

International Symposium on Technology Development
for Nuclear Nonproliferation and Nuclear Security

Nuclear Forensics for Nuclear Security

– Present Situation in Japan –

February 10, 2016

Nobuo SHINOHARA

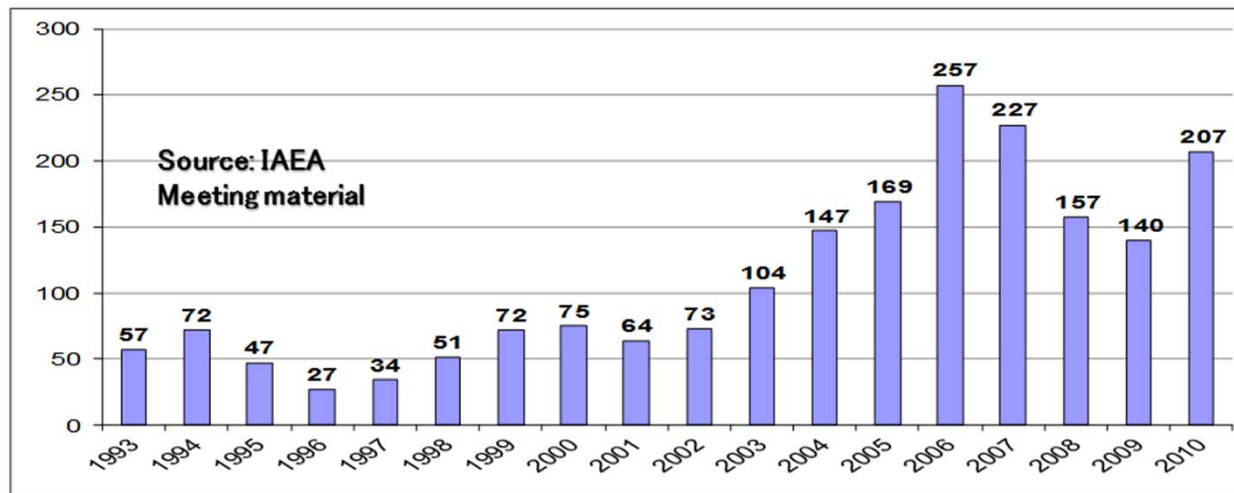
Integrated Support Center for Nuclear Nonproliferation and Nuclear Security
Japan Atomic Energy Agency

Threat of Nuclear Terrorism and the Issue of Nuclear Material Management

[Threat of Nuclear Terrorism]

- Theft of a nuclear weapon
- Theft of nuclear material for creating improvised nuclear device (IND)
- Theft of radiological material for creating Dirty Bomb or Radiological Dispersal Device (RDD)
- Sabotage of nuclear facility or transportation of radiological material

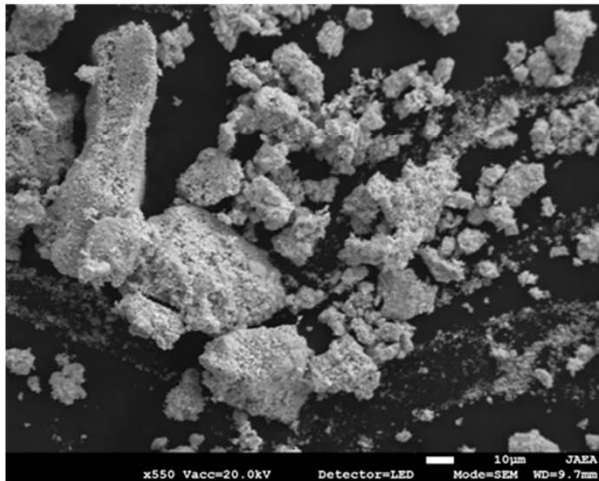
Total **2,331 cases** of nuclear security events reported to IAEA Illicit (Incident) Trafficking Data Base (ITDB) between 1993 and December 31, 2012



HEU uncovered
in Georgia
Source: IAEA

Nuclear Forensics ?

- Process of identifying the source of nuclear or radioactive material used in illegal activities, to determine the point of origin and routes of transit involving such materials.



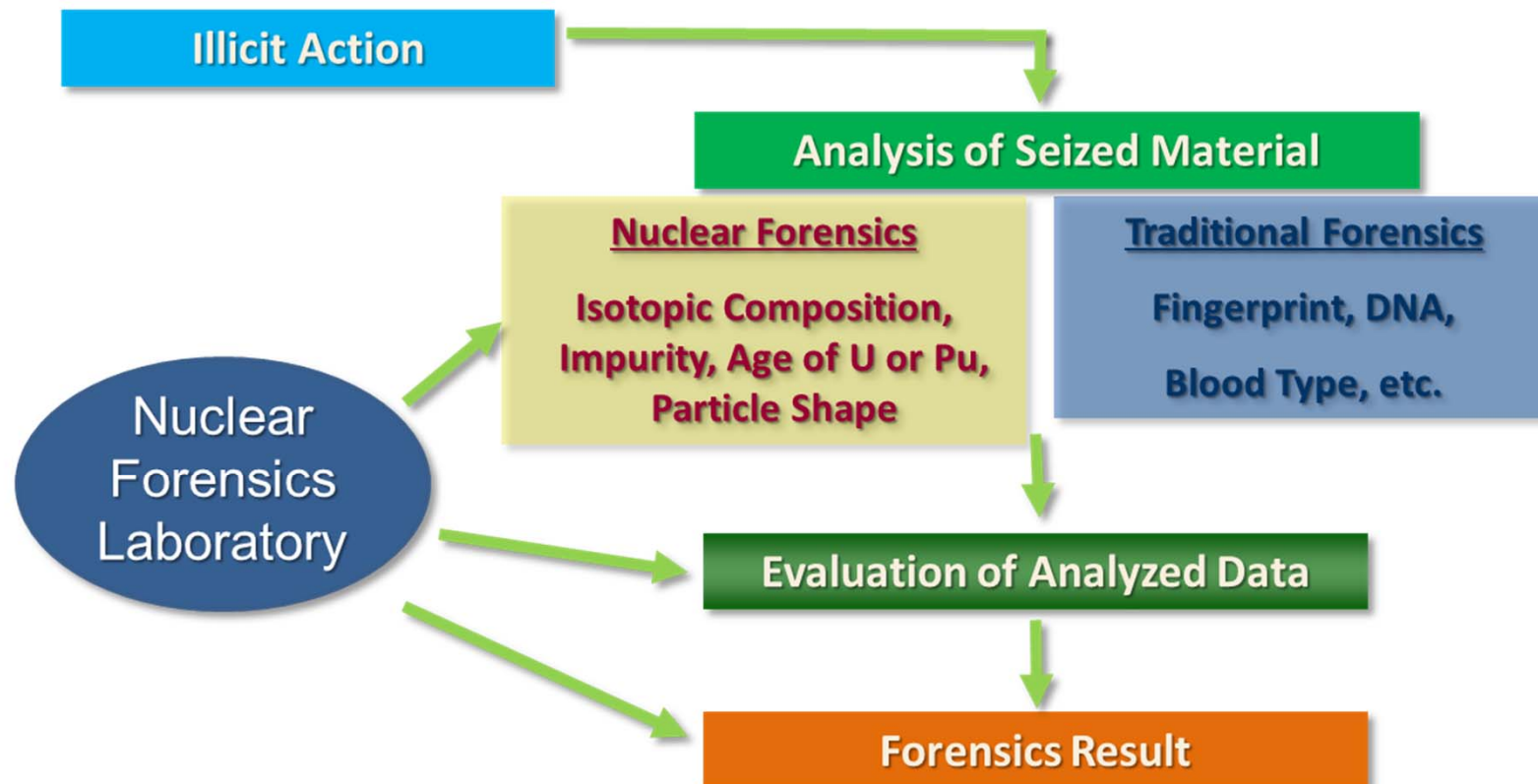
An uranium sample produced in Japan



“Attributions” of NMs and RMs

- What is this ?
- What's the purpose ?
- When is it produced ?
- Where is it produced ?
- How is it produced ?

Analysis of Illicit Nuclear Material



U Case Study

- In June 2003, four uranium dioxide pellets were seized
- All the pellets showed identical geometry
 - they had a central hole and they were dished
- The pellets were weighed and their dimensions were measured



Pellet no.	Weight (g)	Height	Dimensions (mm)	
			Diameter	Hole
1	14.6672	14.12	11.45	2.1
2	14.7614	14.26	11.44	2.1
3	15.3979	14.91	11.45	2.1
4	14.8626	14.46	11.45	2.1

From M. Wallenius et al., *Forensics Science International*, vol. 156, pp. 55-62 (2006)

U Isotopic and Elemental Content

- The isotopic composition of uranium was determined by mass spectrometry using both TIMS and MC-ICP-MS

Technique	²³⁴ U	²³⁵ U	²³⁶ U	²³⁸ U
TIMS	0.0147 ± 0.0010	2.0005 ± 0.0010	0.0071 ± 0.0067	97.9778 ± 0.0019
MC-ICP-MS	0.0142 ± 0.0002	2.0005 ± 0.0001	0.0071 ± 0.0000	97.9782 ± 0.0010

- The uranium content in the pellets was determined by potentiometric titration, HKED, and IDMS

Technique	U Content (%)
HKED	87.43 ± 0.32
Titration	87.90 ± 0.13
IDMS	87.99 ± 0.24

Chemical Impurities Using ICP-MS

Element	Concentration (PPM)
Al	6.08 ± 0.73
Ca	18.4 ± 2.2
Cr	6.12 ± 0.73
Cu	1.80 ± 0.22
Fe	91.9 ± 7.4
K	44.7 ± 3.6
Mg	4.71 ± 0.57
Mn	1.13 ± 0.14
Na	17.9 ± 2.1
Ni	5.14 ± 0.62
Zn	3.40 ± 0.41

From M. Wallenius et al., *Forensics Science International*, vol. 156, pp. 55-62 (2006)

Age Determination

- Age since chemical separation was determined using two parent daughter relationships:
 - $^{235}\text{U} \rightarrow ^{231}\text{Pa}$ ($t_{1/2}=7.038 \times 10^8$ years)
 - $^{234}\text{U} \rightarrow ^{230}\text{Th}$ ($t_{1/2}=2.455 \times 10^5$ years)
- The age of the material was determined to be 12.6 ± 0.8 years at the measurement date of June 16, 2003
 - thus, the pellet was most likely produced on or about November 8, 1990

Conclusion for U Case study

- It was determined with high confidence that this material was from an RBMK fresh fuel batch from the Ignalina Unit 2 reactor in Lithuania and produced by the MZ Electrostal in Moscow.
- There is a report of a theft of a fresh fuel assembly from Ignalina in 1992.

Japan's National Statement at Nuclear Security Summit (Washington D.C. April 2010)

Japan will make increased contributions to the international community by establishing these technologies with more precise and accurate capabilities in detection and **forensics** within an approximate three year time frame and sharing the fruits of these new technologies with the international community.



Response of Japan Atomic Energy Agency (JAEA)

- JAEA, which possesses sufficient capabilities to fulfill the mission of analytical technology development for nuclear forensics (NF), has initiated R&D project from 2011 JFY.

Challenges towards Establishment of NF Capabilities in Japan

Japan's Challenges

The JAEA can contribute to these themes.

- Establishment and improvement of NF analysis technologies
 - Development of National Nuclear Forensics Library (NNFL)
 - Establishment of NF analysis Lab. (analytical devices and system)
 - Human resource development
-
- Establishment of national framework including national response plan
 - Collaborations with traditional forensics
 - Establishment of international cooperative system

JAEA's Contributive Area

- Establishment of “technical” NF capabilities
- Information collection and support for national frameworks including national response plan

Analysis of Seized Material

Nuclear Forensics

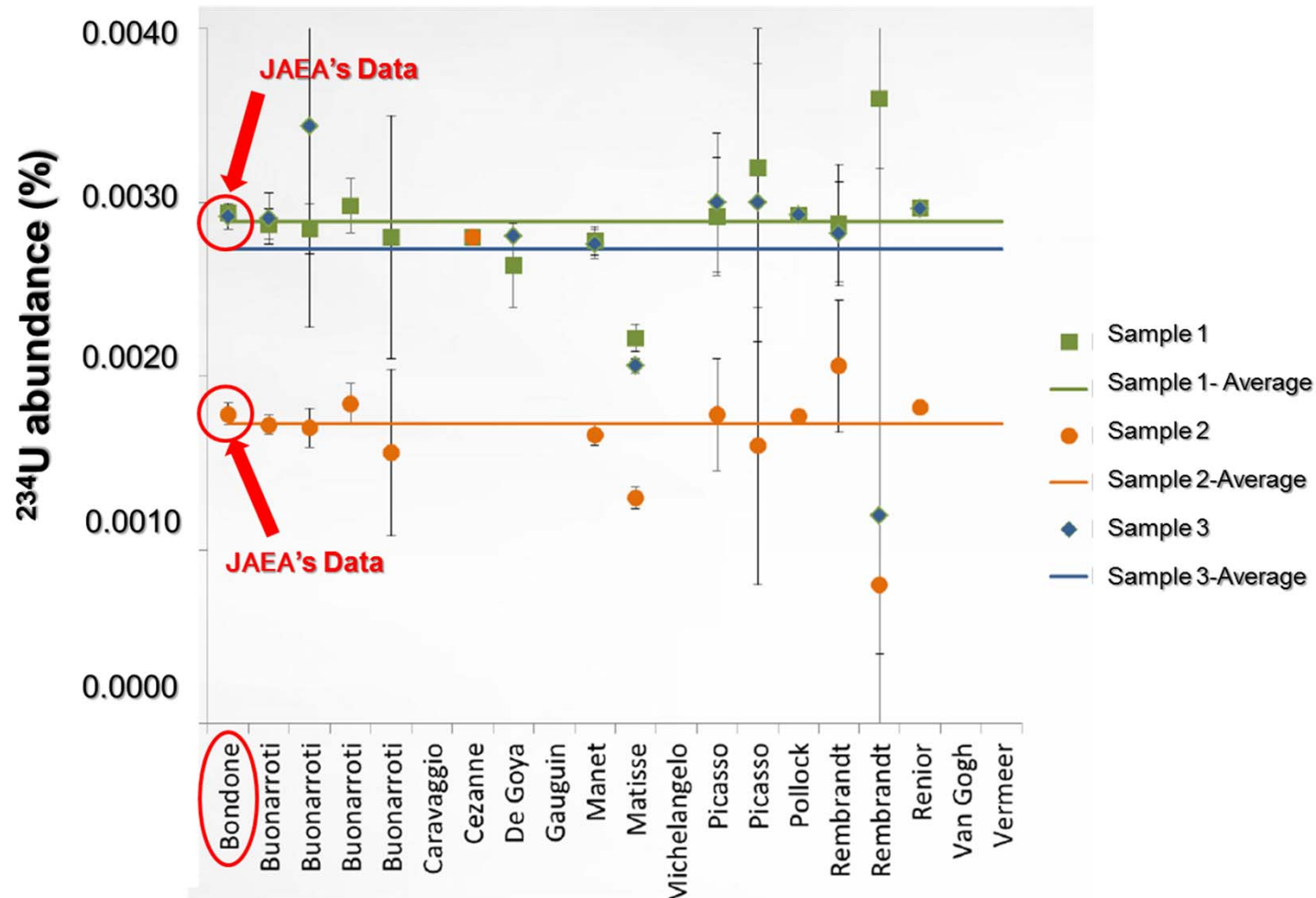
1. Isotopic Composition
2. Impurity
3. Age of U or Pu
4. Particle Shape



5. Nuclear
Forensics
Laboratory

1. Isotopic Composition Measurement

A result of Nuclear Forensics International Technical Working Group (ITWG) Collaborative Materials Exercise 4 (CMX-4)



2. Impurity Measurement

Impurity quantitation test using ICP-MS

All impurity elements could be important "Signature" in NF analysis.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
1 H Hydrogen 1.00794	2 He Helium 4.002602																	
Atomic # Symbol Name Atomic Weight																		
<div>C Solid</div>		<div>Metals</div>										<div>Nonmetals</div>						
<div>Hg Liquid</div>		Alkali metals		Alkaline earth metals		Lanthanoids		Transition metals		Poor metals		Other nonmetals		Noble gases				
<div>H Gas</div>																		
<div>Rf Unknown</div>																		
3 Li Lithium 6.941	4 Be Beryllium 9.012182																	
5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.0067	8 O Oxygen 15.9994	9 F Fluorine 18.9984032	10 Ne Neon 20.1797													
11 Na Sodium 22.98976928	12 Mg Magnesium 24.3050																	
13 Al Aluminum 26.9815386	14 Si Silicon 28.0855	15 P Phosphorus 30.973762	16 S Sulfur 32.065	17 Cl Chlorine 35.453	18 Ar Argon 39.948													
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955912	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938045	26 Fe Iron 55.845	27 Co Cobalt 58.933195	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.63	33 As Arsenic 74.92160	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.798	
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90584	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdenum 95.94	43 Tc Technetium (97.9072)	44 Ru Ruthenium 91.224	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.757	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.293	
55 Cs Cesium 132.9054519	56 Ba Barium 137.327	57-71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.94788	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.222	78 Pt Platinum 195.084	79 Au Gold 196.966569	80 Hg Mercury 200.59	81 Tl Thallium 204.384	82 Pb Lead 207.2	83 Bi Bismuth 208.9804	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)	
87 Fr Francium (223)	88 Ra Radium (226)	89-103	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (266)	107 Bh Bohrium (264)	108 Hs Hassium (277)	109 Mt Meitnerium (268)	110 Ds Darmstadtium (271)	111 Rg Roentgenium (272)	112 Cn Copernicium (285)	113 Uut Ununtrium (284)	114 Fl Flerovium (289)	115 Uup Ununpentium (288)	116 Lv Livermorium (293)	117 Uus Ununseptium (294)	118 Uuo Ununoctium (294)	

For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.

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57 La Lanthanum 138.90547	58 Ce Cerium 140.12	59 Pr Praseodymium 140.90766	60 Nd Neodymium 144.242	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92535	66 Dy Dysprosium 162.500	67 Ho Holmium 164.93033	68 Er Erbium 167.259	69 Tm Thulium 168.93032	70 Yb Ytterbium 173.05468	71 Lu Lutetium 174.967
89 Ac Actinium (227)	90 Th Thorium 232.0377	91 Pa Protactinium 231.03688	92 U Uranium 238.02891	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)

Michael Dayah

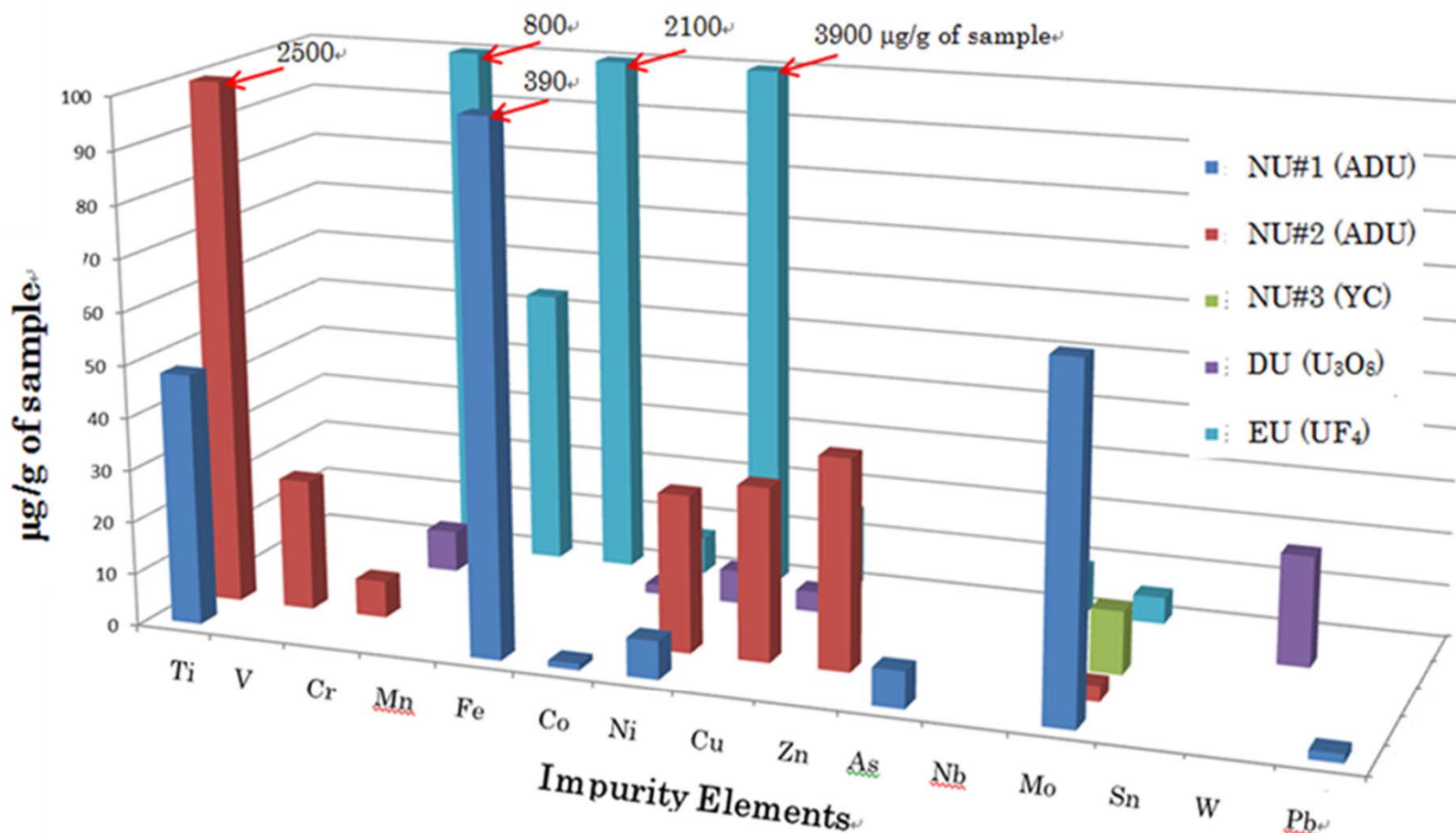
For a fully interactive experience, visit www.ptable.com.

michael@dayah.com



: Now measurable by ICP-MS at JAEA

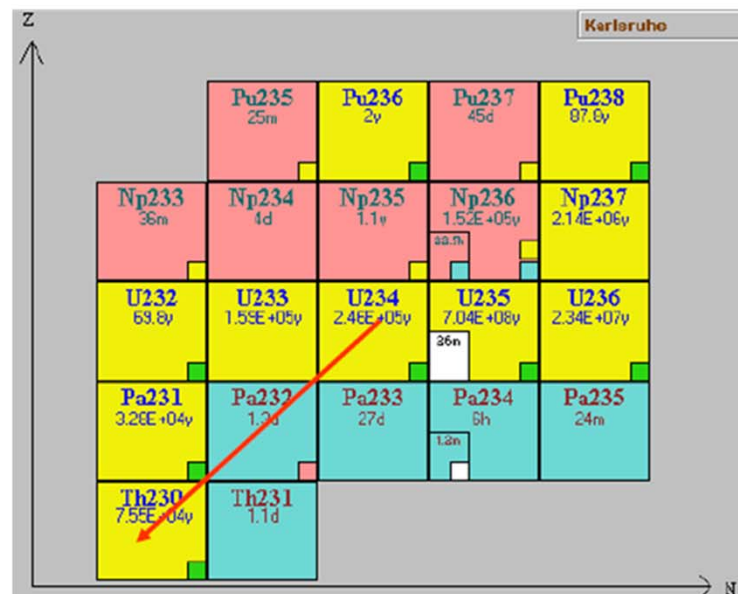
Result of Impurity Measurement



Impurities contained in several uranium samples

3. Uranium Age Determination

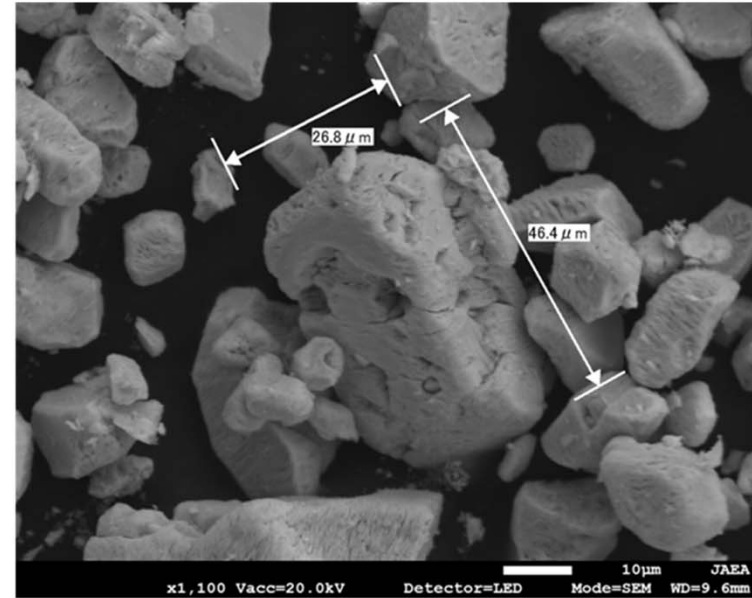
- The age of nuclear material is essential information to identify the source of the material, and ^{234}U - ^{230}Th chronometer is widely applied to NF.
- We conducted procedure exchange and inter-laboratory comparison exercise on uranium age dating between Department of Energy (DOE) of US and JAEA, where the same NBL standard materials of CRM U050 were independently analyzed
- The analysis of age determination on the uranium oxide standard was already performed and the time of its purification can be estimated to be August 4 of 1957 from the JAEA's result.



4. Particle Analysis



TEM (JEM-2100F) for Nuclear Forensics



Particle image of the yellow cake
observed by SEM

Expected Analysis by TEM

- Particle analysis (particle/lattice image)
- Other crystal analysis
- Elemental compositions and their chemical-bonding states by EELS (electron energy-loss spectroscopy)

5. Development of Prototype Nuclear Forensics Library (NNFL)

The NNFL Development in 2011- 2013 JFY

- Database of Nuclear Materials (NMs)
- Basic Data Handling Functions (Data Entry, Search & Update)

Current Status

- Database design based on items of NMs and nuclear fuel cycle facilities in JAEA (completed)
- A model database for the review of data structure and the basic data handling functions (proto-type was already developed)
- Data survey and data gathering of NMs available in JAEA in order to populate the prototype library (in progress)

General Concept of an NNFL

- Minimum function required for an NNFL



Database

- An organized collection of data.
- Data structure should be designed according to its objectives and kinds of collected data.



Data handling (query & Interface)

- Data handling functions should be designed according to the database structure appropriately.

6. International Collaborations

- **Collaboration with US-DOE (Project Action Sheet: PAS)**
 - Uranium age determination (PAS19): inter-laboratory comparison
 - Evaluation of fuel attributions (PAS20 and 29): Information exchange and inter-laboratory comparison
 - NNFL (PAS21): establishment of proto-type NNFL at JAEA
- **Collaboration with EC-JRC**
 - Uranium age determination: information exchange and sample provision for inter-laboratory comparison in progress
- **Others**
 - Contribution on the activities of GICNT, ITWG and IAEA
 - Information exchange for establishment of the national framework and response plan in Japan
 - Participation to table top exercise on NNFL (*Galaxy Serpent*)

NF Capability in Japan

- Japan should improve capability to search for, confiscate, and establish safe control over unlawfully held nuclear or other radioactive materials and substances or devices using them.

- In view of construction of NF regime, the pertinent agencies* in Japan must cooperate with one another.

**Nuclear Regulation Authority, National Police Agency, Japan Coast Guard, Ministry of Foreign Affairs, Ministry of Finance Japan, Ministry of Education, Culture, Sports, Science and Technology, Ministry of Defense, and so on*

- It is necessary to organize Japan's own system for NF by establishing a national NF laboratory and collaborating with traditional forensics which targets the evidences of finger prints, DNS, etc.

Future Considerations

- Efforts to establish national frameworks including national response plan
- Increase internal cooperation with government and other labs to continue R&Ds toward establishment of national NF capabilities.

Conclusions

- JAEA has initiated the R&D project on nuclear forensics (NF) technologies from 2011 JFY.
- R&Ds on fundamental NF analysis technologies and prototype NNFL have been finished in 2013 JFY. The results will be shared with international community.
- Implementation and advanced NF technologies including NNFL is on going after 2014 JFY.
- To achieve the establishment of national NF capabilities, it is required to make efforts on national frameworks including national response plan in Japan.

Thank you.

The works in this presentation have been supported by Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan.