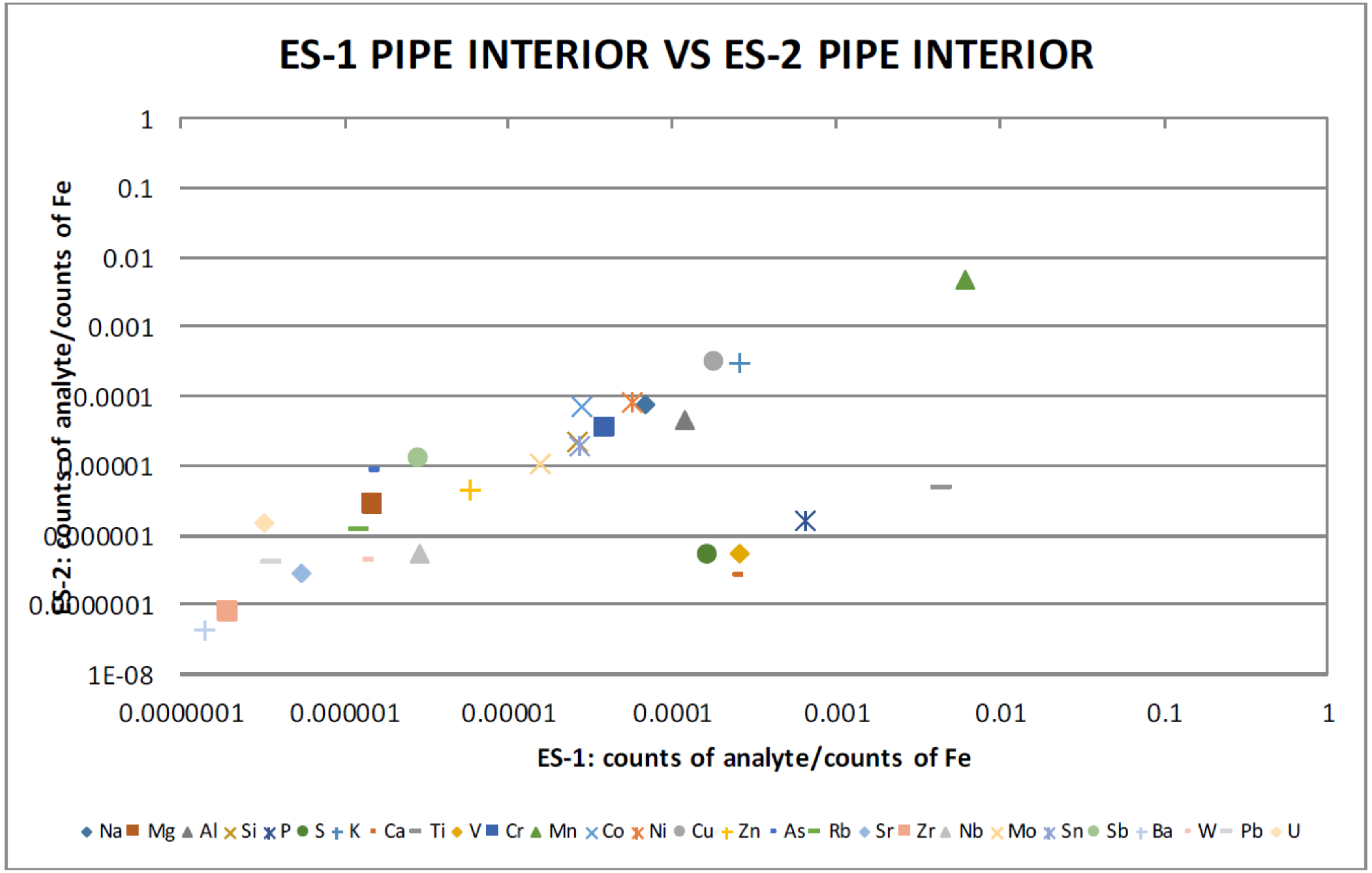
Evaluation – Graded Decision Framework

- 18 labs reporting GDF answers
- Indications of some inconsistency with interpretation of question 5 (…rad materials similar?)
  - Those considering radioactive contamination part of material answered CP
  - Those interpreting contamination as “Other evidence” answered CN to Q5 and CP to Q6



Notable Efforts after 1 Week

- Chomo Lonzo, Batura Sar, Rakaposhi, and Annapurna – application of XRD within 1 Week for phase ID
- Exceptional evaluation of LA-QQQ-ICP-MS for analysis of trace elements, Everest



Trace element pattern comparison in ES-1 and ES-2 pipes (Everest)

Notable Efforts in 1 Week

- K2 – Fiber analysis
- Rakaposhi – tool marks on bags
- Gasherbrum – detection of ^{22}Na

$$^{19}F(\alpha, n)^{22}Na$$

  - Alpha energy barrier for this reaction is ~5MeV…suggesting the presence of Pu in fluoride form
- Tirich Mir & Ngadi Chuli - Group Inclusion / Exclusion using $^{241}Am/^{239}Pu$

Discussion – 1 Week

Small Group Discussion

Group 1: Romania, Russia, Ukraine, Azerbaijan

Group 2: Japan, Korea, Singapore, Australia, USA

Group 3: Switzerland, Poland, Sweden, Germany, UK

Group 4: Hungary, Israel, JRC, Canada, France

Questions to discuss (spend 10-15 minutes per question):

1) Did you attempt to subsample the ingots for analysis? If so, discuss the techniques that were used to do this.
2) Did you attempt to segregate surface contamination from the bulk ingot for isotopic analysis? If so, discuss the different methods that were employed to do this.
3) What were the three most useful measurement techniques used during the first week of CMX-6?
4) What was the most challenging aspect of producing the 1 week report?
5) What would you have changed about your approach to the 1 week report?
6) What would you have changed about the execution of the exercise up to the 1-week reporting?

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6th Collaborative Materials Exercise (CMX-6) of the Nuclear Forensics International Technical Working Group (ITWG)

Inject 3 & Introduction to 2-Month (Final) Report

Jon Schwantes & Olivia Marsden
Co-Chairs ETG, ITWG

Inject 3 & Introduction to Final (2-Month) Report

- Exercise Objectives / Performance Metrics for Final Report
- Inject 3
- Schedule of lab presentations

ITWG Nuclear Forensics International Technical Working Group

Exercise Objectives

- Obj 1: Novel Materials
- Obj 2: NDA Categorization (24 hrs)
- Obj 3: 1-Week Characterization
- Obj 4: 2 Month Characterization
- Obj 5: Evaluation

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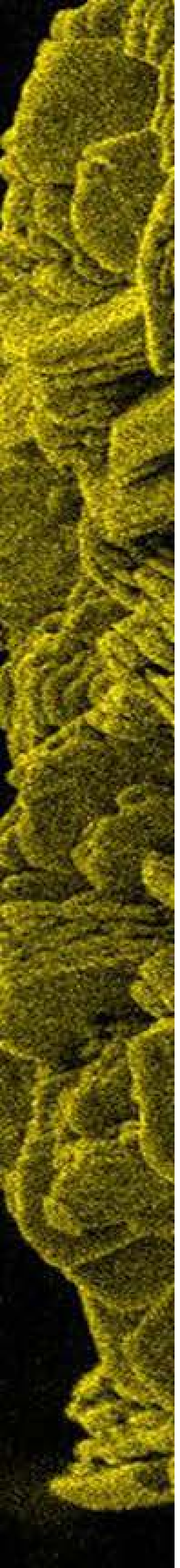
Performance Indicators

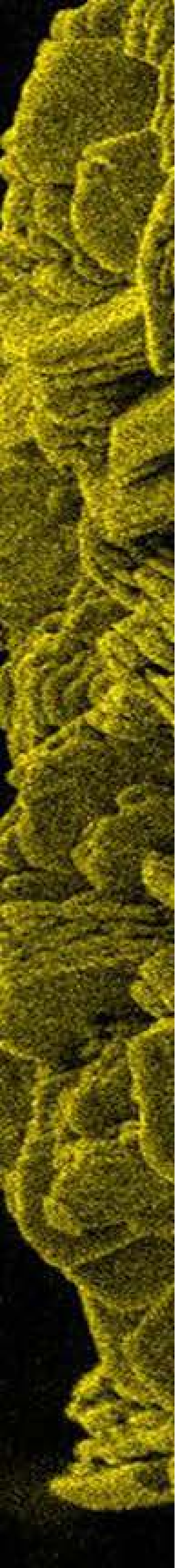
- Obj 4: 2 Month Characterization
  - Cap 4.1: Isotopics
    - PI 4.1.1: Detect Pu in ES1 in 24 hrs
    - PI 4.1.2: Detect U in ES1 in 24 hrs
    - PI 4.1.3: Detect U in ES2 in 24 hrs
    - PI 4.1.4: Detect Pu in ES2 in 24 hrs
  - Cap 4.2: Elemental/Chemical
    - PI 4.2.1: ID Ce Metal in ES1 in 24 hrs
    - PI 4.2.2: ID trace in ES1 in 24 hrs
    - PI 4.2.3: ID U metal in ES2 in 24 hrs
    - PI 4.2.4: ID trace in ES2 in 24 hrs
  - Cap 4.3 Physical
    - PI 4.3.1: Microscopy of pipes
    - PI 4.3.2: Microscopy of ES's
  - Cap 4.4: Age Date
    - PI 4.4.1: U age
    - PI 4.4.2: Pu age
  - Cap 4.5: Traditional Forensics
    - Act 4.5.1: Fingerprinting
      - Task 4.5.1.1: Patent Prints
        - PI 4.5.1.1.1: Locate
        - PI 4.5.1.1.2: Image
      - Task 4.5.1.2: Latent Prints
        - PI 4.5.1.2.1: Develop
        - PI 4.5.1.2.2: Image
    - Act 4.5.2: Toolmarks
      - PI 4.5.2.1: Image and compare cut surfaces on pipes
      - PI 4.5.2.2: Image and compare cut surfaces on ES's



Performance Indicators

Obj 5: Evaluation

- Cap 5.1: Age Dating
  - PI 5.1.1: Age of trace Pu in ES1
  - PI 5.1.2: Age of trace U in ES1
  - PI 5.1.3: Age of U in ES2
  - PI 5.1.4: Age of trace Pu in ES2
- Cap 5.2: Group Inclusion/Exclusion
  - PI 5.2.1: ID Ce Metal in ES1
  - PI 5.2.2: compare trace
  - PI 5.2.3: ID U metal in ES2
  - PI 5.2.4: compare bags
  - PI 5.2.5 Compare pipe composition
  - PI 5.2.6 Compare toolmarks
- Cap 5.3 Provenance
  - PI 5.3.1: PuF4 id by ^{22}Na
  - PI 5.3.2: PuF4 by direct measure



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Case No. 52521, Sample ID: ES-3A & ES-3B

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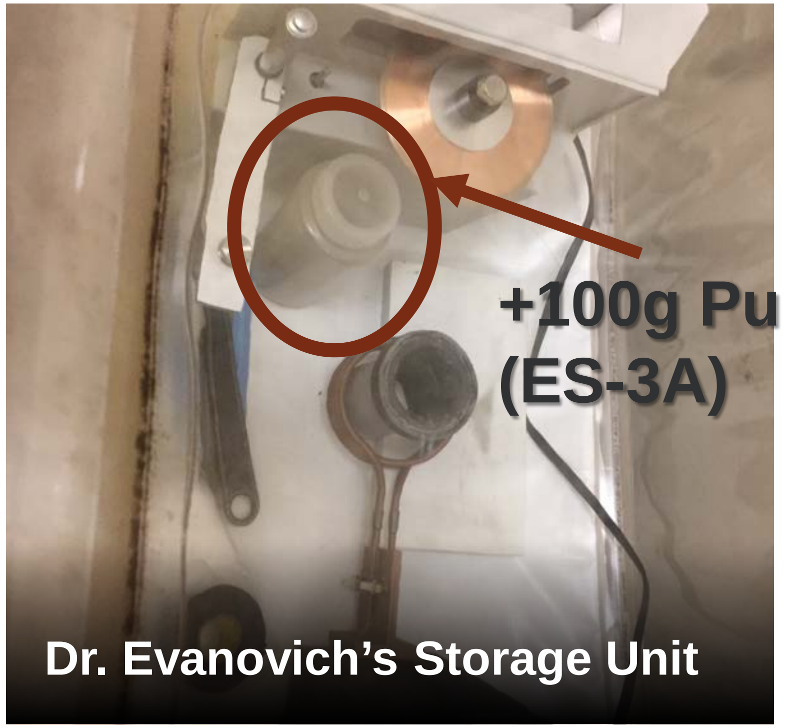
Inject 3 – Final Report

- Dr. Evanovich, staff scientist at Rodesia National Laboratory (RNL), Person Of Interest (POI)
- POI had access to large quantities of SNM located at RNL
- Determine if materials recovered at storage unit are consistent with ES-1 or ES-2 or RNL holdings

Dr. Evanovich’s Storage Unit



Dr. Evanovich’s Storage Unit

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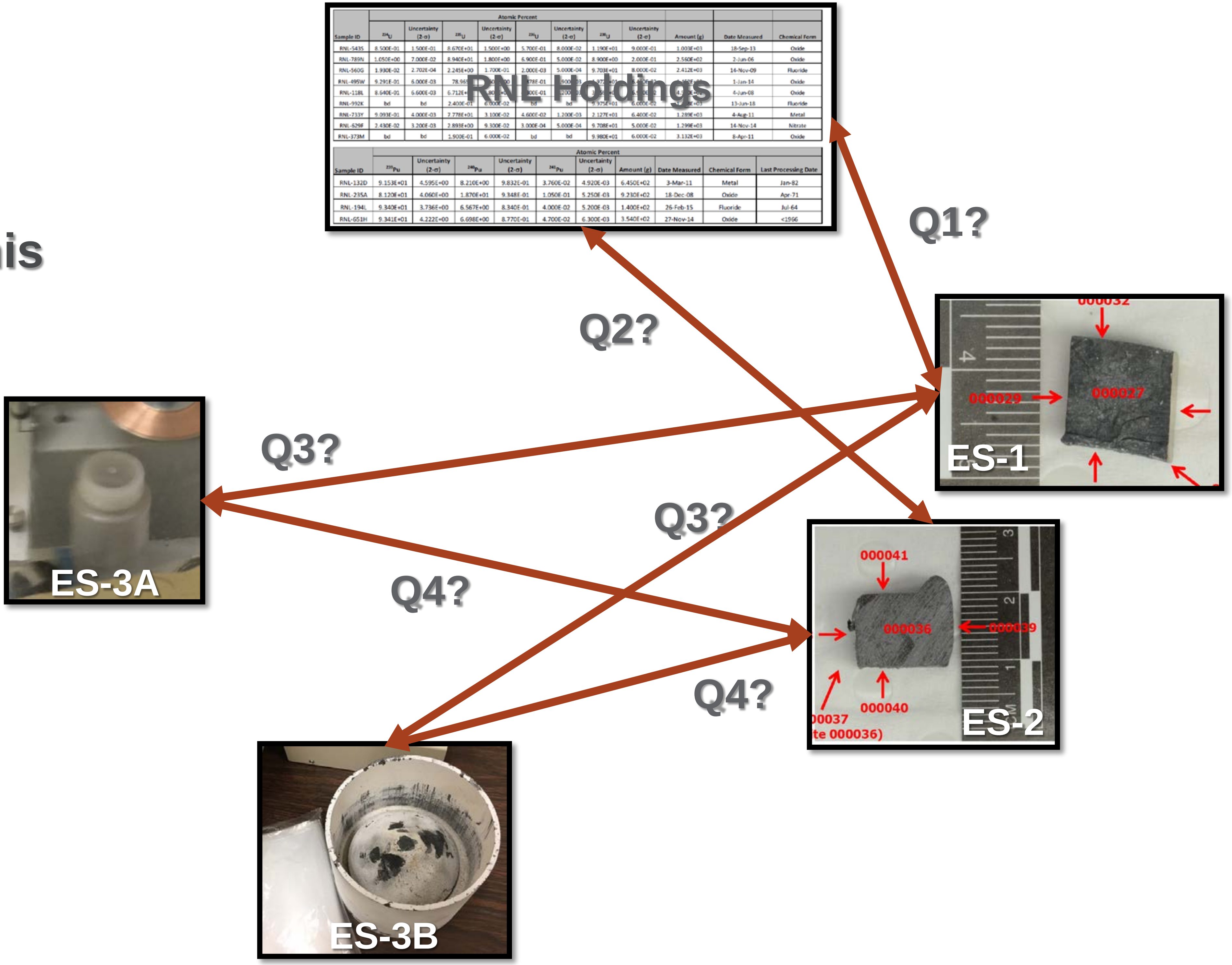
Inject 3 – Final Report



Sample ID	Atomic Percent										
	^{234}U	Uncertainty (2-σ)	^{235}U	Uncertainty (2-σ)	^{236}U	Uncertainty (2-σ)	^{238}U	Uncertainty (2-σ)	Amount (g)	Date Measured	Chemical Form
RNL-543S	8.500E-01	1.500E-01	8.670E+01	1.500E+00	5.700E-01	8.000E-02	1.190E+01	9.000E-01	1.003E+03	18-Sep-13	Oxide
RNL-789N	1.050E+00	7.000E-02	8.940E+01	1.800E+00	6.900E-01	5.000E-02	8.900E+00	2.000E-01	2.560E+02	2-Jun-06	Oxide
RNL-560G	1.930E-02	2.702E-04	2.245E+00	1.700E-01	2.000E-03	5.000E-04	9.703E+01	8.000E-02	2.412E+03	14-Nov-09	Fluoride
RNL-495W	9.291E-01	6.000E-03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1-Jan-14	Oxide
RNL-118L	8.640E-01	6.600E-03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4-Jun-08	Oxide
RNL-992K	bd	bd	2.400E-01	6.000E-02	bd	bd	9.975E+01	6.000E-02	[illegible]	13-Jun-18	Fluoride
RNL-733Y	9.093E-01	4.000E-03	7.778E+01	3.100E-02	4.600E-02	1.200E-03	2.127E+01	6.400E-02	1.289E+03	4-Aug-11	Metal
RNL-629F	2.430E-02	3.200E-03	2.893E+00	9.300E-02	3.000E-04	5.000E-04	9.708E+01	5.000E-02	1.299E+03	14-Nov-14	Nitrate
RNL-373M	bd	bd	1.900E-01	6.000E-02	bd	bd	9.980E+01	6.000E-02	3.132E+03	8-Apr-11	Oxide

Sample ID	Atomic Percent									
	^{239}Pu	Uncertainty (2-σ)	^{240}Pu	Uncertainty (2-σ)	^{241}Pu	Uncertainty (2-σ)	Amount (g)	Date Measured	Chemical Form	Last Processing Date
RNL-132D	9.153E+01	4.595E+00	8.210E+00	9.832E-01	3.760E-02	4.920E-03	6.450E+02	3-Mar-11	Metal	Jan-82
RNL-235A	8.120E+01	4.060E+00	1.870E+01	9.348E-01	1.050E-01	5.250E-03	9.230E+02	18-Dec-08	Oxide	Apr-71
RNL-194L	9.340E+01	3.736E+00	6.567E+00	8.340E-01	4.000E-02	5.200E-03	1.400E+02	26-Feb-15	Fluoride	Jul-64
RNL-651H	9.341E+01	4.222E+00	6.698E+00	8.770E-01	4.700E-02	6.300E-03	3.540E+02	27-Nov-14	Oxide	<1966

Using the Graded Decision Framework, answer questions 1-4.

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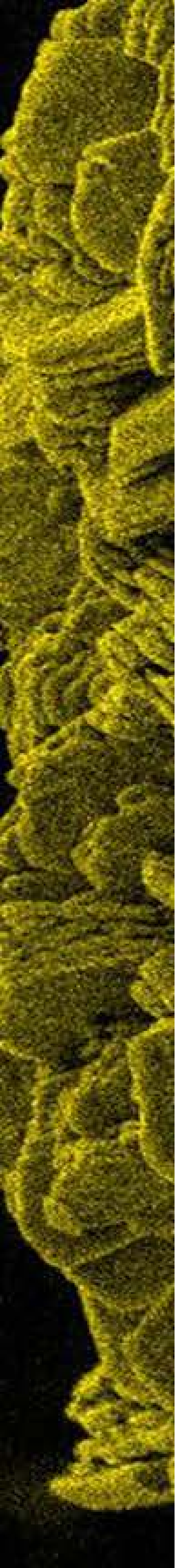
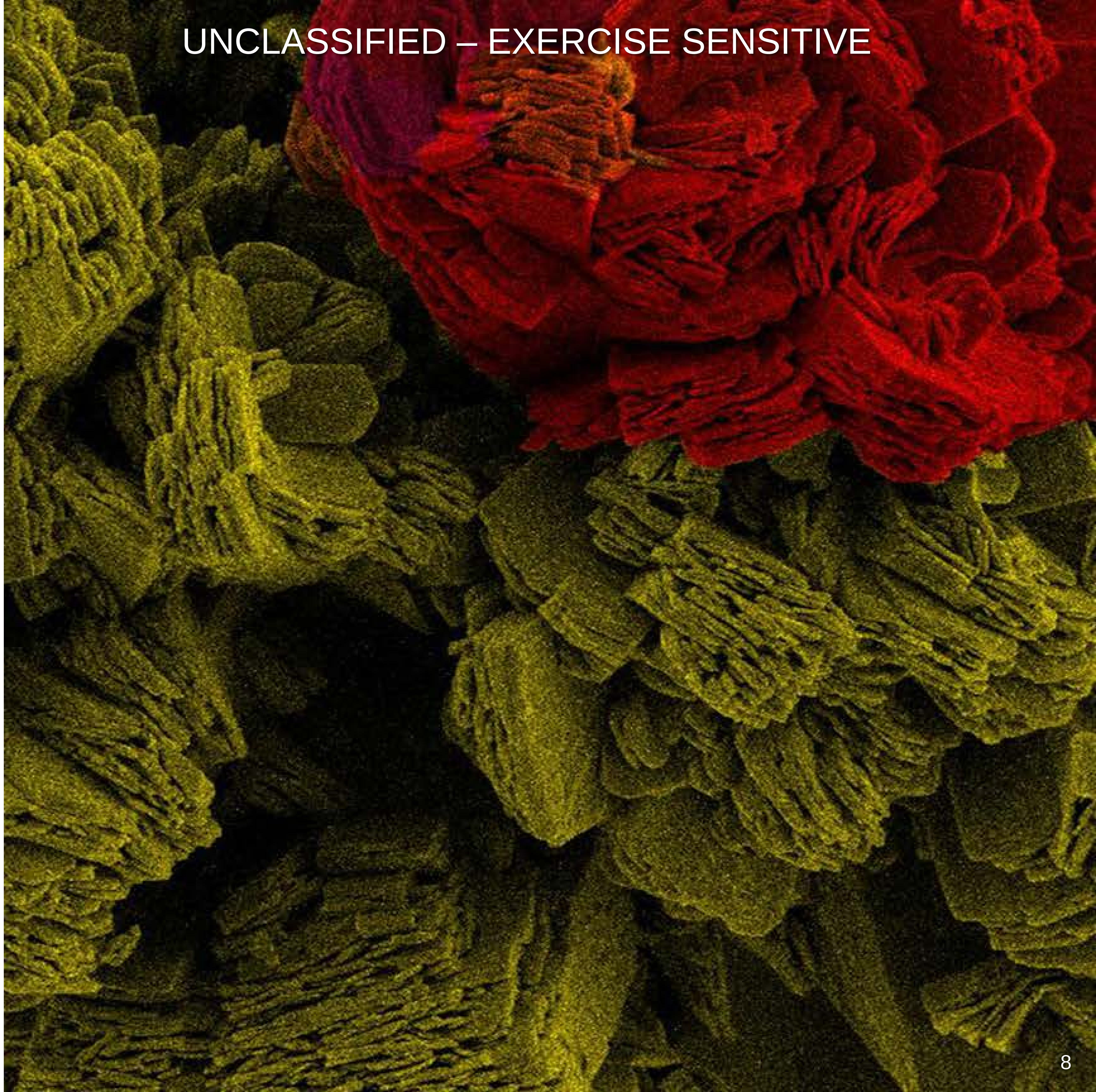
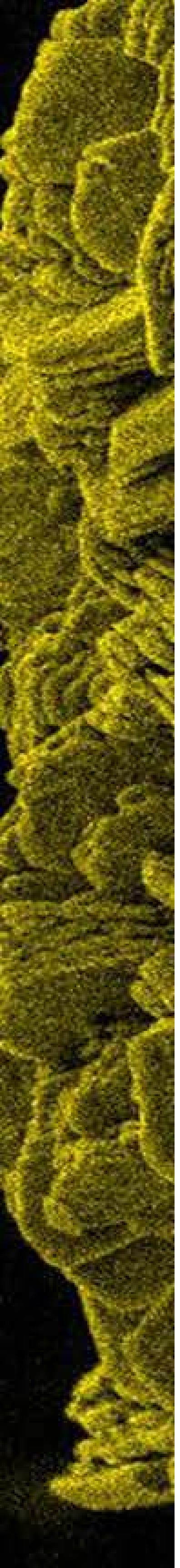


Thank you





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Laboratory Presentations – Final Reporting

9:15 – 9:30 am	Welcome, Schedule & Announcements	Olivia
9:30 – 9:50 am	2-Month report results, U only	Hungary
9:50 – 10:10 am	2-Month report results	Canada
10:10 – 10:30 am	2-Month results	UK
10:30 – 10:50 am	Break	
10:50 – 11:10 am	2-Month report results	Switzerland
11:10 – 11:30 am	Novel Methodologies 2-Month – (Raman/SEM)	France
	Novel Methodologies 2-Month – Radiochronometry	USA

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Pacific Northwest NATIONAL LABORATORY

ITWG Nuclear Forensics International Technical Working Group

Operation Celestial Skónis

Summary of 2-Month Reporting

6th Collaborative Materials Exercise (CMX-6) of the Nuclear Forensics International Technical Working Group (ITWG)

Jon Schwantes & Olivia Marsden
Co-Chairs ETG, ITWG

ITWG Nuclear Forensics
International Technical Working Group

Traditional Forensics

- 8 labs developed fingerprints during CMX-6
  - Most reported those results in 1 week
- Everest and Rakaposhi performed DNA analysis
- 4 labs performed tool mark analysis on ingots
- 9 labs performed tool marks on pipes
- Kanjut Sar conducted tool mark analysis on plastic bags
- K2 collected fiber and insect evidence

Code	Fingerprints			DNA			tool marks bags			tool marks ingots			tool marks pipes			Fiber			Insect			Worked with LE
	24 hr	1 wk	2 mn	24 hr	1 wk	2 mn	24 hr	1 wk	2 mn	24 hr	1 wk	2 mn	24 hr	1 wk	2 mn	24 hr	1 wk	2 mn	24 hr	1 wk	2 mn	
Kanjut Sar																						
Dhaulagiri																						
Everest																						
Ngadi Chuli																						
Cho Oyu																						
Chomo Lonzo																						
Nanda Devi																						
K2																						
Makalu																						
Himalchuli																						
Namcha Barwa																						
Tirich Mir																						
Batura Sar																						
Shispare																						
Distaghil Sar																						
Rakaposhi																						
Kamet																						
Annapurna																						
Gasherbrum																						
Masherbrum																						

Summary of the application of traditional forensics during CMX-6

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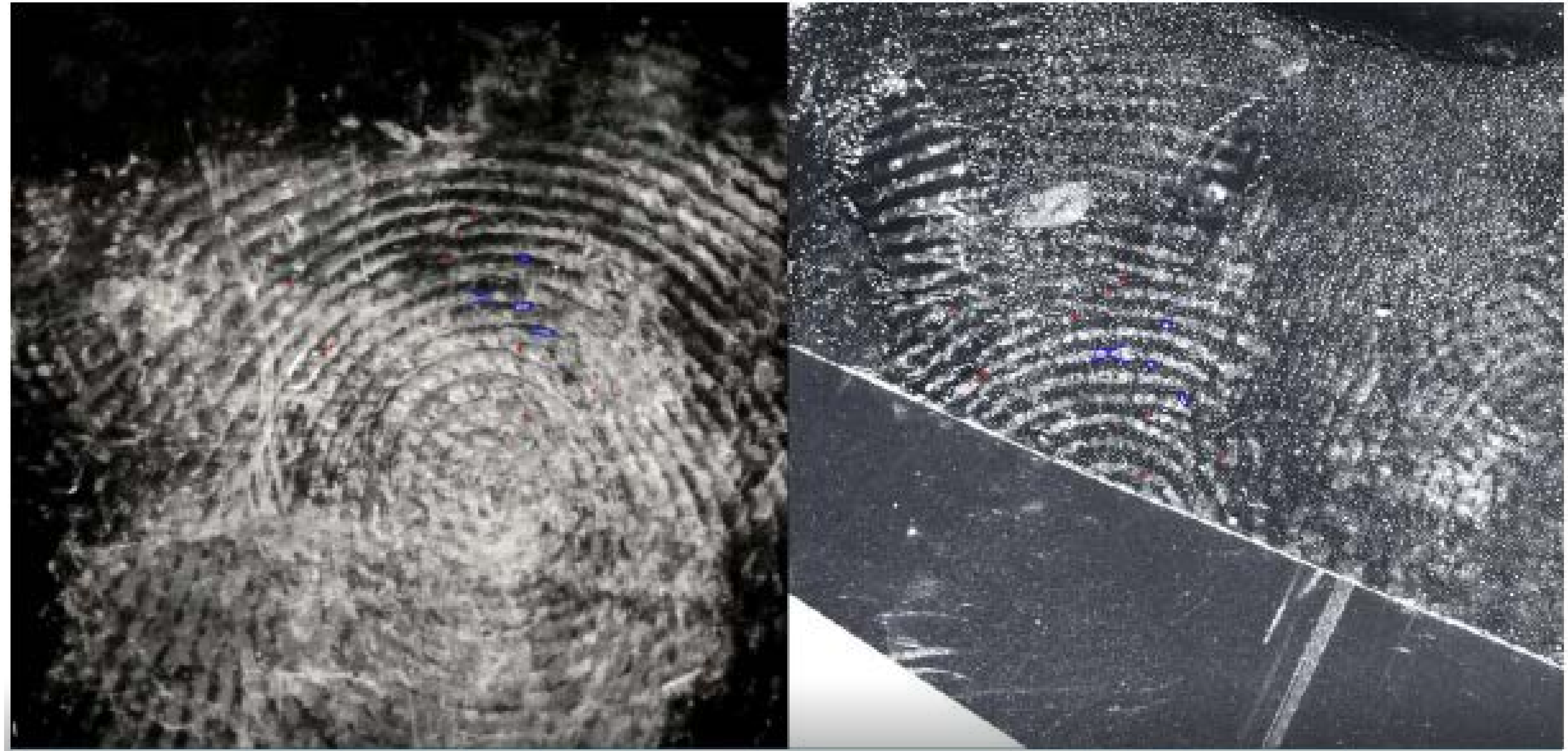
Matching Latent Prints on ES-1 & ES-2



Successful match by Kanjut Sar of latent fingerprints collected on ES-1 (left) and ES-2 (right). Red markings indicate corresponding features between the two latents. Blue markings indicate ridge shape features of interest to examiner.

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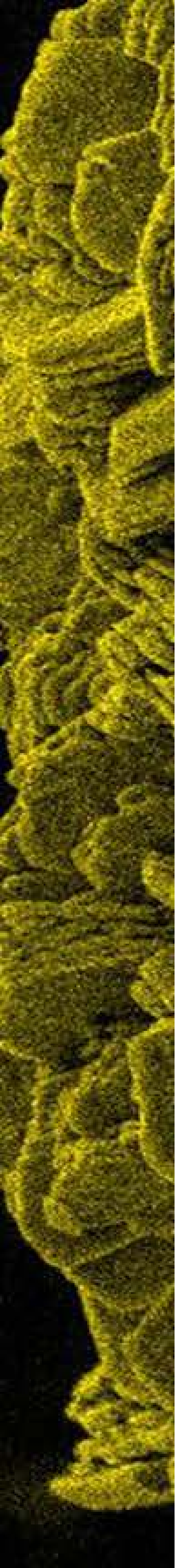
Physical Characterization

- Most labs characterized mass, dimensions, and densities within the first 24 hrs
- 8 labs utilized x-ray radiography, most within 24 hrs
- 9 labs conducted OM, most within 1st week of exercise
- 16 labs conducted SEM, most within 1 week
- Kanjut Sar, Annapurna & Masherbrum surface roughness

Code	Mass			Density			Dimensional Analysis			X-ray radiography			Surface Roughness			Optical Microscopy			SEM		
	24 hr	1 wk	2 mth	24 hr	1 wk	2 mth	24 hr	1 wk	2 mth	24 hr	1 wk	2 mth	24 hr	1 wk	2 mth	24 hr	1 wk	2 mth	24 hr	1 wk	2 mth
Kanjut Sar																					
Dhaulagiri																					
Everest																					
Ngadi Chuli																					
Cho Oyu																					
Chomo Lonzo																					
Nanda Devi																					
K2																					
Makalu																					
Himalchuli																					
Namcha Barwa																					
Tirich Mir																					
Batura Sar																					
Shispare																					
Distaghil Sar																					
Rakaposhi																					
Kamet																					
Annapurna																					
Gasherbrum																					
Masherbrum																					

Summary of the application of traditional forensics during CMX-6



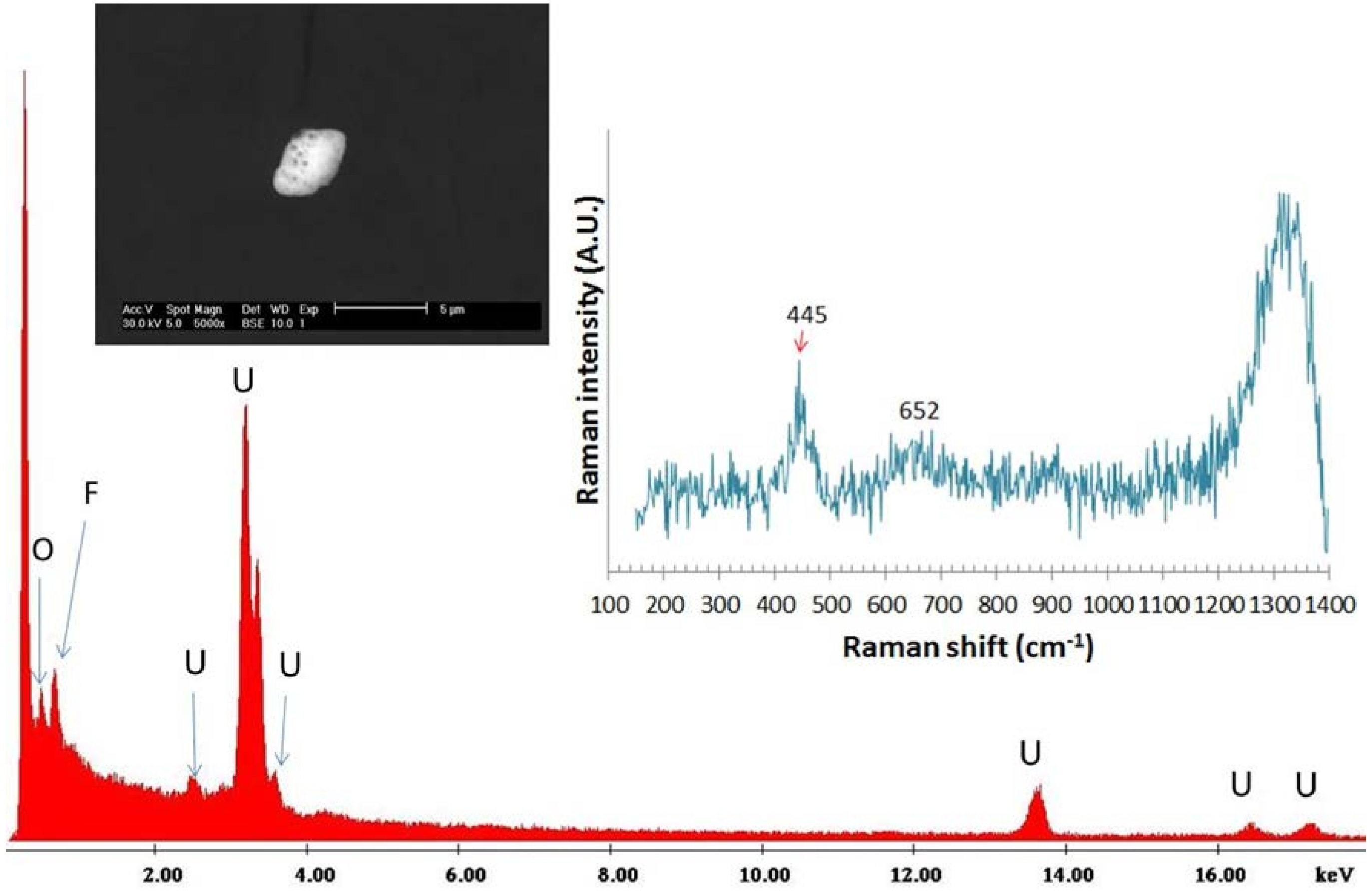
Phase ID / Chemical / Elemental Analysis

- 7 labs employed pXRD, most in 1 week
- 3 labs used Raman spectroscopy within 2 months
- Masherbrum employed LIBS
- Most labs employed XRF, half of those during 24 hrs

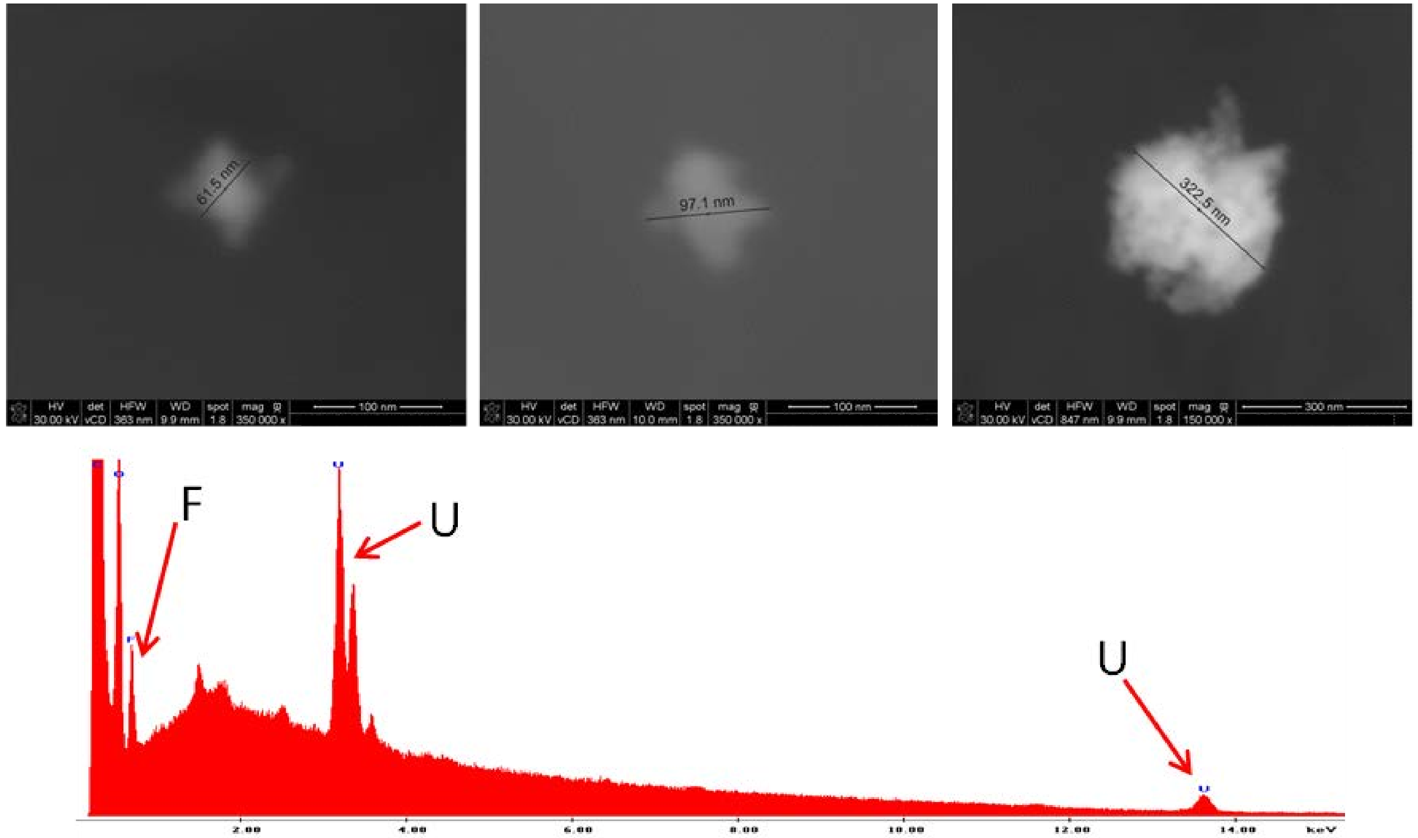
							Elemental Surface												Elemental Bulk					
Code	Powder XRD			Raman			LIBS			XRF			EDX			LA-ICPMS			ICP-OES			ICP-MS		
	24 hr	1 wk	2 mn	24 hr	1 wk	2 mn	24 hr	1 wk	2 mn	24 hr	1 wk	2 mn	24 hr	1 wk	2 mn	24 hr	1 wk	2 mn	24 hr	1 wk	2 mn	24 hr	1 wk	2 mn
Kanjut Sar			■								■				■									■
Dhaulagiri											■													
Everest			■								■						■							■
Ngadi Chuli						■				■	■				■									
Cho Oyu										■					■						■			
Chomo Lonzo		■									■													
Nanda Devi						■				■													■	
K2											■													■
Makalu										■														■
Himalchuli										■														
Namcha Barwa														■									■	
Tirich Mir										■				■										■
Batura Sar		■								■				■									■	
Shispare														■									■	
Distaghil Sar			■			■					■													■
Rakaposhi		■									■													
Kamet										■										■			■	
Annapurna		■								■		■			■									
Gasherbrum														■										
Masherbrum								■		■	■			■										

Summary of Phase ID and Trace Element Analysis during CMX-6

Outstanding Example by Ngadi Chuli of Physical and Trace Elemental Analysis during CMX-6

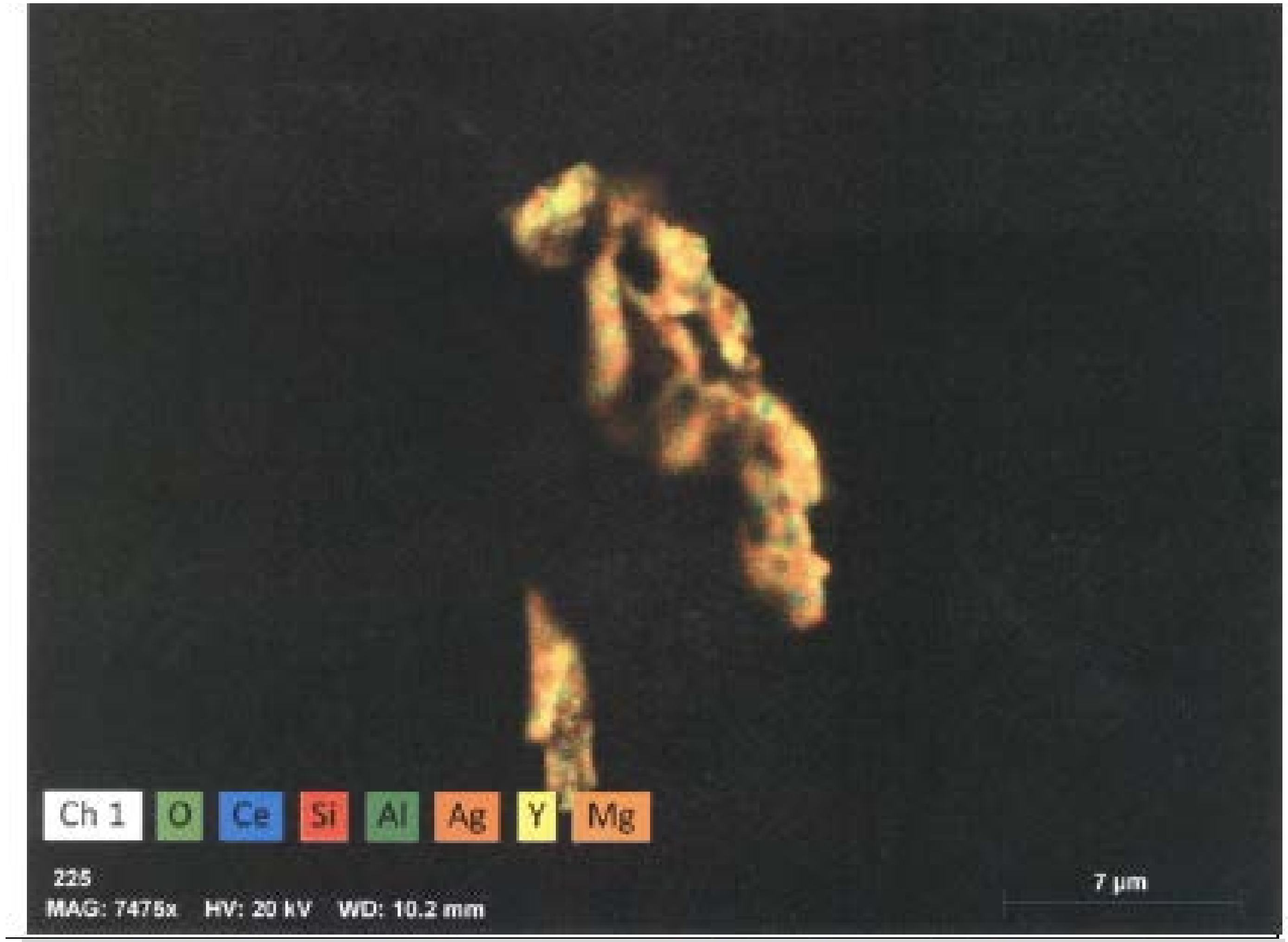


Typical example of results obtained by combined SEM – Raman spectrometry analysis of a UO_2 particle (sample ES-1, particle #4): EDX spectrum (bottom) showing presence of U as the major compound, along with F and O, electronic image (top, left) of the particle and Raman spectrum (top, right) showing the bands at 445 cm^{-1} which is characteristic of UO_2.

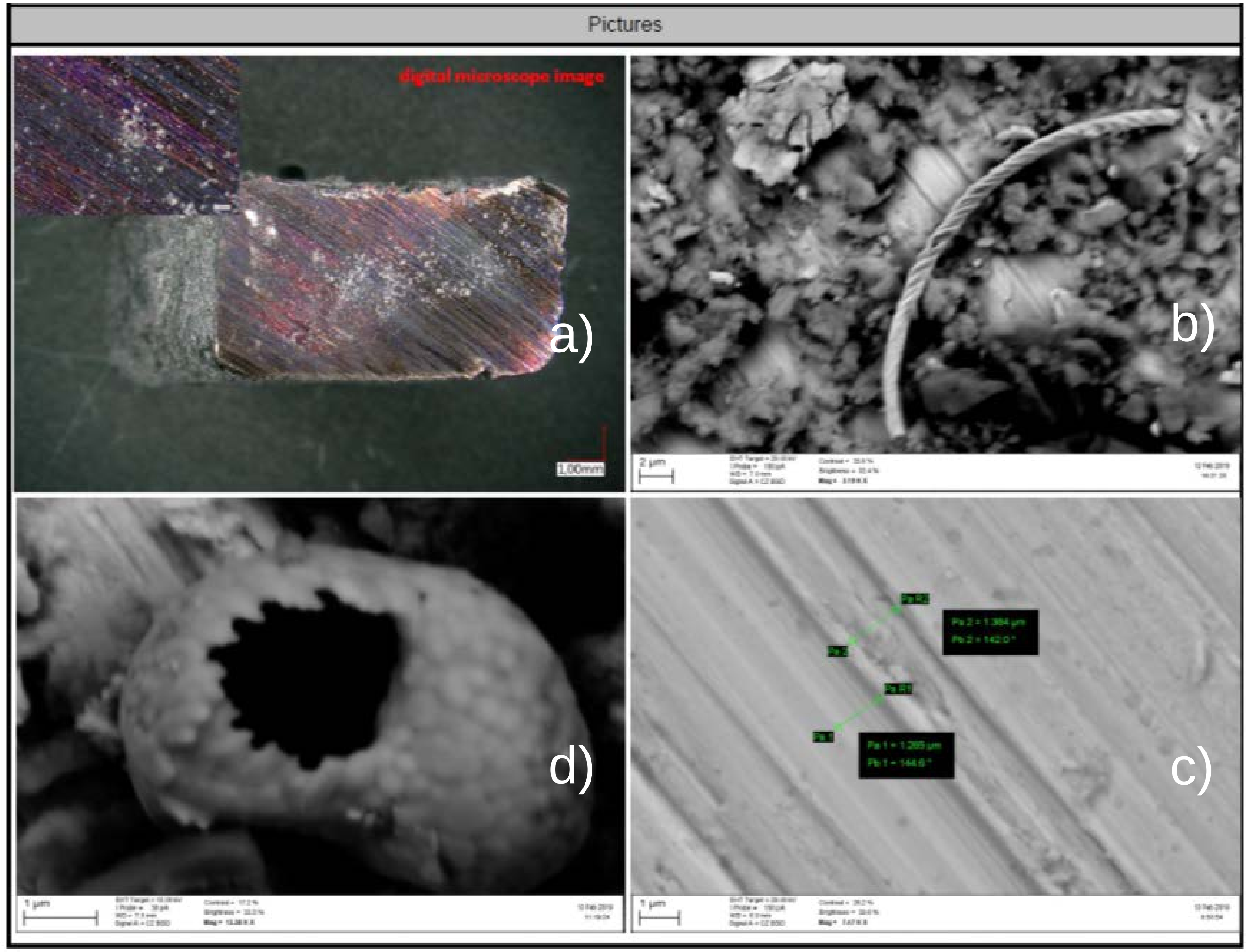


Examples of electronic images of very small (60 – 500 nm) U particles sampled on the surface of the sample ES-2 and a typical EDX spectrum obtained for one of these particles. F was detected as a minor constituent in all of the particles. A low abundance of O was also detected in all of these particles.

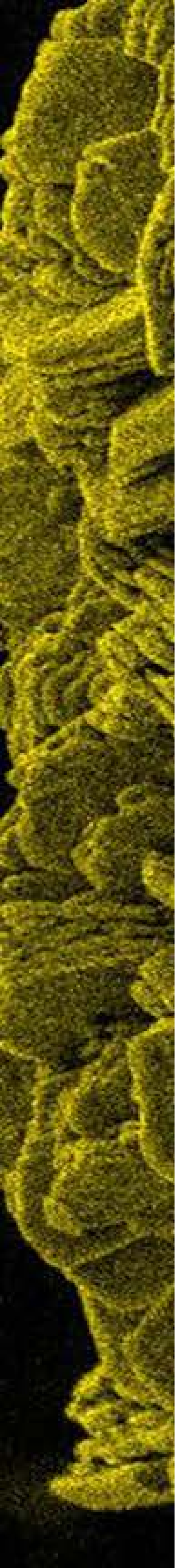
Outstanding Example by Nanda Devi and Cho Oyo of Physical and Trace Elemental Analysis



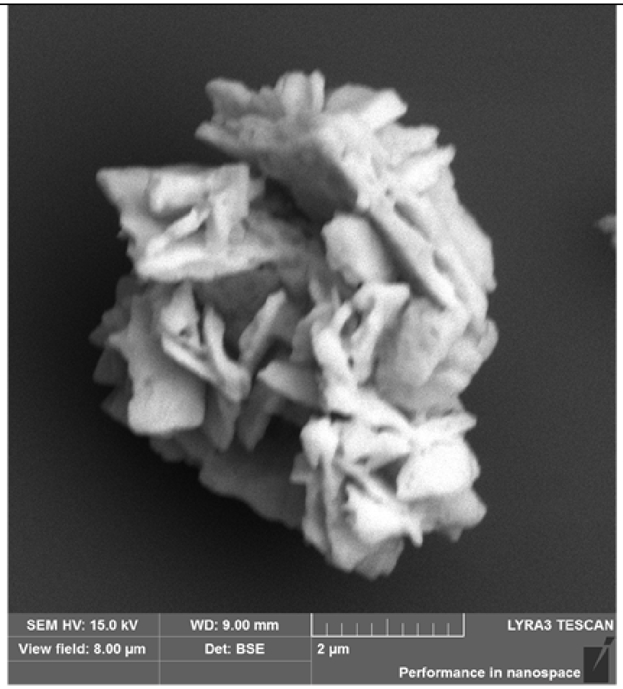
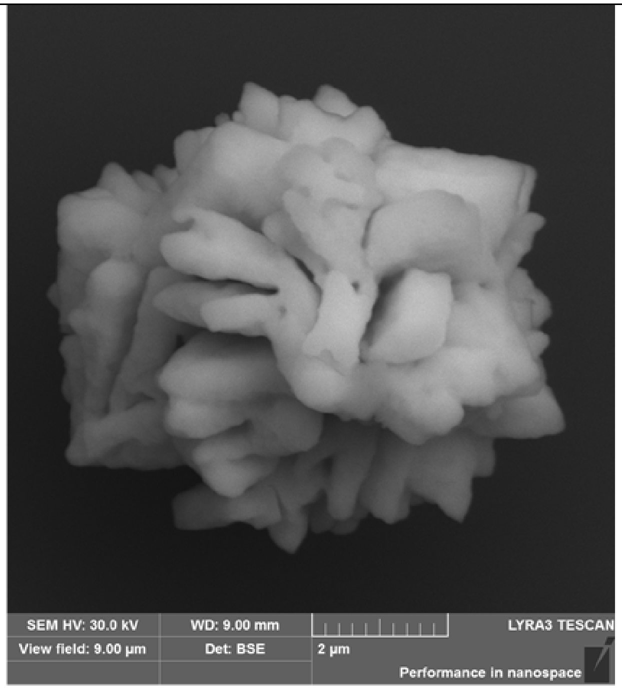
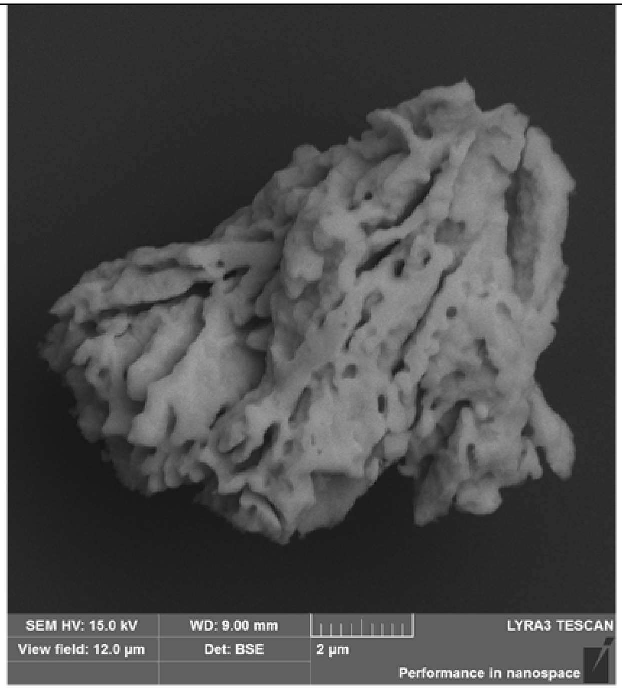
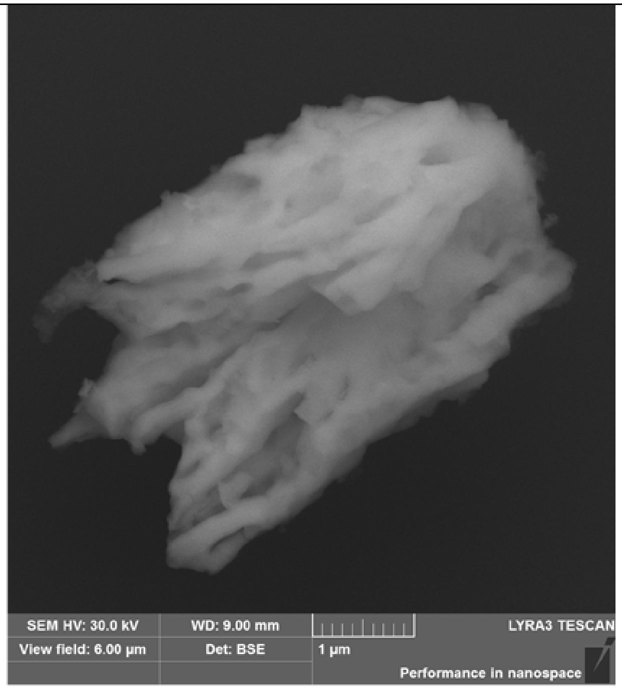
SEM-EDX of ES-1 performed by Nanda Devi using special purpose hermetic cell to seal potentially dispersible radioactive contamination from the instrument during analysis. Analysis shows detection of Al and Y, among other elements.



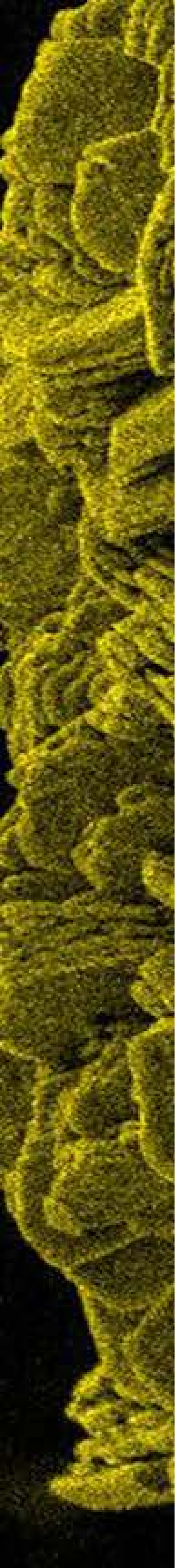
Tool mark analysis by Cho Oyo of cut edge of pipe. (a) Striations suggest straight cutting tool (band, jigsaw or large diameter circular saw). (b) Possible saw fragment. (c) Saw marks over the diameter of the wire found. (d) Hollow (possibly aerosol) particle consisting of mainly U.



Outstanding Example by Batura Sar of Physical and Trace Elemental Analysis

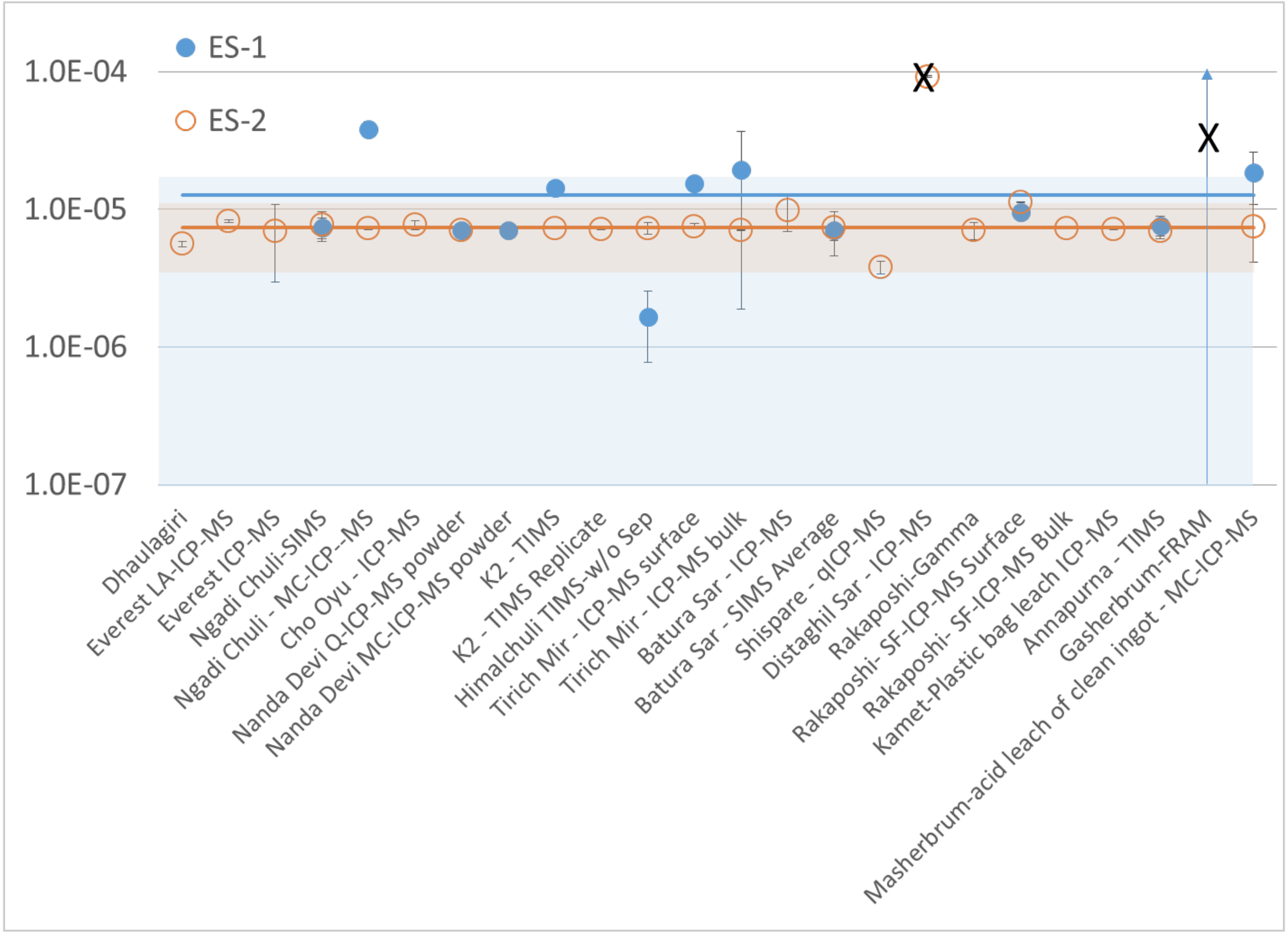
ES-1	ES-2	ES-1	ES-2
			
Approximate quantification of X-Ray spectrum: Pu – 83.6%, O – 9.5%, F – 5.1%, Al, Ni and Fe – less than 1%. Concentration of Pu-239 – (93.518 ± 0.003)%.	Approximate quantification of X-Ray spectrum: Pu – 82.2%, O – 3.3%, F – 14.0%, Ni – less than 1%. Concentration of Pu-239 – (93.504 ± 0.005)%.	Approximate quantification of X-Ray spectrum: Pu – 85.2%, O – 7.0%, F – 5.7%, Al, Ni, Cr and Fe – less than 1%. Concentration of Pu-239 – (93.473 ± 0.005)%.	Approximate quantification of X-Ray spectrum: Pu – 82.8%, O – 9.5%, F – 6.0%, Al, Ni and Fe – less than 1%. Concentration of Pu-239 – (93.545 ± 0.003)%.

Morphological and compositional comparisons of two Pu particles collected from ES-1 and ES-2 (Batura Sar).



Isotopic Results – $^{234}U/^{238}U$

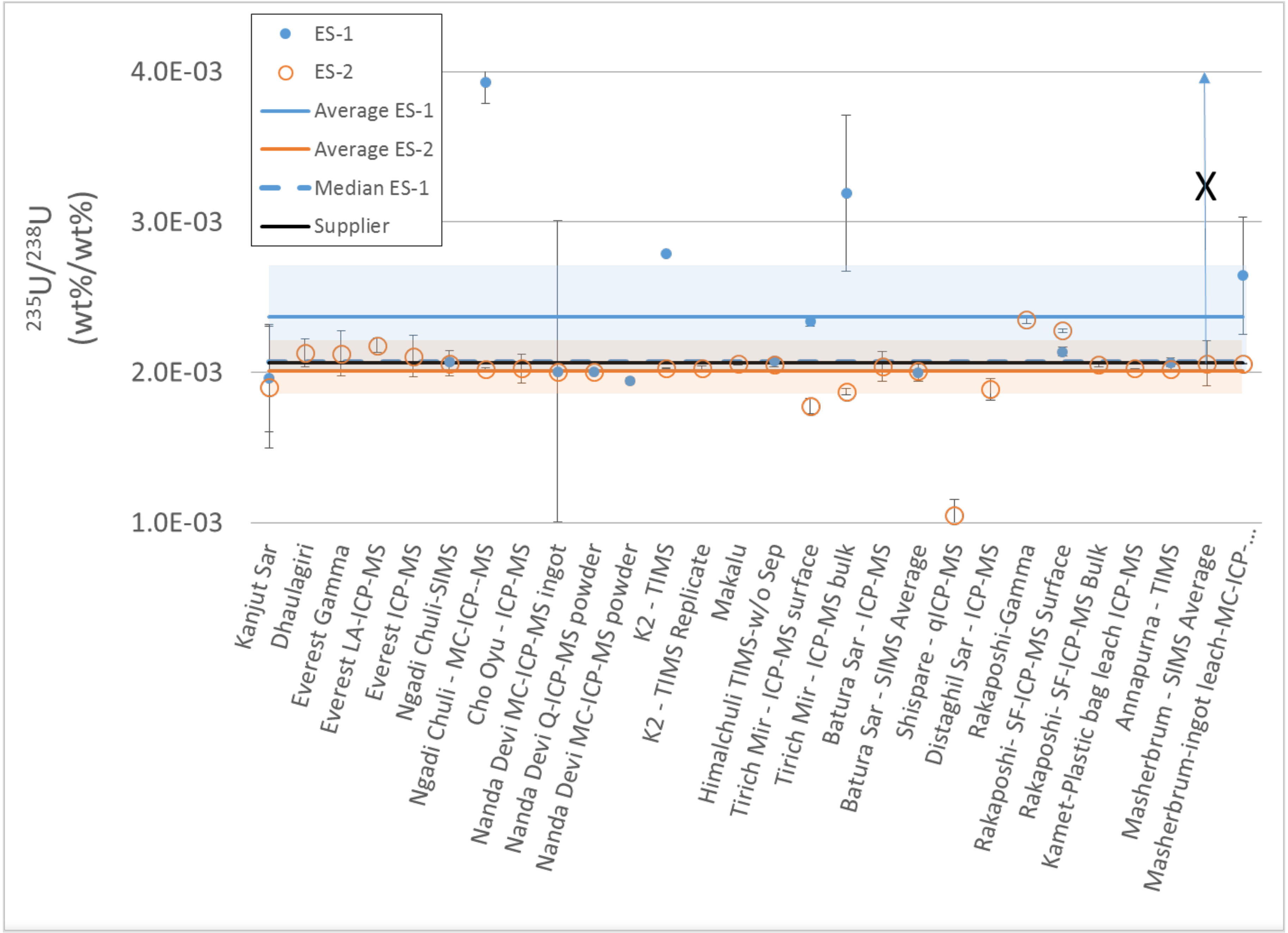
- 12 labs reported values for ES-1
- 20 labs reported values for ES-2
- Of the 11 labs reporting for both ES-1 & ES-2, 5 labs found both to be consistent relative to 234/238 ratio



$^{234}U/^{238}U$ mass ratios in ES-1 and ES-2 at 2 months

Isotopic Results – $^{235}U/^{238}U$

- 9 labs reported values for ES-1
- 16 labs reported values for ES-2
- Of the 13 labs reporting for both ES-1 & ES-2, 8 labs found both to be consistent relative to 235/238 ratio
- With few exceptions, labs consistent with Supplier Declarations



$^{234}U/^{238}U$ mass ratios in ES-1 and ES-2 at 2 months

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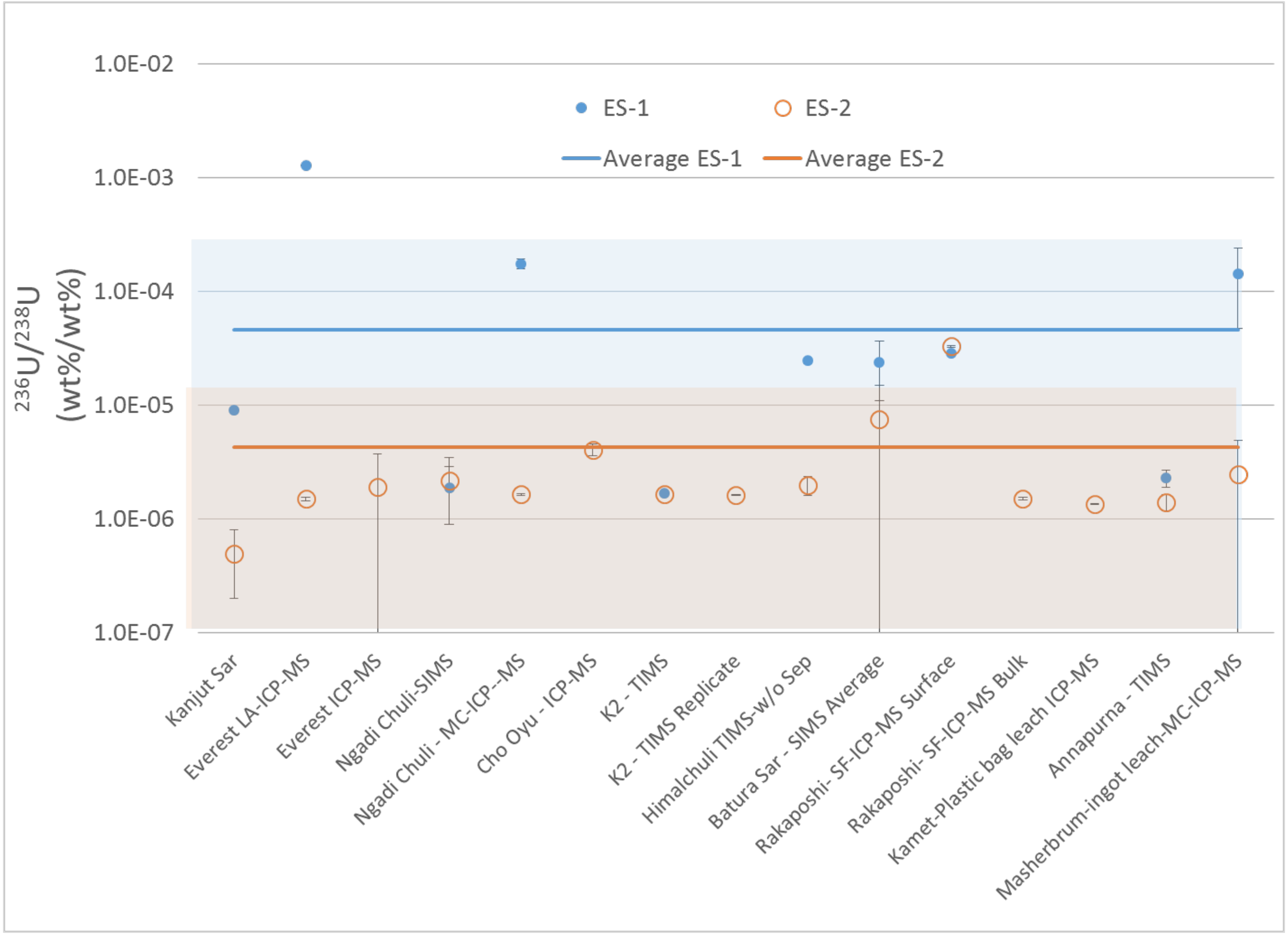
Isotopic Results – $^{236}U/^{238}U$

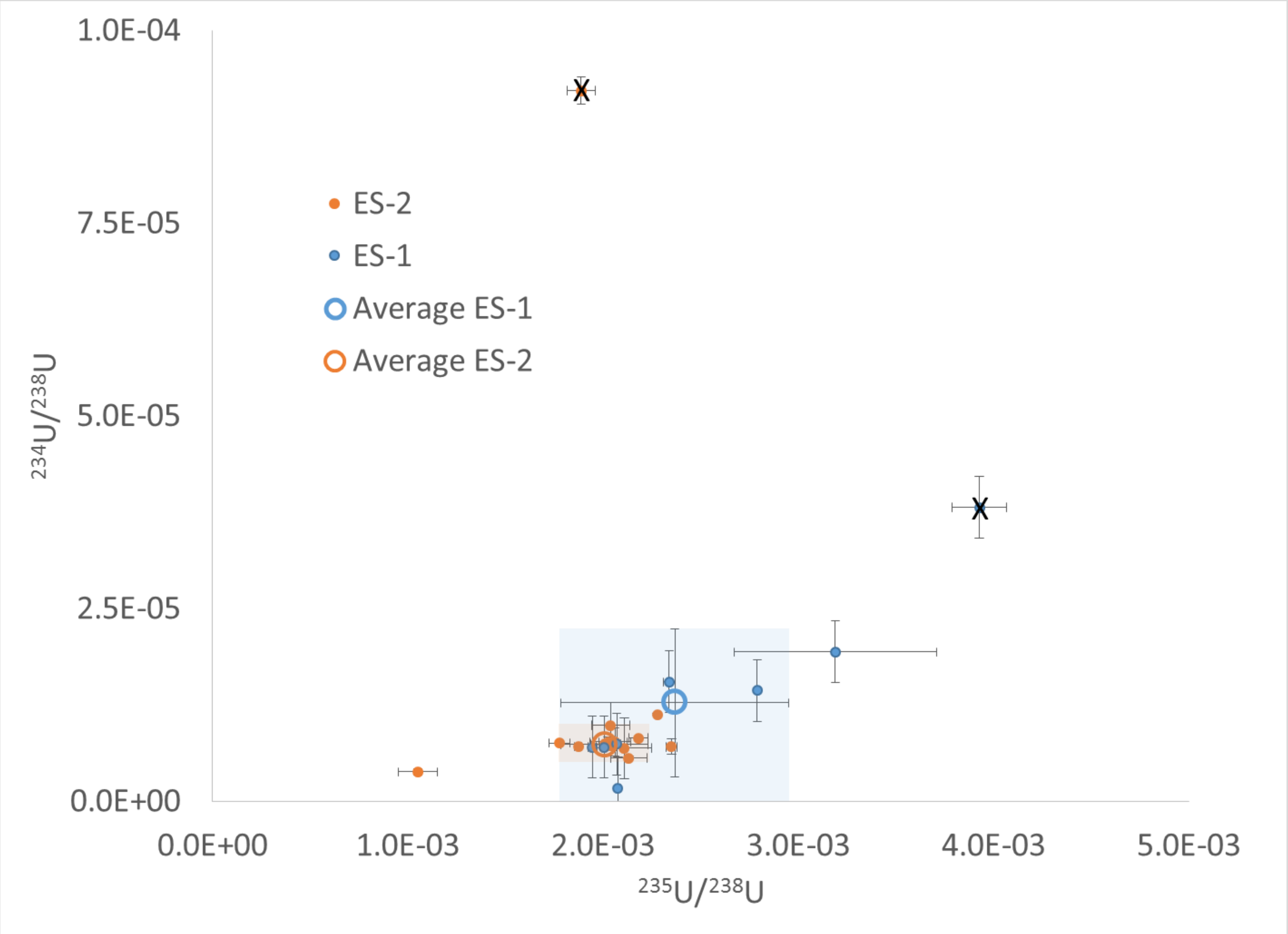
- 9 labs reported values for ES-1
- 11 labs reported values for ES-2
- Of the 8 labs reporting for both ES-1 & ES-2, 3 labs found both to be consistent relative to 236/238 ratio



$^{236}U/^{238}U$ mass ratios in ES-1 and ES-2 at 2 months

Tri-plot of $^{235}U/^{238}U$ vs $^{234}U/^{238}U$

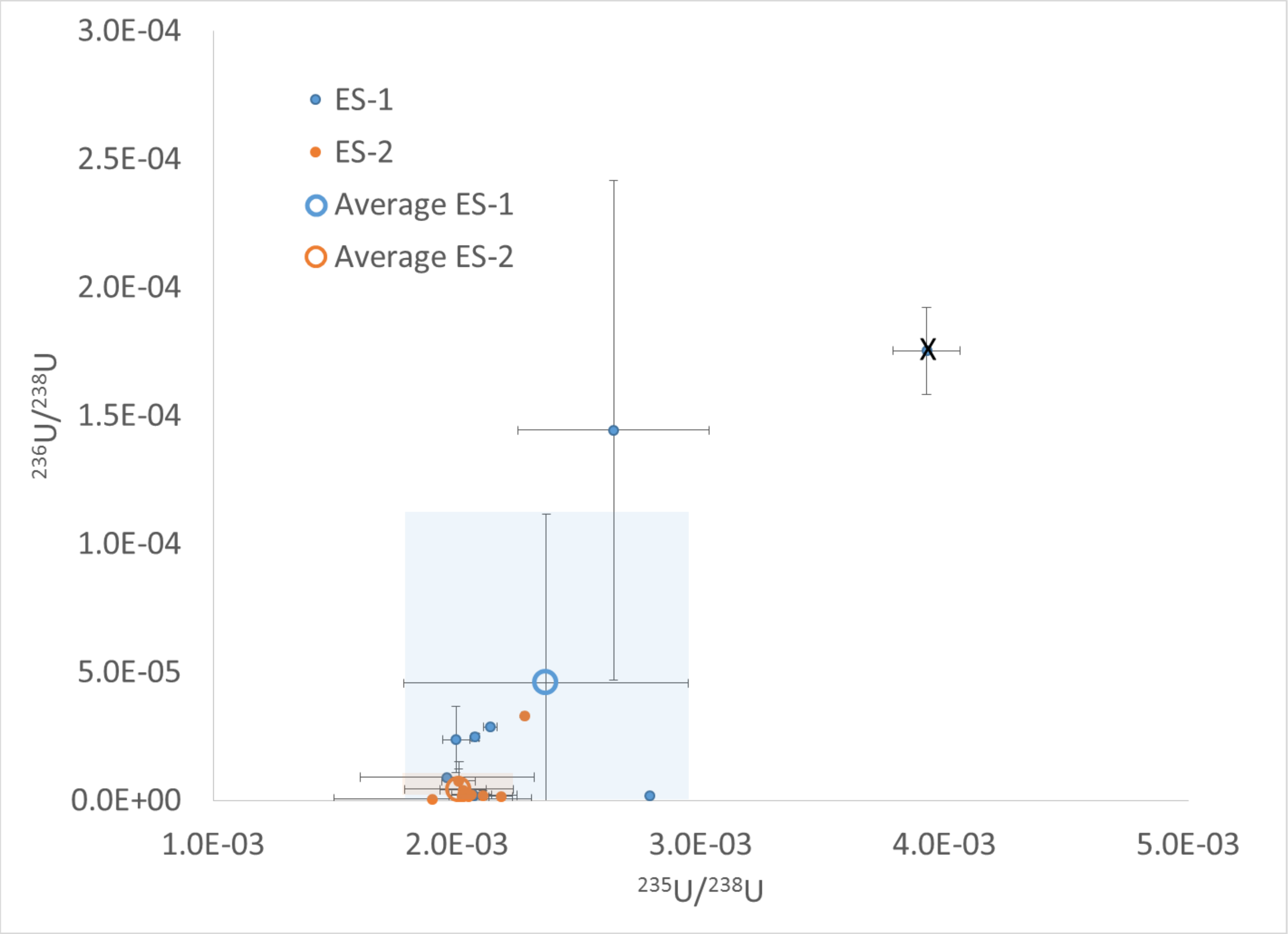
- 8 labs reported values for ES-1
- 15 labs reported values for ES-2
- Most results agree well with no significant difference between ES-1 and ES-2



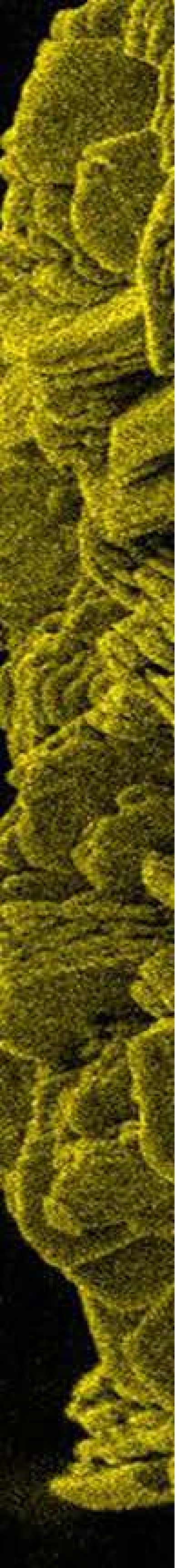
$^{234}U/^{238}U$ vs $^{235}U/^{238}U$ tri-plot for ES-1 and ES-2 at 1 week.

Tri-plot of $^{235}U/^{238}U$ vs $^{236}U/^{238}U$

- 7 labs reported values for ES-1
- 10 labs reported values for ES-2
- Most results agree well with no significant difference between ES-1 and ES-2



Tri-plot of $^{235}U/^{238}U$ vs $^{236}U/^{238}U$ for ES-1 and ES-2 at 2 months



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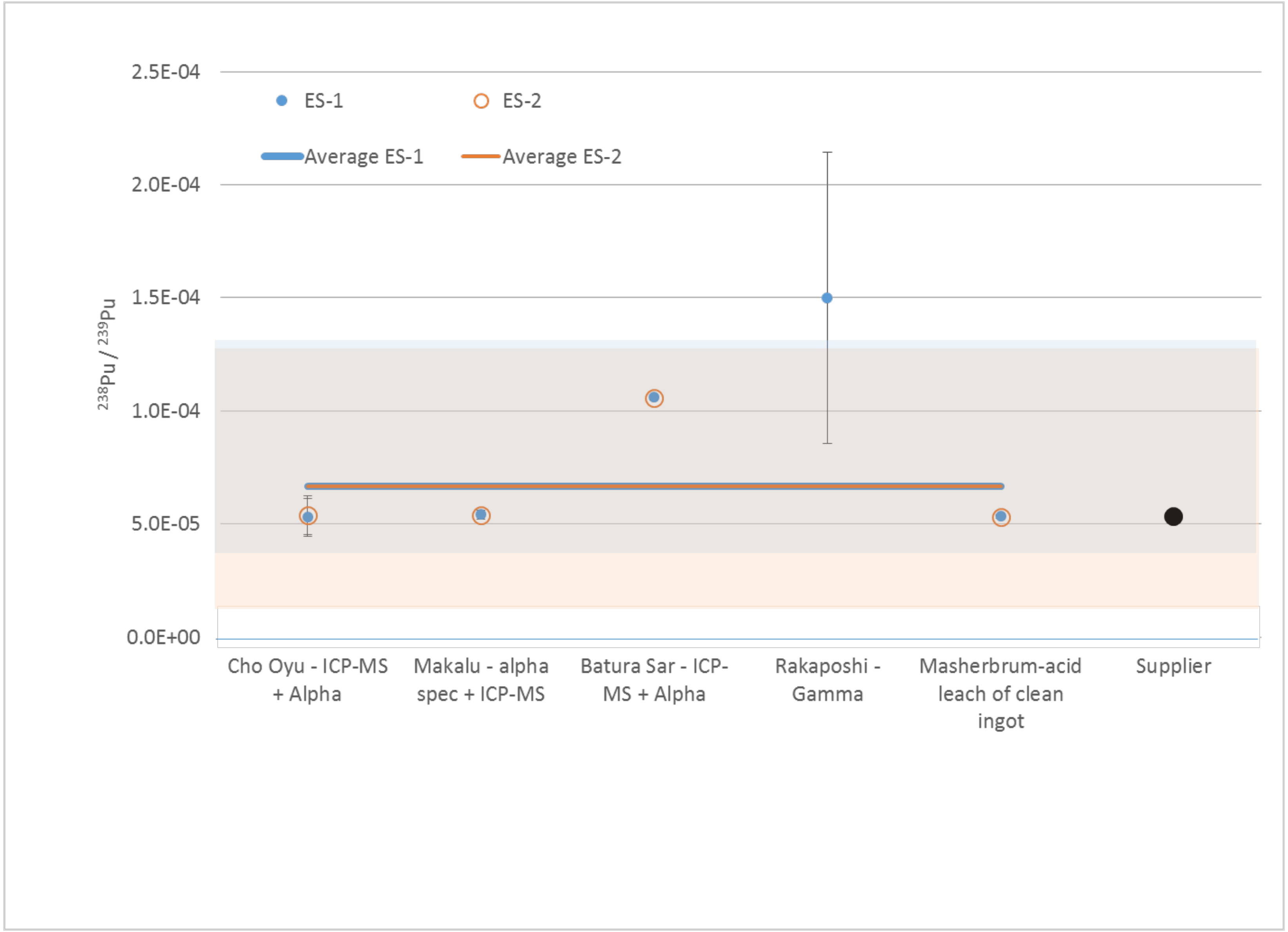
Isotopic Results – $^{238}Pu/^{239}Pu$

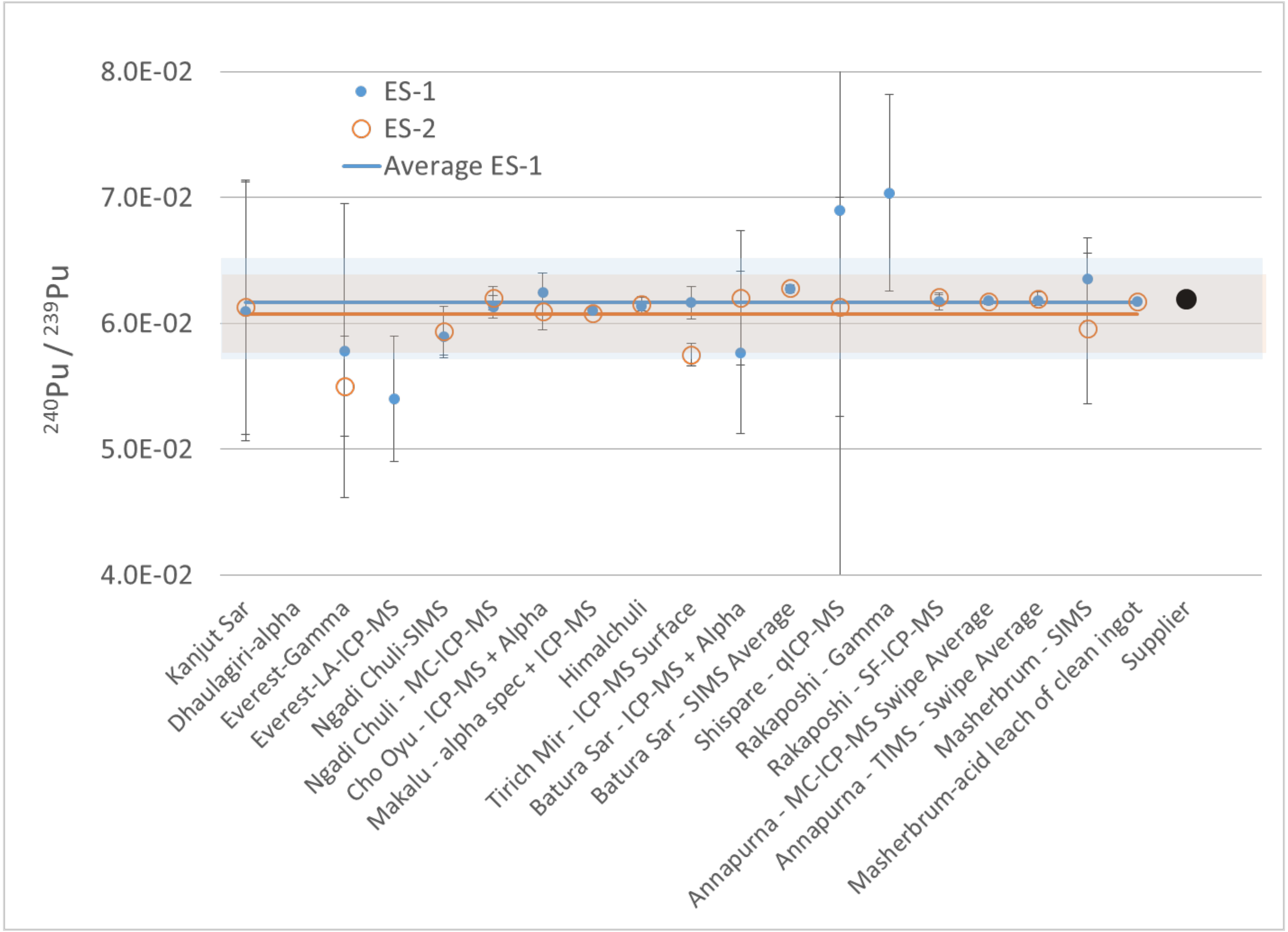
- 5 labs reported values for ES-1
- 4 labs reported values for ES-2
- Of the 4 labs reporting for both ES-1 & ES-2, all labs found both results with one another
- All measurements are consistent with supplier declarations



$^{238}Pu/^{239}Pu$ isotopic ratios in ES-1 and ES-2 at 2 months

Isotopic Results – $^{240}Pu/^{239}Pu$

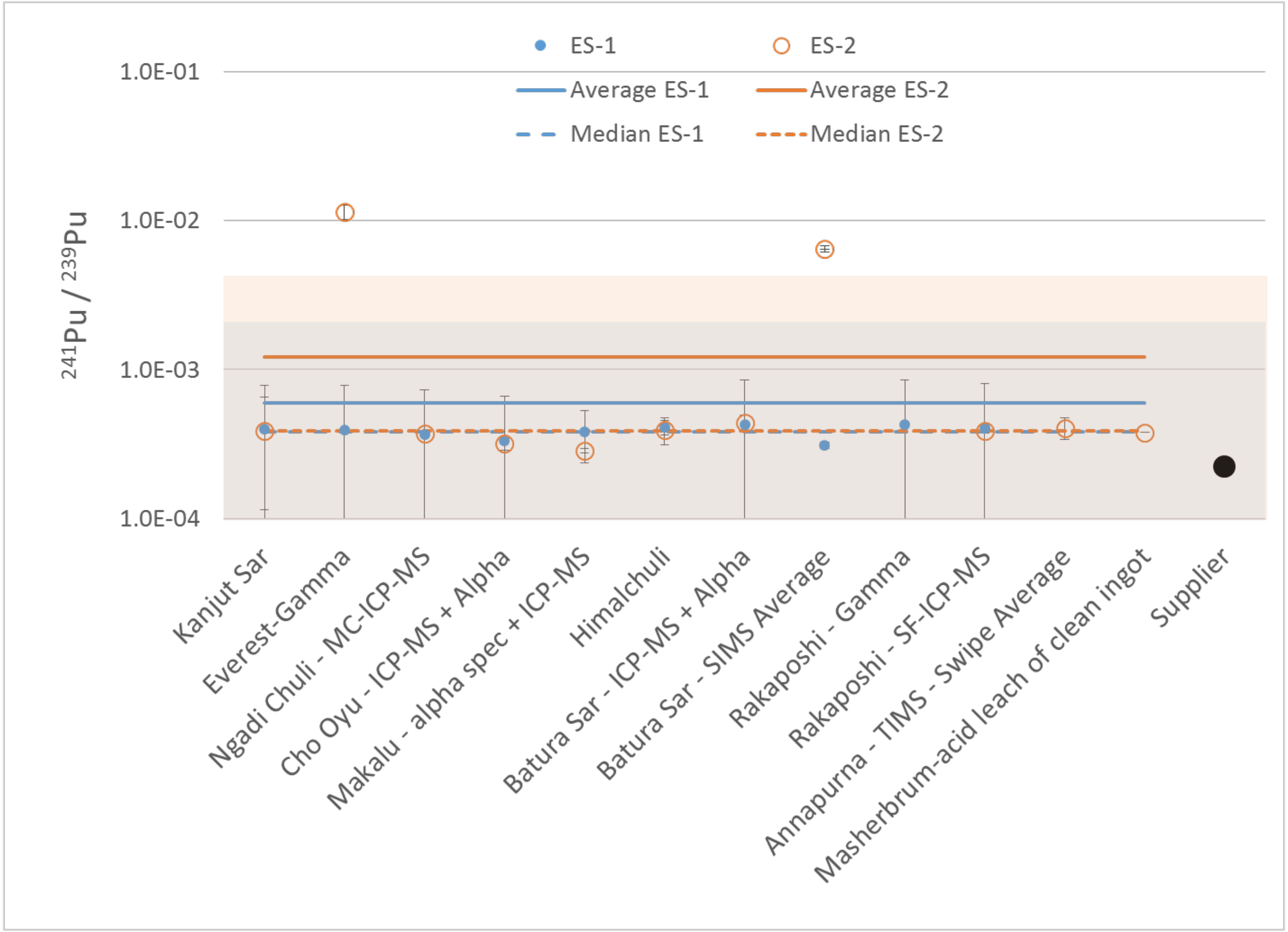
- 18 values reported for ES-1
- 16 values reported for ES-2
- Of the 16 labs reporting values for both ES-1 & ES-2, 15 labs found both to be consistent
- 90% of the analyses consistent with supplier declarations



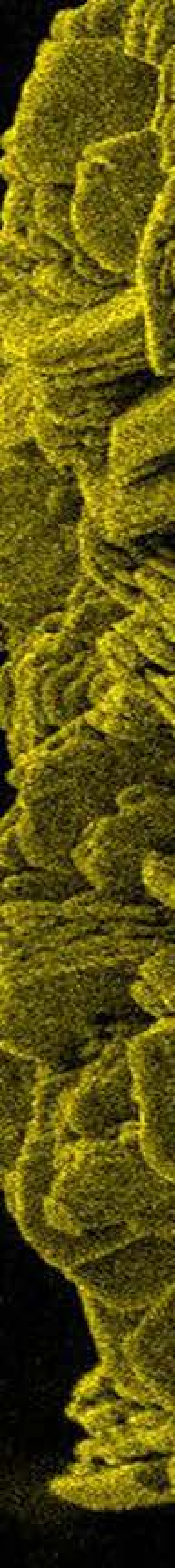
$^{240}Pu/^{239}Pu$ mass ratios for ES-1 and ES-2 at 2 months.

Isotopic Results – $^{241}Pu/^{239}Pu$

- 15 values reported for ES-1
- 13 values reported for ES-2
- All of the 13 labs reporting values for both ES-1 & ES-2, found the two samples to be consistent



$^{241}Pu/^{239}Pu$ mass ratios for ES-1 and ES-2 at 2 months. Shaded areas show standard deviation of participant values.



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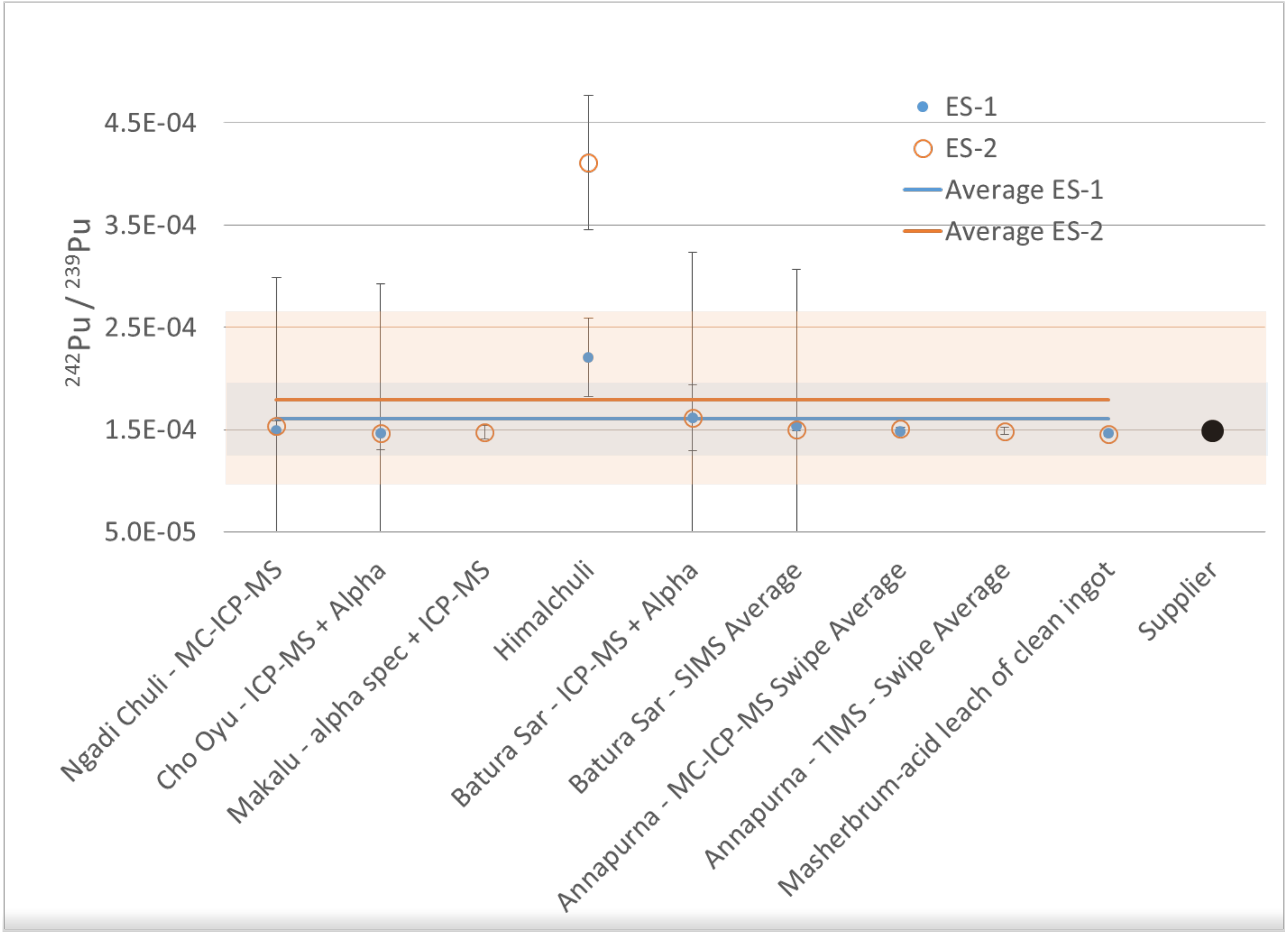
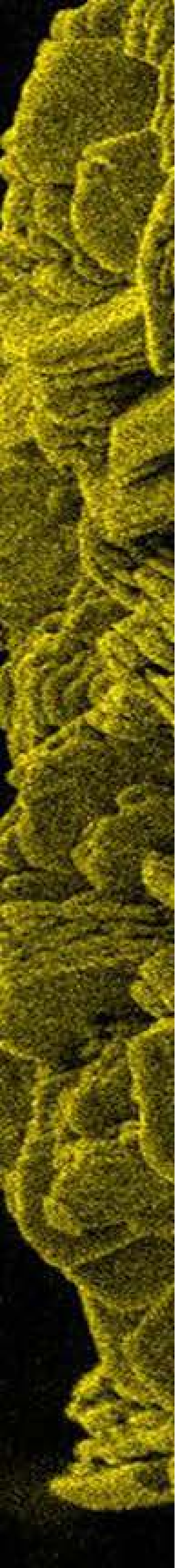
Isotopic Results – $^{242}Pu/^{239}Pu$

- 8 values reported for ES-1
- 9 values reported for ES-2
- 6 of the 7 labs reporting values for both ES-1 & ES-2, found the two samples to be consistent

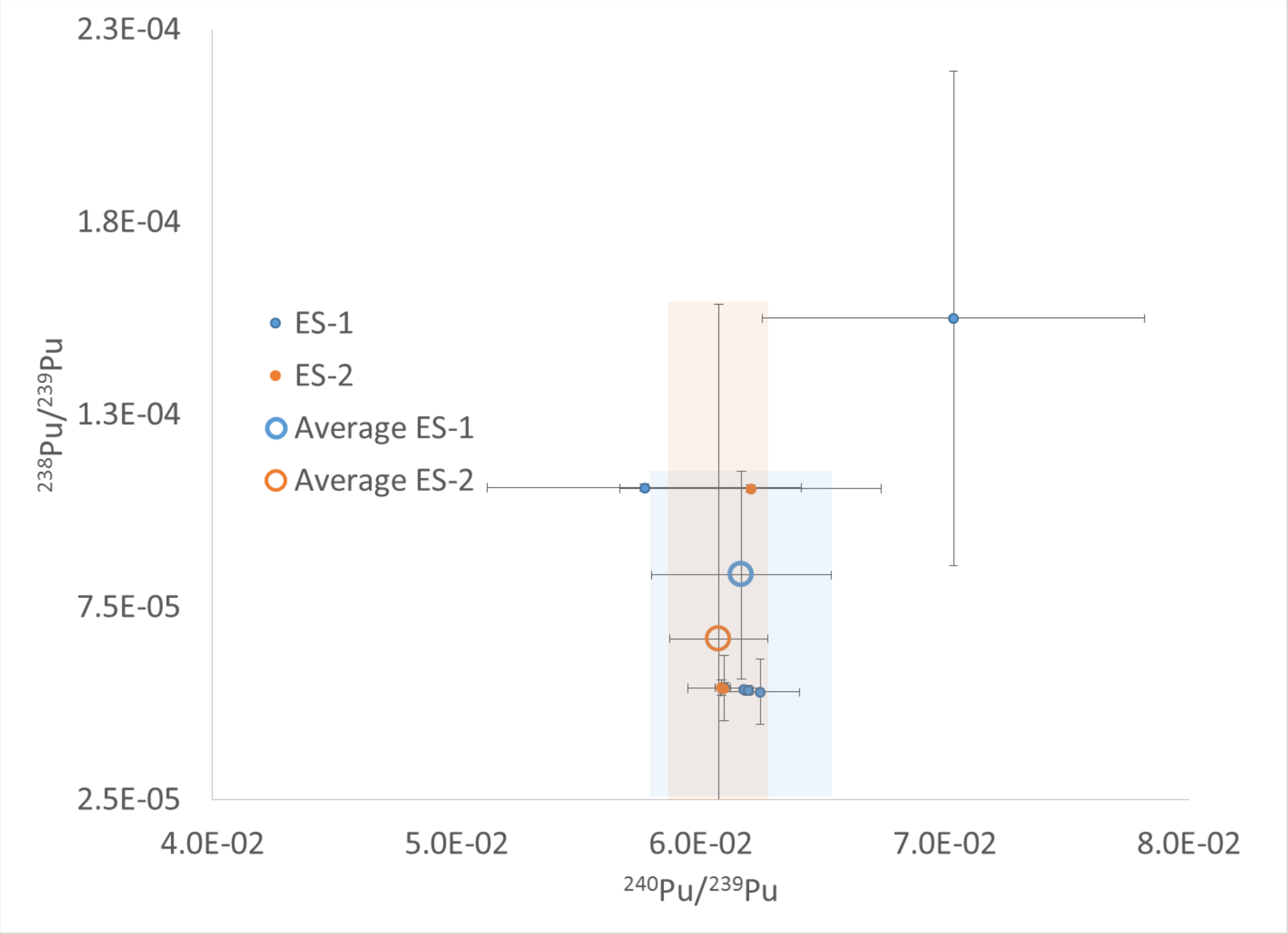


$^{242}Pu/^{239}Pu$ mass ratios for ES-1 and ES-2 at 2 months. Shaded areas show standard deviation of participant values.



Isotopic Results – Tri-plot of $^{238}Pu/^{239}Pu$ vs $^{240}Pu/^{239}Pu$

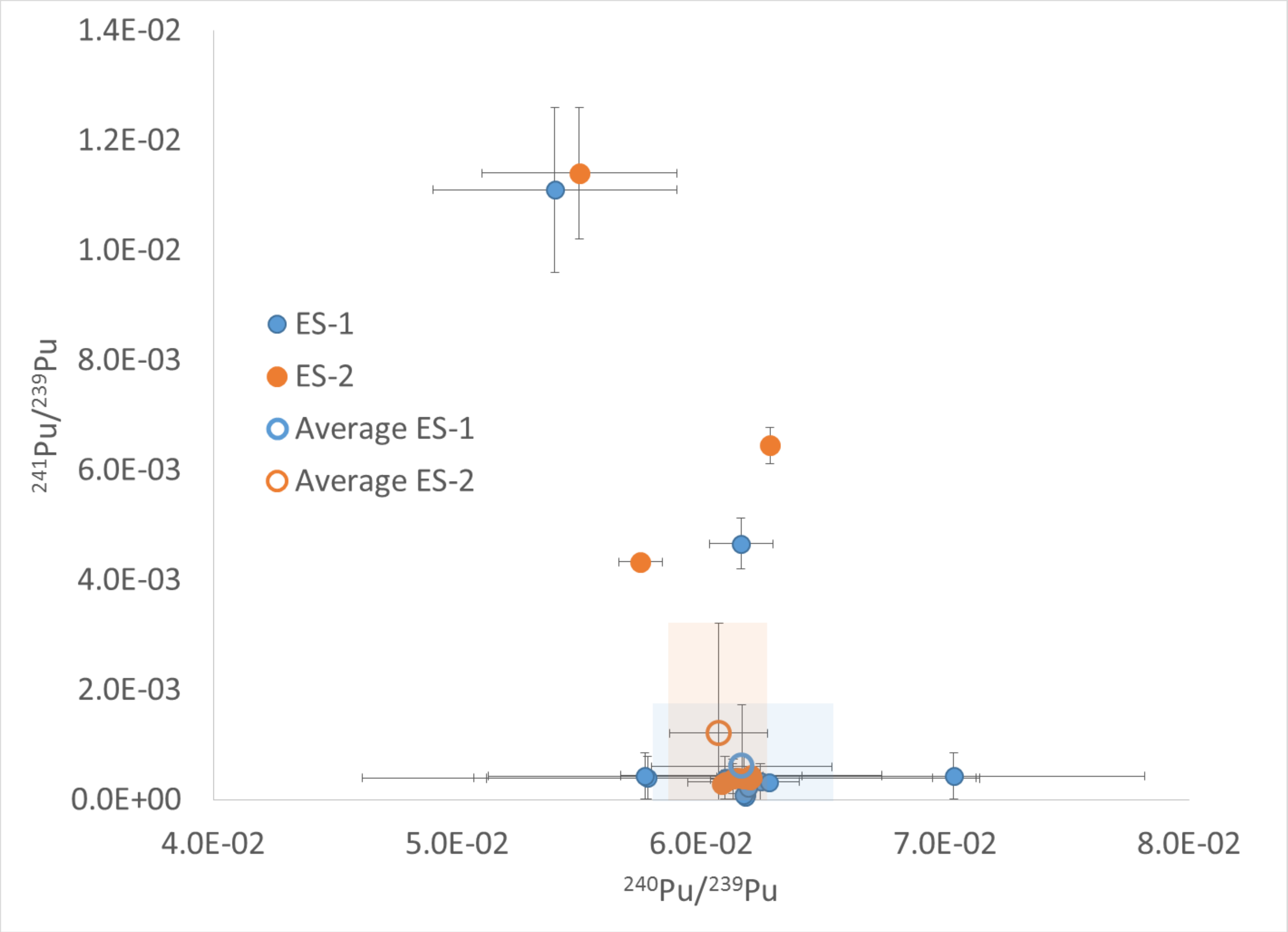
- 5 labs reported values for ES-1
- 4 labs reported values for ES-2
- Results suggest ES-1 and ES-2 are similar



$^{238}Pu/^{239}Pu$ vs $^{240}Pu/^{239}Pu$ mass ratios for ES-1 and ES-2 at 2 months. Shaded areas show standard deviation of participant values.

Isotopic Results – Tri-plot of $^{241}Pu/^{239}Pu$ vs $^{240}Pu/^{239}Pu$

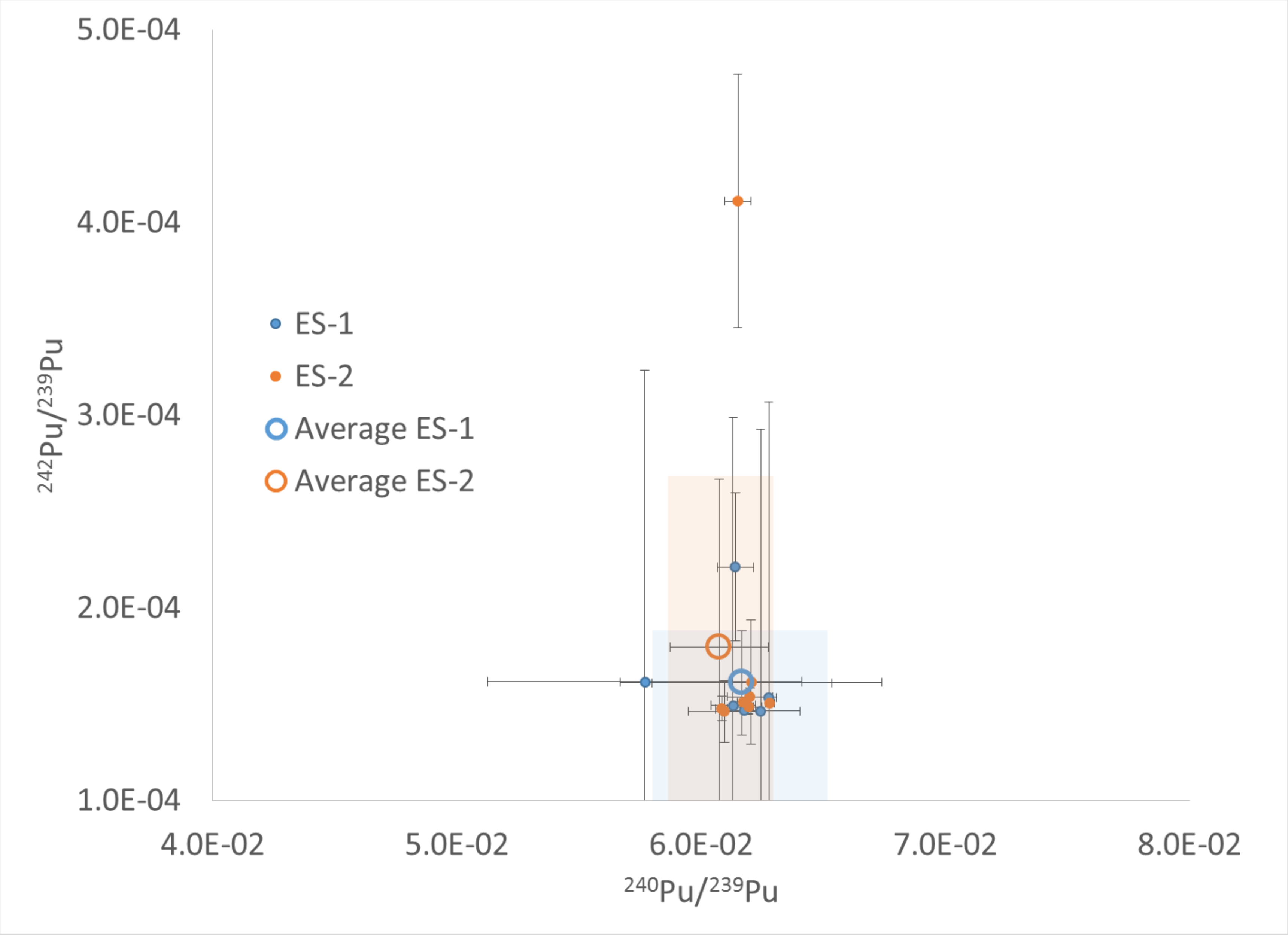
- 6 labs reported values for ES-1
- 4 labs reported values for ES-2
- Results suggest ES-1 and ES-2 are similar



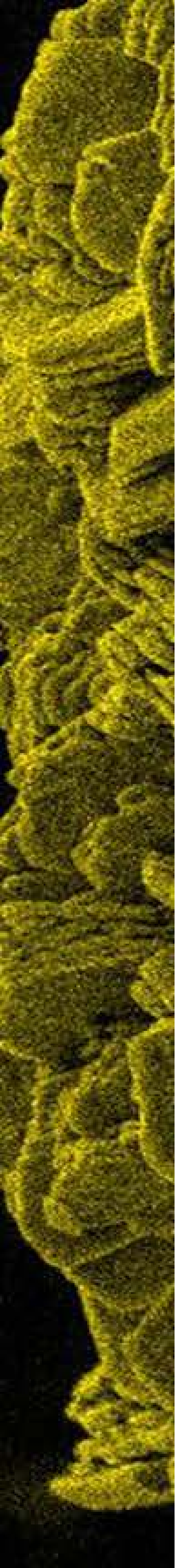
$^{241}Pu/^{239}Pu$ vs $^{240}Pu/^{239}Pu$ mass ratios for ES-1 and ES-2 at 2 months. Shaded areas show standard deviation of participant values.

Isotopic Results – Tri-plot of $^{242}Pu/^{239}Pu$ vs $^{240}Pu/^{239}Pu$

- 6 labs reported values for ES-1
- 7 labs reported values for ES-2
- Results suggest ES-1 and ES-2 are similar



$^{242}Pu/^{239}Pu$ vs $^{240}Pu/^{239}Pu$ mass ratios for ES-1 and ES-2 at 2 months. Shaded areas show standard deviation of participant values.



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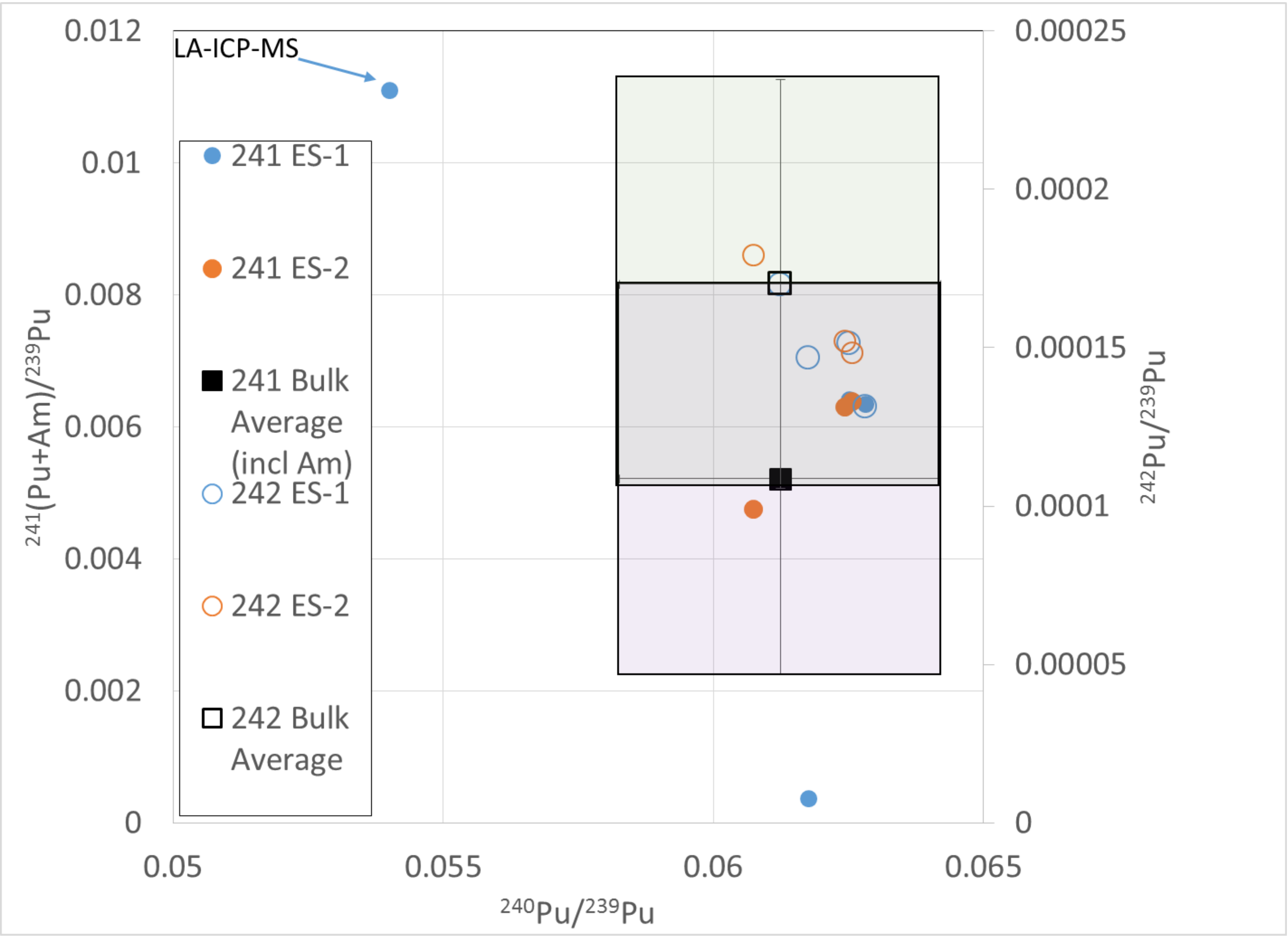
Particle Analysis – $^{241}Pu/^{239}Pu$ & $^{242}Pu/^{239}Pu$ vs $^{240}Pu/^{239}Pu$

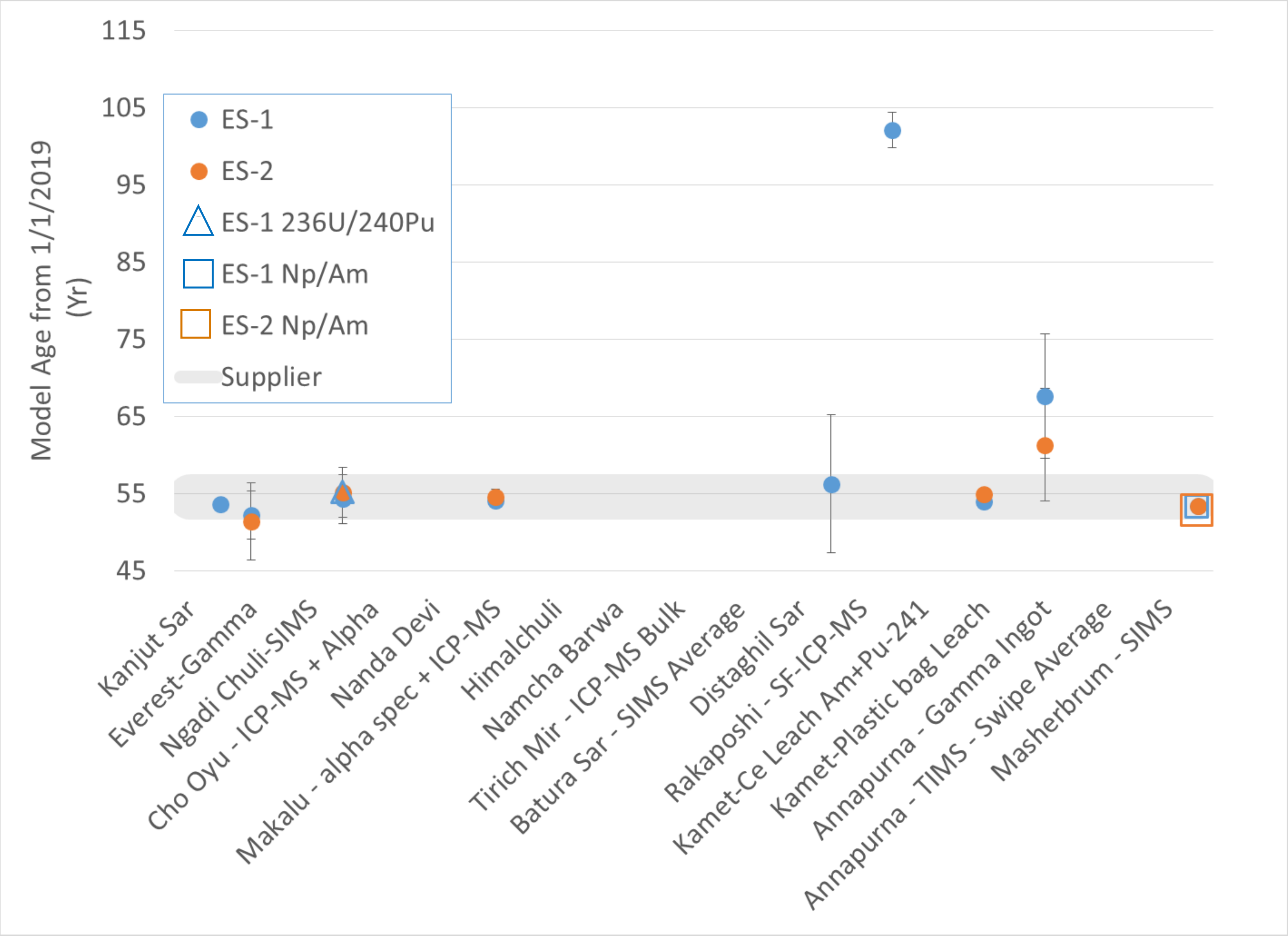
- Gnadi Chuli, Masherbrum, and Batura Sar reported SIMS data for ES-1 and ES-2
- Everest reported LA-ICP-MS results
- Majority of data suggest ES-1 and ES-2 are consistent
- Most particle analysis consistent with bulk analysis



$^{242}Pu/^{239}Pu$ vs $^{240}Pu/^{239}Pu$ mass ratios for ES-1 and ES-2 at 2 months. Shaded areas show standard deviation of participant values.

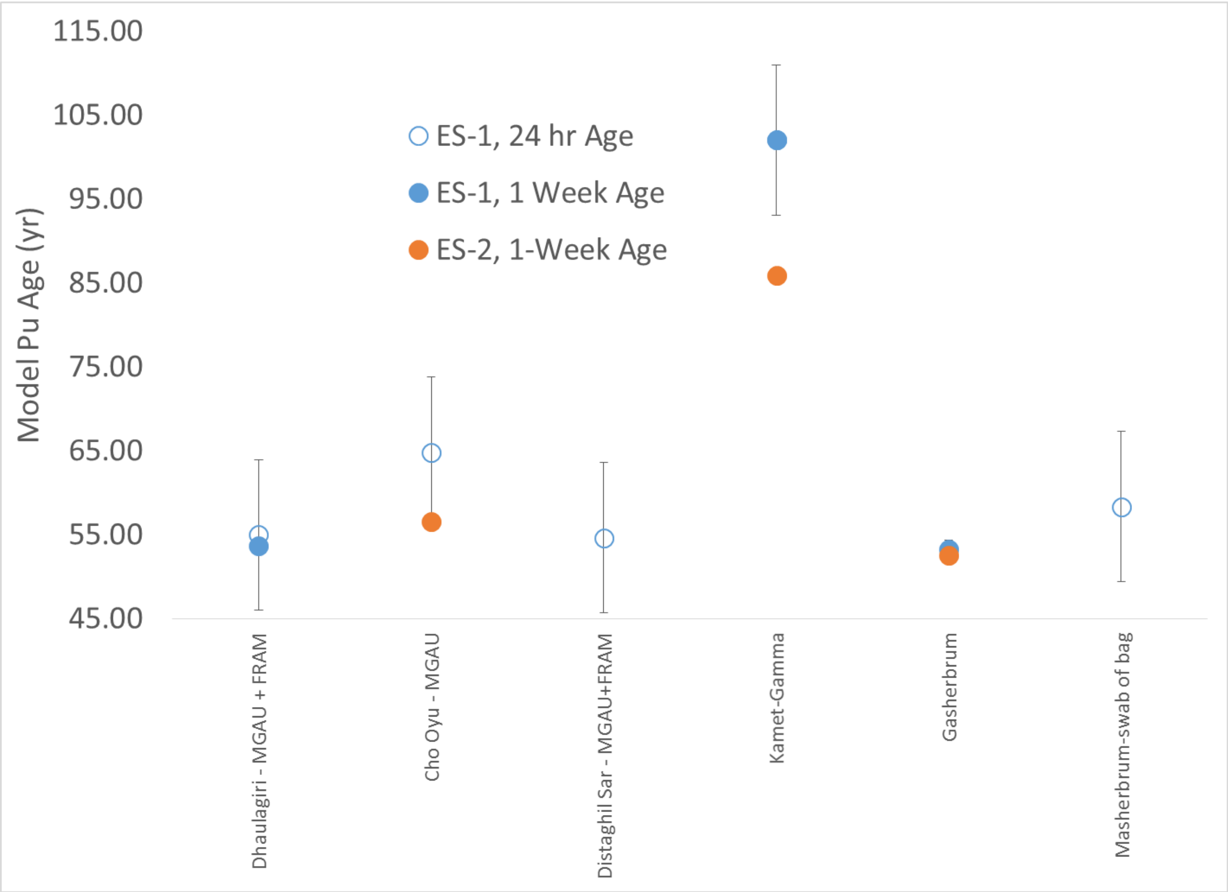
Evaluation Results – Radiochronometry

- 9 labs reported values for ES-1
- 6 labs reported values for ES-2
- 6 out of 6 labs reporting for both ES-1 & ES-2 found ages to be consistent
- Cho Oyu and Masherbrum employed multiple chronometers effectively
- 15 out of 17 measurements consistent with supplier model age

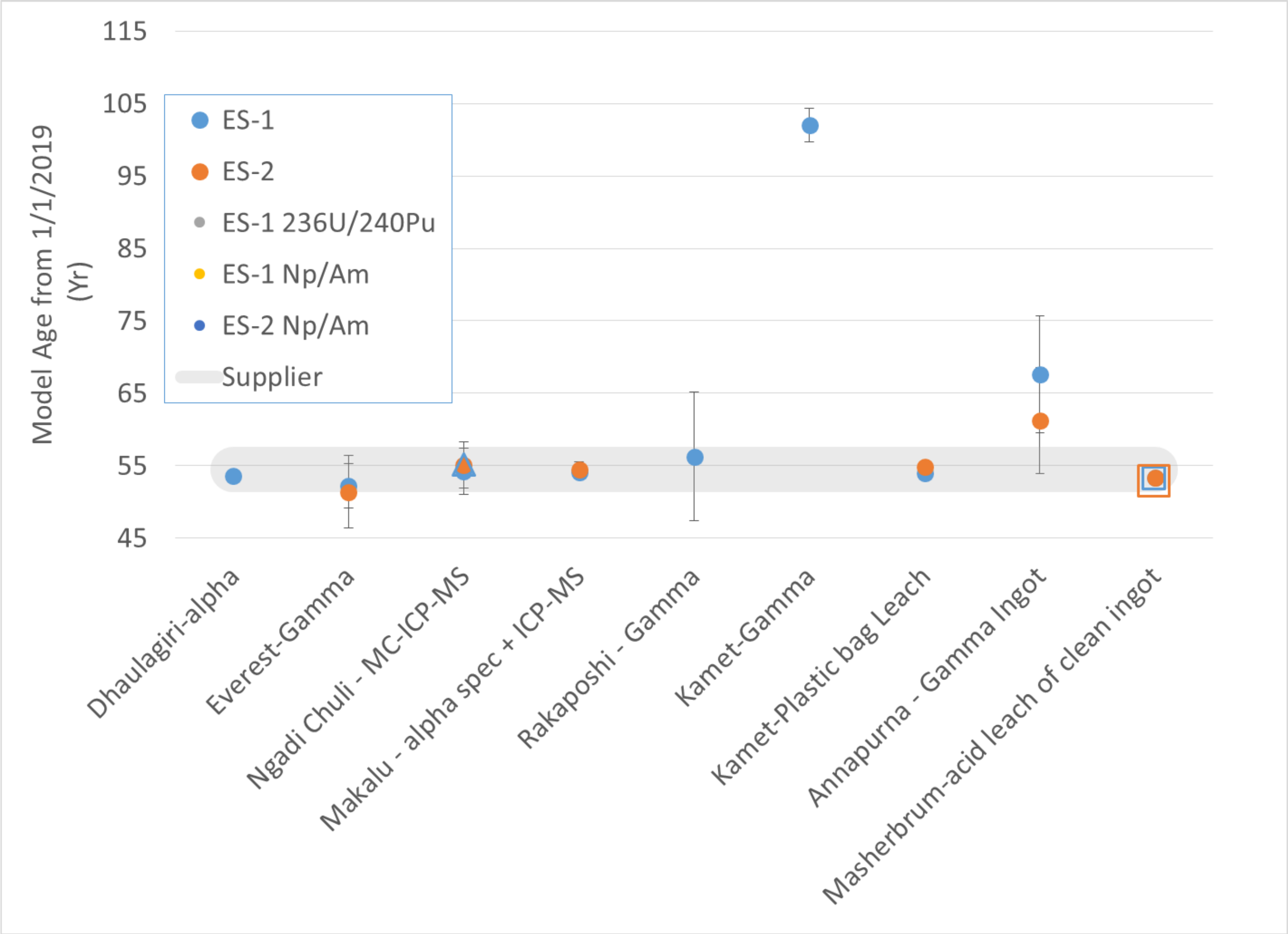


Model age of Pu derived from multiple chronometers

Evolution of Radiochronometry from 24 hr report to 2 month report

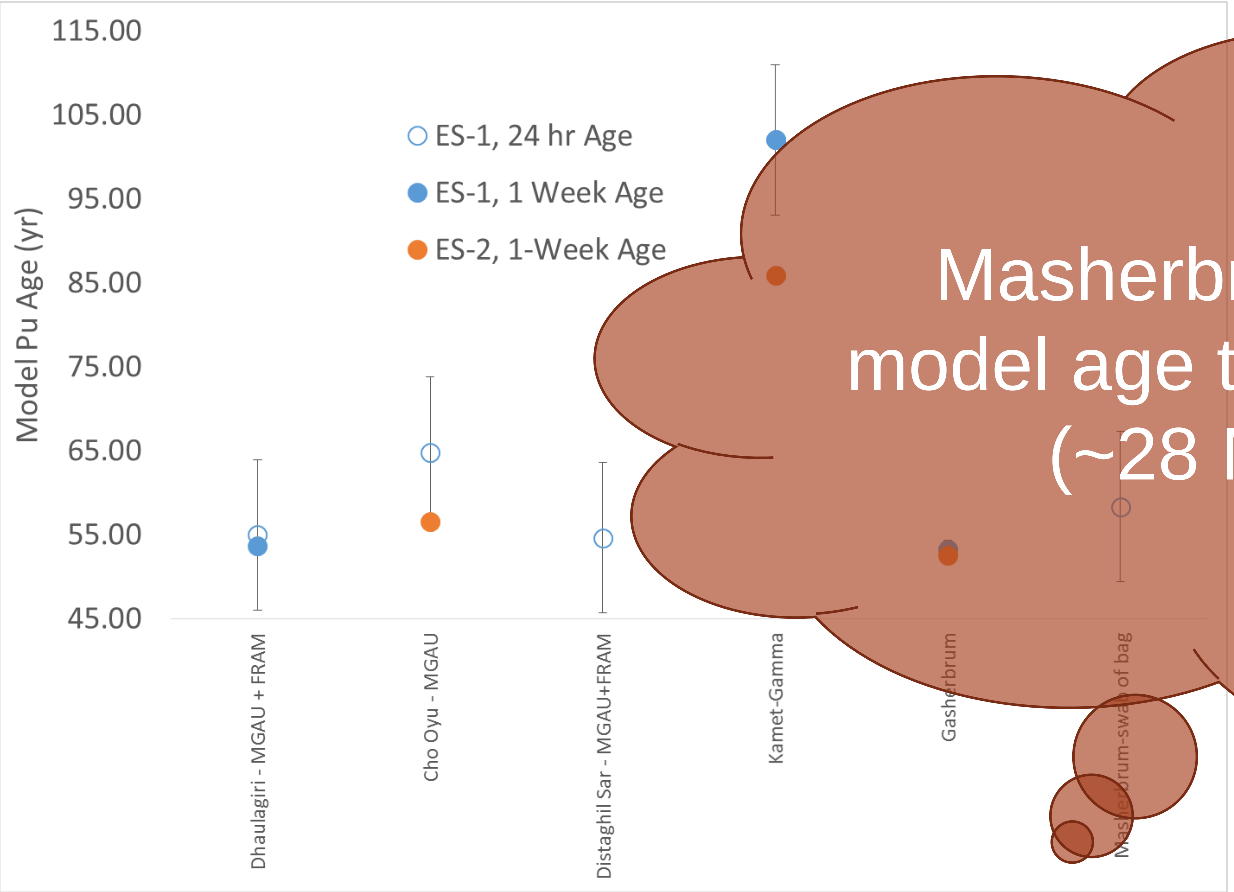


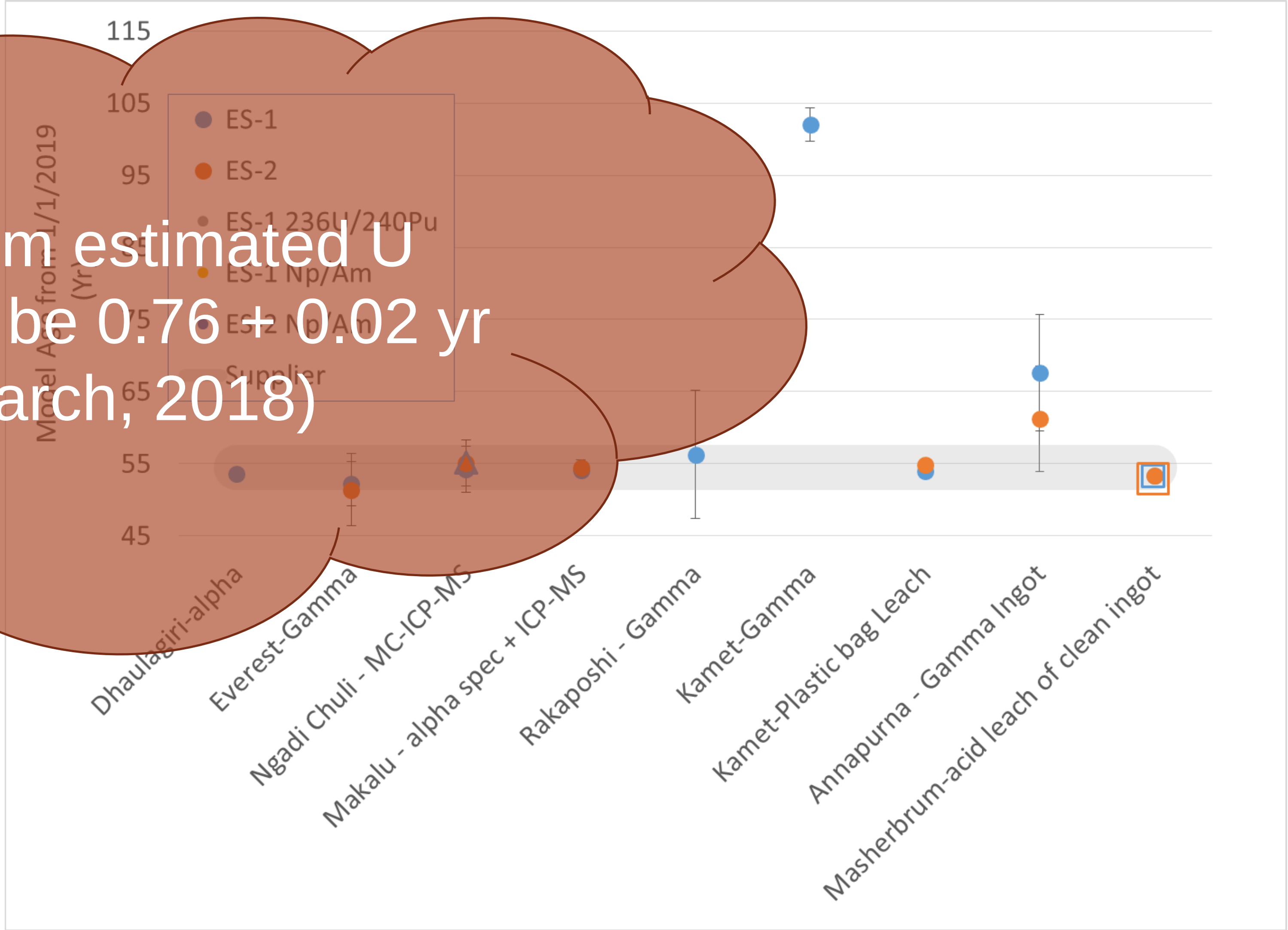
Model age of Pu at 24 hours and 1 week



Model age of Pu at 2 months

Evolution of Radiochronometry from 24 hr report to 2 month report

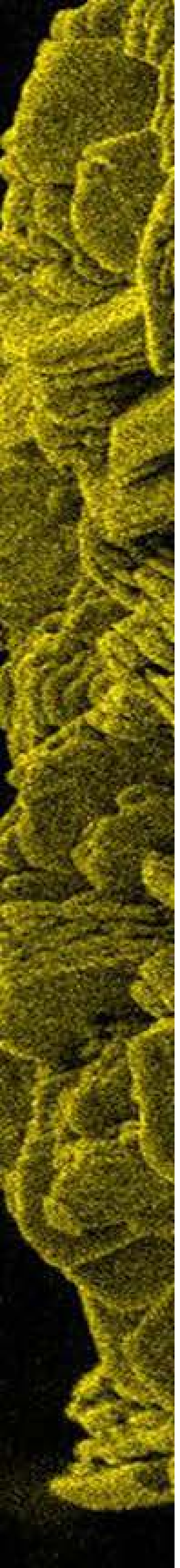




Masherbrum estimated U model age to be 0.76 + 0.02 yr (~28 March, 2018)

Model age of Pu at 24 hours and 1 week

Model age of Pu at 2 months



Discussion – 2 Month

Small Group Discussion

Group 1: Romania, Russia, Ukraine, Azerbaijan

Group 2: Japan, Korea, Singapore, Australia, USA

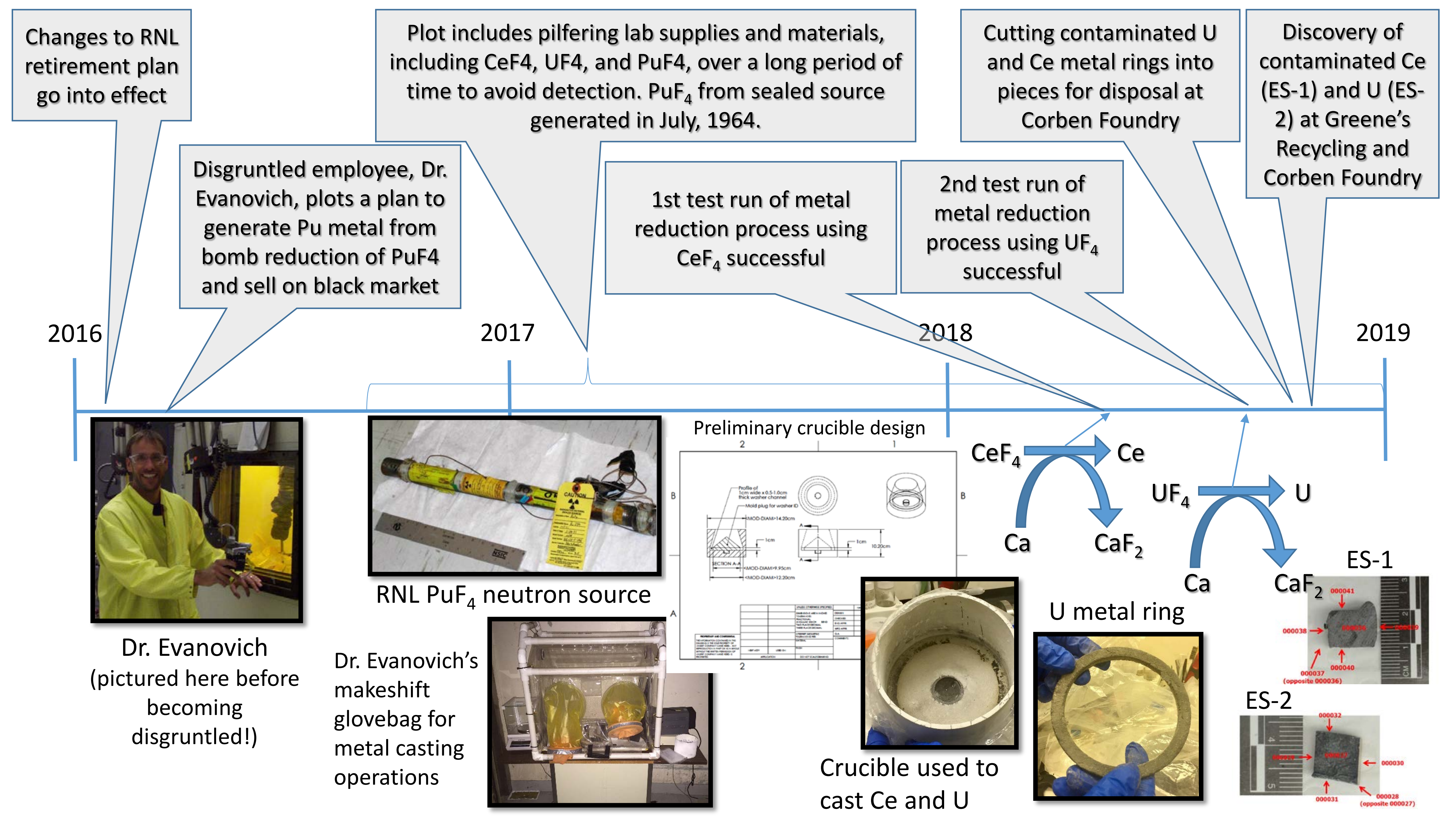
Group 3: Switzerland, Poland, Sweden, Germany, UK

Group 4: Hungary, Israel, JRC, Canada, France

Questions to discuss (spend 10 minutes per question):

1) What were the three most useful measurement techniques used during CMX-6?
2) Are there any analytical results that you believe provide insight into the process history of the materials or the intent by any person of interest to authorities?
3) List three aspects of the exercise that you liked.
4) List three aspects of the exercise that you would change.
5) Please provide any additional comments/suggestions you have about the Data Review Meeting.
6) Regarding future exercises:
   - What would you like the scope to include (e.g. linking with the Libraries Task Group and Galaxy Serpent, linking with the Evidence Task Group?, etc.)
   - What materials would you like to see be used in future exercises?

CMX-6 Full Design, Development, Scenario & Backstory


Changes to RNL retirement plan go into effect
Disgruntled employee, Dr. Evanovich, plots a plan to generate Pu metal from bomb reduction of PuF4 and sell on black market
Plot includes pilfering lab supplies and materials, including CeF4, UF4, and PuF4, over a long period of time to avoid detection. PuF_4 from sealed source generated in July, 1964.
1st test run of metal reduction process using CeF_4 successful
2nd test run of metal reduction process using UF_4 successful
Cutting contaminated U and Ce metal rings into pieces for disposal at Corben Foundry
Discovery of contaminated Ce (ES-1) and U (ES-2) at Greene's Recycling and Corben Foundry
2016
2017
2018
2019
Dr. Evanovich (pictured here before becoming disgruntled!)
RNL PuF_4 neutron source
Dr. Evanovich's makeshift glovebag for metal casting operations
Preliminary crucible design
Crucible used to cast Ce and U
CeF_4
Ce
Ca
CaF_2
UF_4
U
Ca
CaF_2
U metal ring
ES-1
ES-2

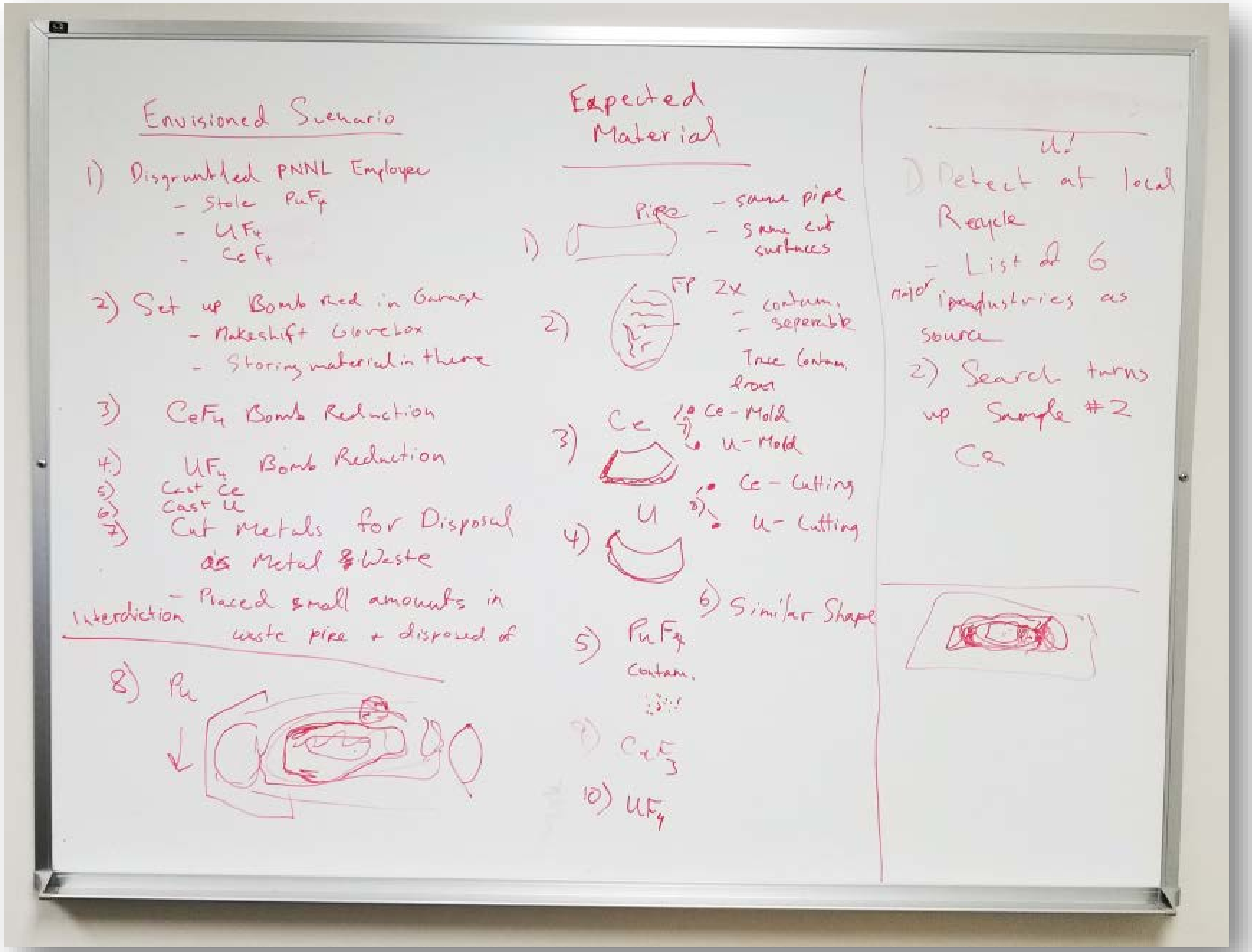
Exercise Design

Parameters:

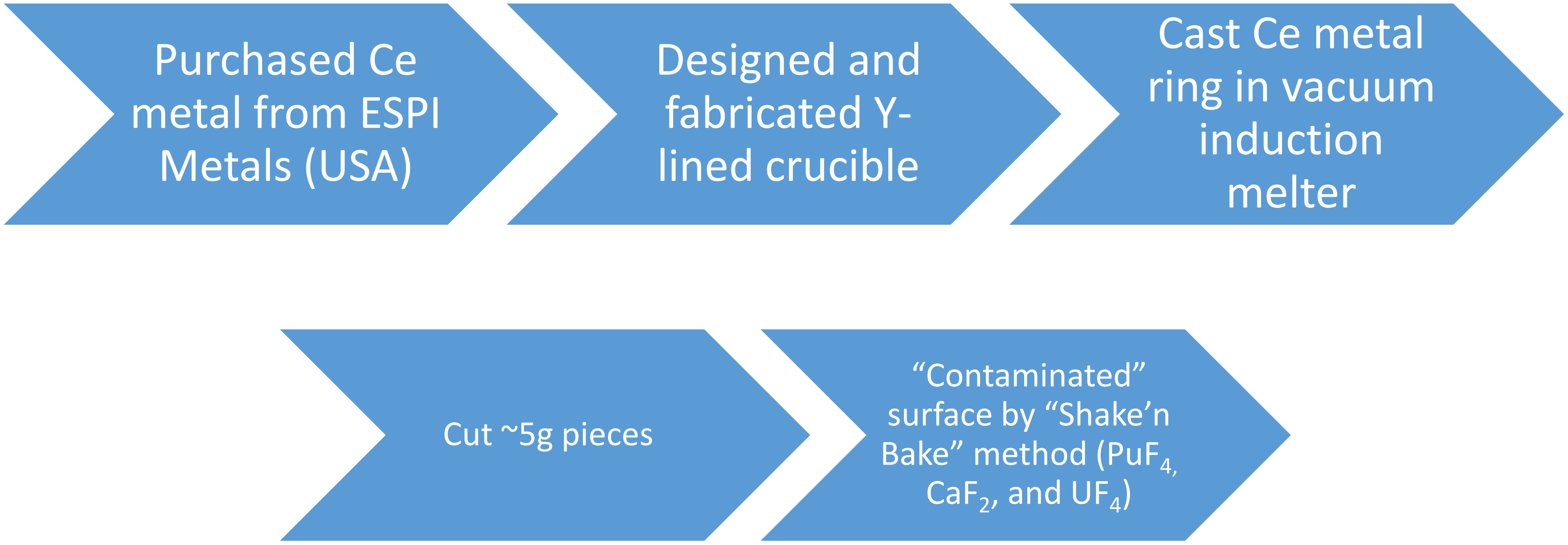
- New material (Pu)
- Exempted quantity for ease of shipping (<200 µg)
- A scenario that makes sense!

Features:

- Difficult to ID with HPGe (U masking)
- Incorporate TE that is separable from radioactivity
    - Patent print
    - Latent print
    - Tool marks
    - Trace elements
    - Contaminants from cutting, casting
- Isotopics defining feature
- Age defining feature
- Chemical form defining feature
- Shape defining feature
- Possible detection of ^{22}Na



CMX-6 Exercise Sample 1 Production



First attempt at casting Ce ring

Graphite mold with yttria wash post cast

Casting surface showing oxidation and cavities

Casting retrieval

Final version of Ce cast

Degassed Ce metal

Optimized casting

CMX-6 Exercise Sample 2 Production

- Aerojet DU Metal starting material (0.2% ^{235}U)
- Used identical crucible design to Ce ring
- Cast U metal ring in vacuum induction melter (~1200 ^{o}C)
- Cut ~10g pieces
- "Contaminated" surface by "Shake'n Bake" method (PuF_4, CaF_2, and UF_4)

Uranium Metal Casting: Casting Retrieval in Fume Hood

Top down view of casting in mold post cast

Base of broken graphite plug showing base of fused U ring

Top of casting

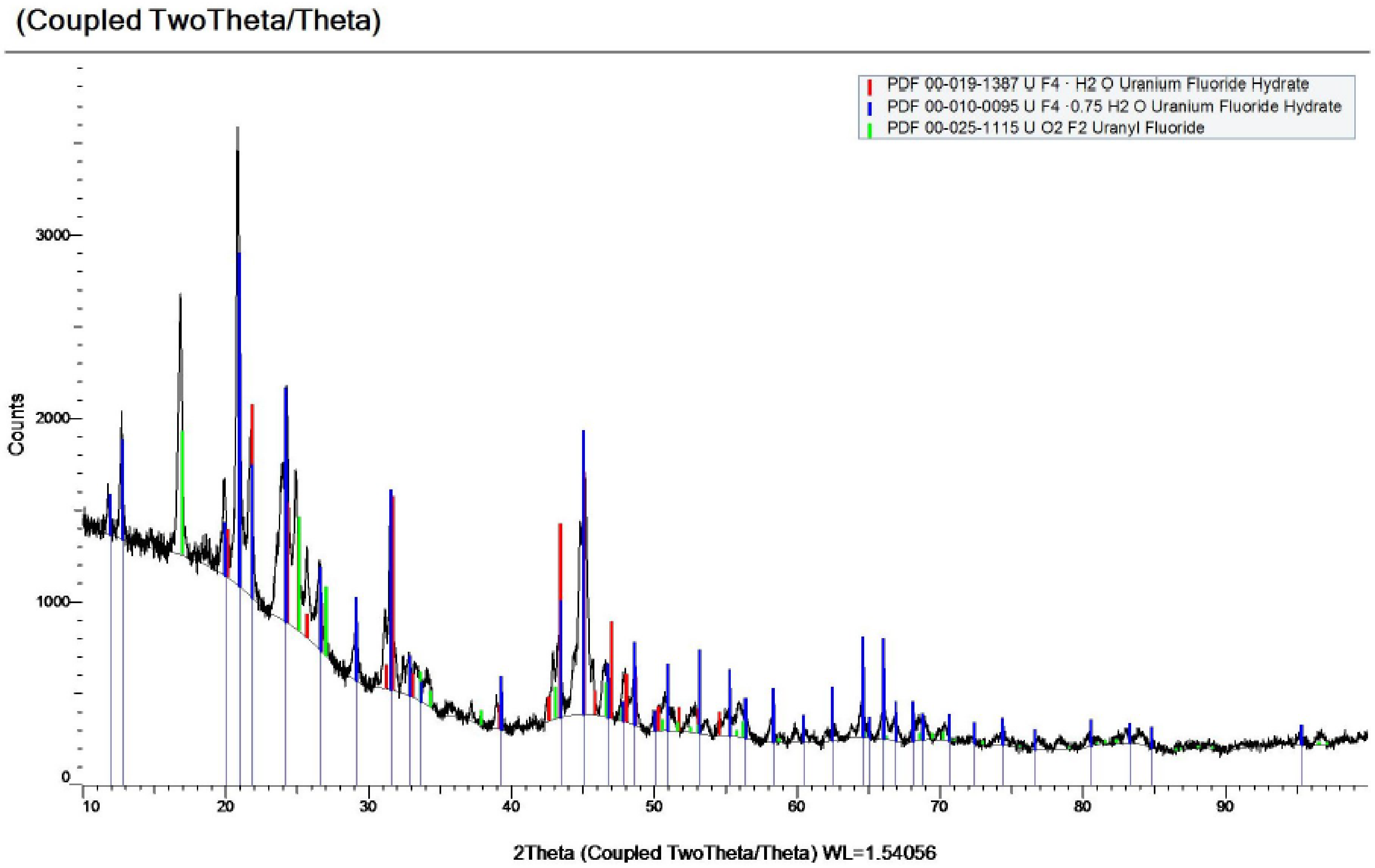
Base of casting

Pacific Northwest
NATIONAL LABORATORY

Uranium Metal Sectioning

Glovebox saw used to section U

UF_4 Starting Material for Bomb Reduction to U Metal



X-ray diffraction pattern of uranium fluoride and related species

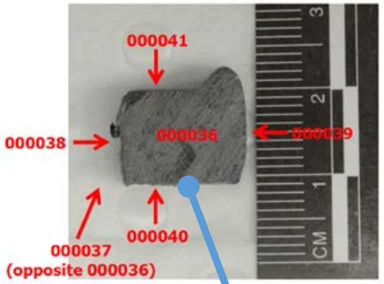
Traditional Forensic Evidence

ES-1

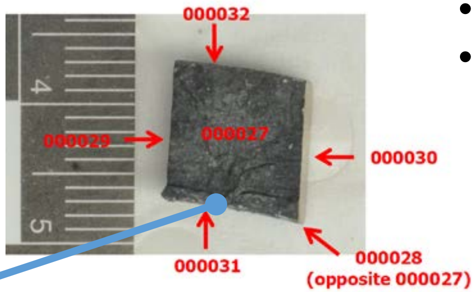
ES-2

Conclusive Similar
- Composition
- Dimensions / Manufacturing characteristics
- Tool marks

ES-1



ES-2

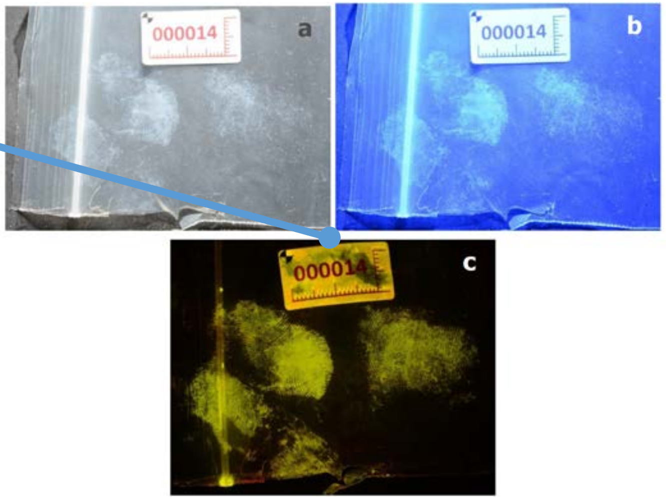


Conclusive Dissimilar
- Composition

Conclusive Similar
- Tool marks
- Trace evidence
- Dimensions

Conclusive Similar
- Fingerprints

ES2 Latent Prints



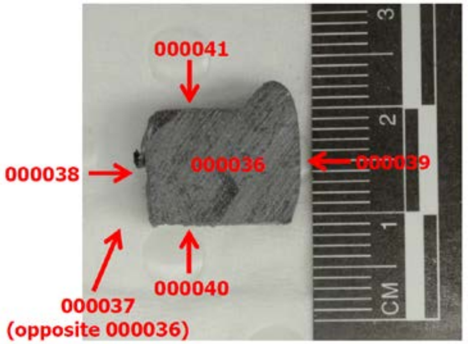
ES1 Patent Prints

Nuclear Forensic Evidence

ES-1

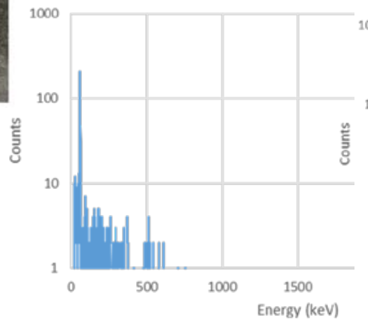
ES-2

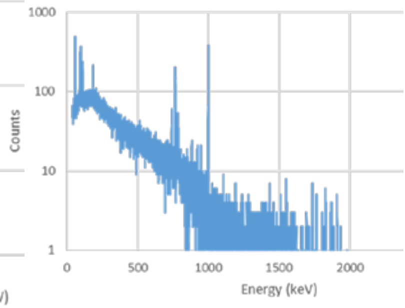
ES-1



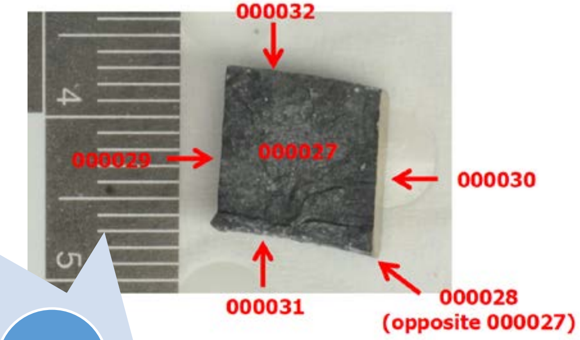
24 Hour Report

- Gamma Spectrometry
- Inconclusive
- ^{22}Na detection



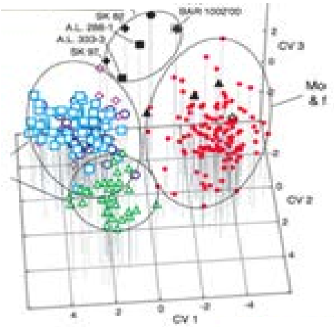


ES-2



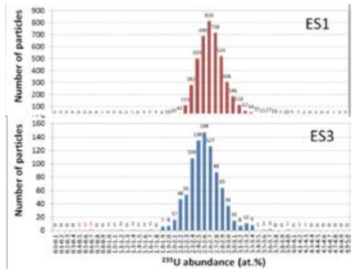
1 Week Report

- Bulk Isotopics
- Suggestive Similar
- Morphology of Pu particles

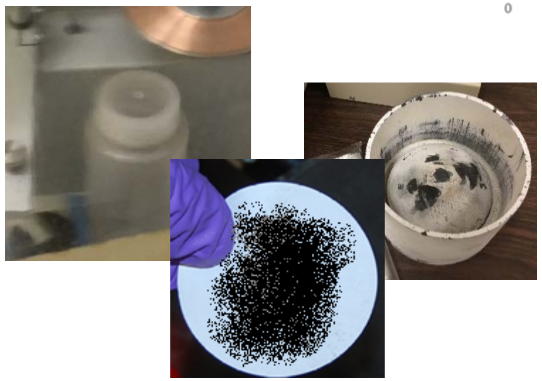


2-Month Report

- Radiochronometry
- Composition
- Particle Analysis
- Conclusive Similar



ES-3



Uranium Pedigree

Sample ID	Atomic Percent								Amount (g)	Date Measured	Chemical Form
	^{234}U	Uncertainty (2-σ)	^{235}U	Uncertainty (2-σ)	^{236}U	Uncertainty (2-σ)	^{238}U	Uncertainty (2-σ)			
~~RNL-543S~~	~~8.500E-01~~	~~1.500E-01~~	~~8.670E+01~~	~~1.500E+00~~	~~5.700E-01~~	~~8.000E-02~~	~~1.190E+01~~	~~9.000E-01~~	~~1.003E+03~~	~~18-Sep-13~~	~~Oxide~~
~~RNL-789N~~	~~1.050E+00~~	~~7.000E-02~~	~~8.940E+01~~	~~1.800E+00~~	~~6.900E-01~~	~~5.000E-02~~	~~8.900E+00~~	~~2.000E-01~~	~~2.560E+02~~	~~2-Jun-06~~	~~Oxide~~
~~RNL-560G~~	~~1.930E-02~~	~~2.702E-04~~	~~2.245E+00~~	~~1.700E-01~~	~~2.000E-03~~	~~5.000E-04~~	~~9.703E+01~~	~~8.000E-02~~	~~2.412E+03~~	~~14-Nov-09~~	~~Fluoride~~
~~RNL-495W~~	~~9.291E-01~~	~~6.000E-03~~	~~78.965~~	~~3.600E+00~~	~~3.878E-01~~	~~1.900E-03~~	~~1.972E+01~~	~~6.400E-02~~	~~1.452E+03~~	~~1-Jan-14~~	~~Oxide~~
~~RNL-118L~~	~~8.640E-01~~	~~6.600E-03~~	~~6.712E+01~~	~~3.800E+00~~	~~4.300E-01~~	~~3.200E-03~~	~~3.159E+01~~	~~6.900E-02~~	~~4.520E+02~~	~~4-Jun-08~~	~~Oxide~~
RNL-992K	bd	bd	2.400E-01	6.000E-02	bd	bd	9.975E+01	6.000E-02	1.438E+03	13-Jun-18	Fluoride
~~RNL-733Y~~	~~9.093E-01~~	~~4.000E-03~~	~~7.778E+01~~	~~3.100E-02~~	~~4.600E-02~~	~~1.200E-03~~	~~2.127E+01~~	~~6.400E-02~~	~~1.289E+03~~	~~4-Aug-11~~	~~Metal~~
~~RNL-629F~~	~~2.430E-02~~	~~3.200E-03~~	~~2.893E+00~~	~~9.300E-02~~	~~3.000E-04~~	~~5.000E-04~~	~~9.708E+01~~	~~5.000E-02~~	~~1.299E+03~~	~~14-Nov-14~~	~~Nitrate~~
RNL-373M	bd	bd	1.900E-01	6.000E-02	bd	bd	9.980E+01	6.000E-02	3.132E+03	8-Apr-11	Oxide

- ^{235}U and ^{238}U consistent with two possibilities in RNL holdings
- Form (UF_4) and amount most consistent with RNL-992K

Pu Pedigree

Sample ID	Atomic Percent									
	^{239}Pu	Uncertainty (2-σ)	^{240}Pu	Uncertainty (2-σ)	^{241}Pu	Uncertainty (2-σ)	Amount (g)	Date Measured	Chemical Form	Last Processing Date
~~RNL-132D~~	~~9.153E+01~~	~~4.595E+00~~	~~8.210E+00~~	~~9.832E-01~~	~~3.760E-02~~	~~4.920E-03~~	~~6.450E+02~~	~~3-Mar-11~~	~~Metal~~	~~Jan-82~~
~~RNL-235A~~	~~8.120E+01~~	~~4.060E+00~~	~~1.870E+01~~	~~9.348E-01~~	~~1.050E-01~~	~~5.250E-03~~	~~9.230E+02~~	~~18-Dec-08~~	~~Oxide~~	~~Apr-71~~
RNL-194L	9.340E+01	3.736E+00	6.567E+00	8.340E-01	4.000E-02	5.200E-03	1.400E+02	26-Feb-15	Fluoride	Jul-64
~~RNL-651H~~	~~9.341E+01~~	~~4.222E+00~~	~~6.698E+00~~	~~8.770E-01~~	~~4.700E-02~~	~~6.300E-03~~	~~3.540E+02~~	~~27-Nov-14~~	~~Oxide~~	~~<1966~~

- ^{239}Pu inconsistent with RNL-235A
- ^{240}Pu and age inconsistent with RNL-132D
- Form (PuF_4) most consistent with RNL-194L

Summary

- CMX-6 largest exercise in ITWG history

  …also the most complex!
- Essentially every major design feature introduced as evidence in CMX-6 samples were identified by at least one laboratory
- Tool marks
- Fingerprints
- Cutting tools
- Bag composition
- Pipe composition
- Contaminants – Ca, F, U, Pu
- Pu age
- U age
- F composition of Pu and U contaminants