Nuclear Forensics

Capabilities, Limits, and the "CSI Effect"

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Revision 5

Overview

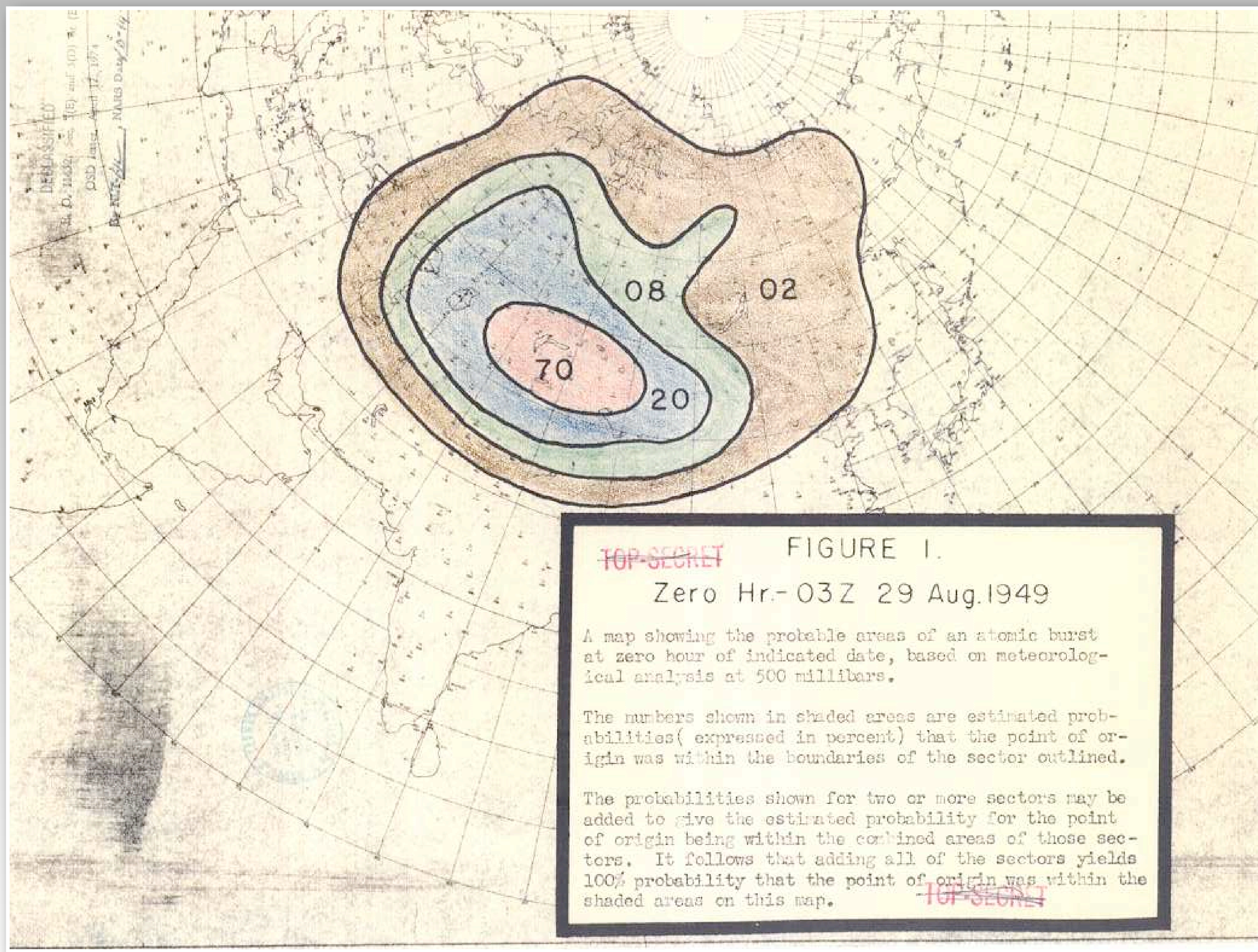
What is Nuclear Forensics?

The Technical Basis of Nuclear Forensics

(2 examples)

What Can (or Should) Be the Role of Nuclear Forensics Today?

Detection of "Joe-1" in August 1949



Source: *U.S. Weather Bureau Report on Alert Number 112 of the Atomic Detection System,* 29 September 1949, PSF: Subject File 1940-1953, National Security Council – Atomic Files, Box 173, Folder: "Atomic Bomb: Reports," Harry S. Truman Presidential Library; *Courtesy: Michael D. Gordin, Princeton University*

What is Nuclear Forensics?

Nuclear forensic analysis seeks to determine
the physical, chemical, elemental, and isotopic characteristics
of nuclear [or radiological] material of unknown origin

Based on this analysis, some (first-principle) conclusions can be drawn, e.g.:

- *Age of the material (time elapsed since production or last purification)*
- *General statements about the production process*

If intercepted or recovered material is registered in a database,
then it can be "matched" with high confidence

Other a priori knowledge might be helpful, too

Database may or may not contain a physical sample of the same material

What is Nuclear Forensics?

Pre-explosion vs Post-explosion Forensics

Analysis of the post-explosion debris is used to determine pre-explosion isotopics
Type and "sophistication" of weapon design

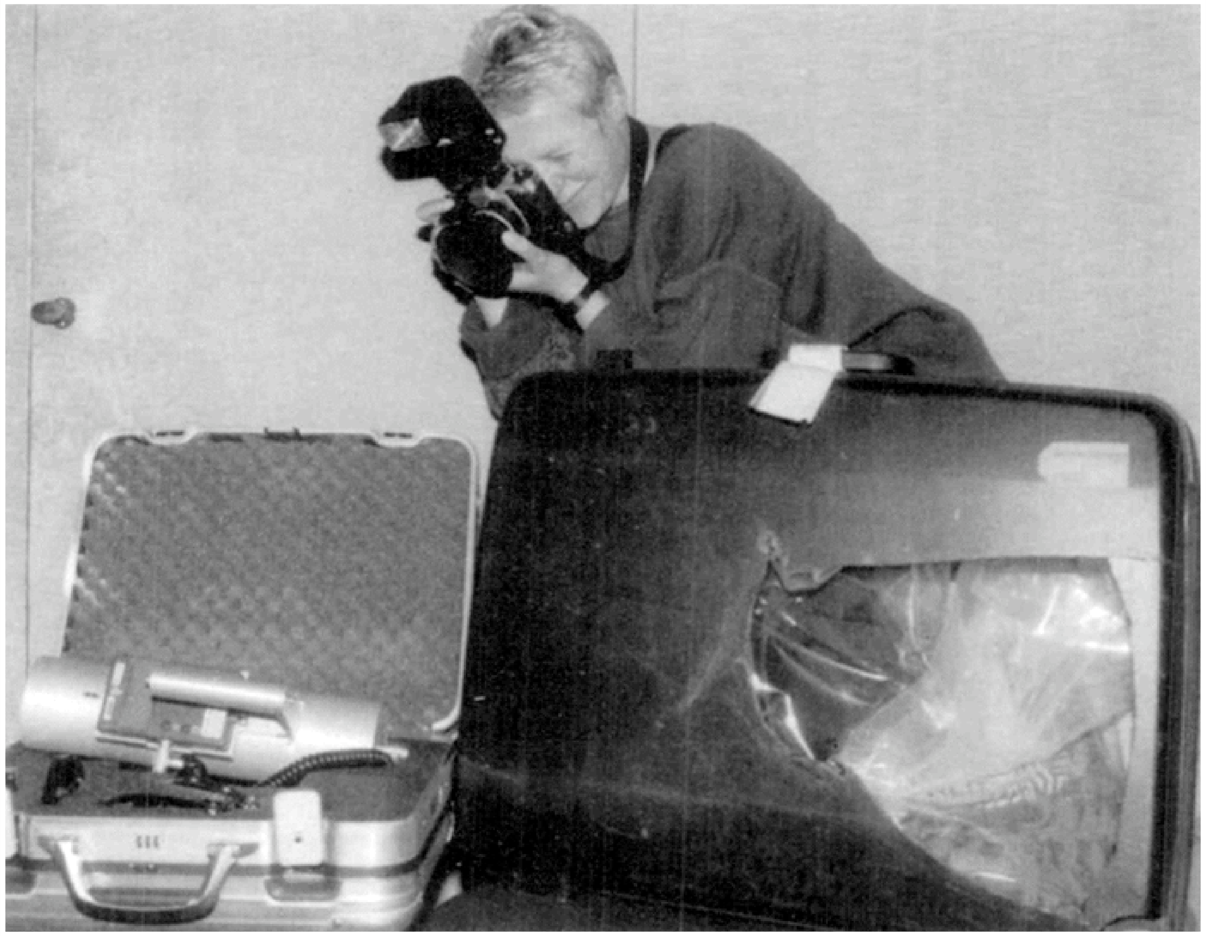
Most important (technical) difference: fewer signatures for post-explosion analysis

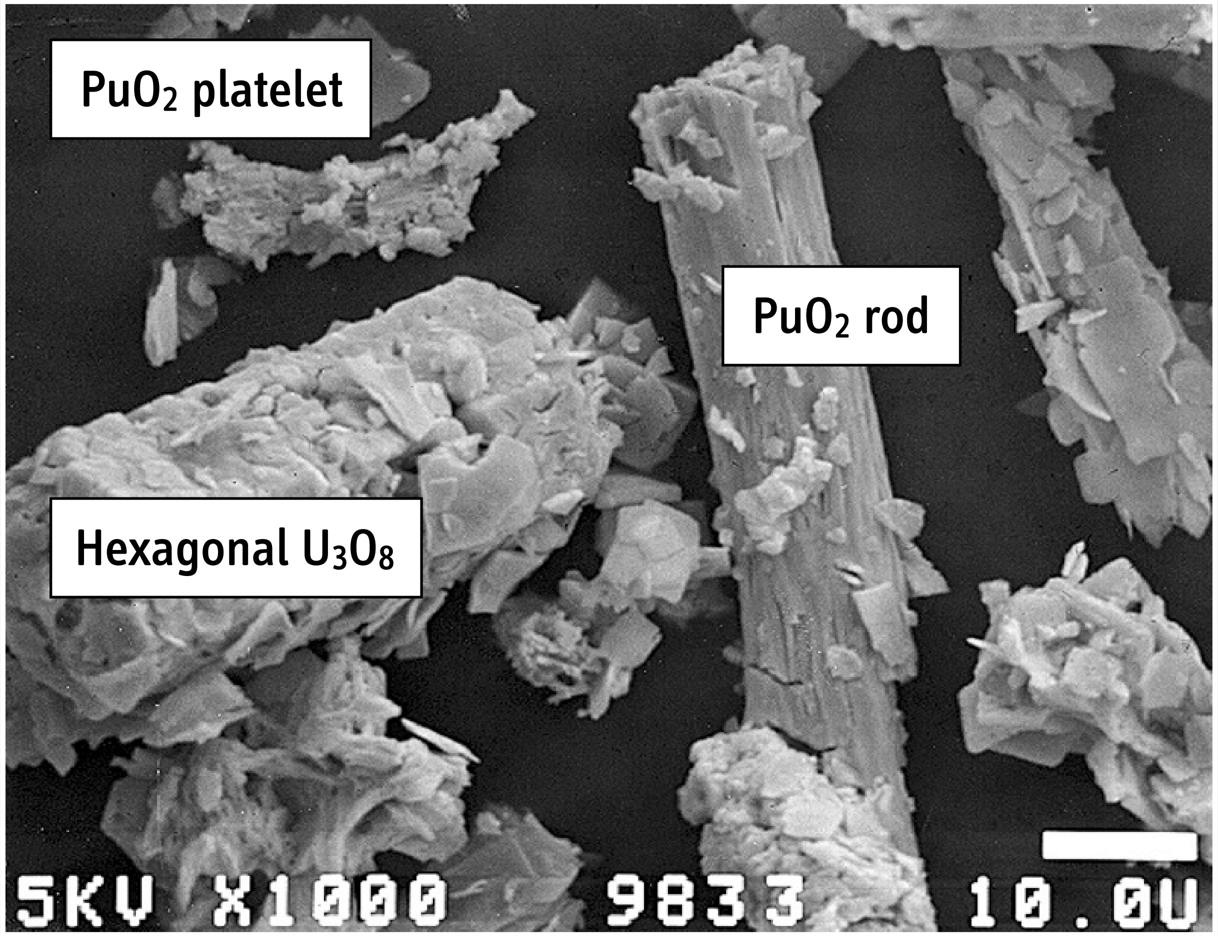
No residual information on physical characteristics (e.g. morphology)
Less/no information on trace elements

Nuclear Forensics vs Attribution

An attribution process, in which the origin or route of intercepted nuclear material is identified, combines the nuclear forensic analysis with law enforcement and intelligence data

1994 Munich Plutonium





Source: ITU

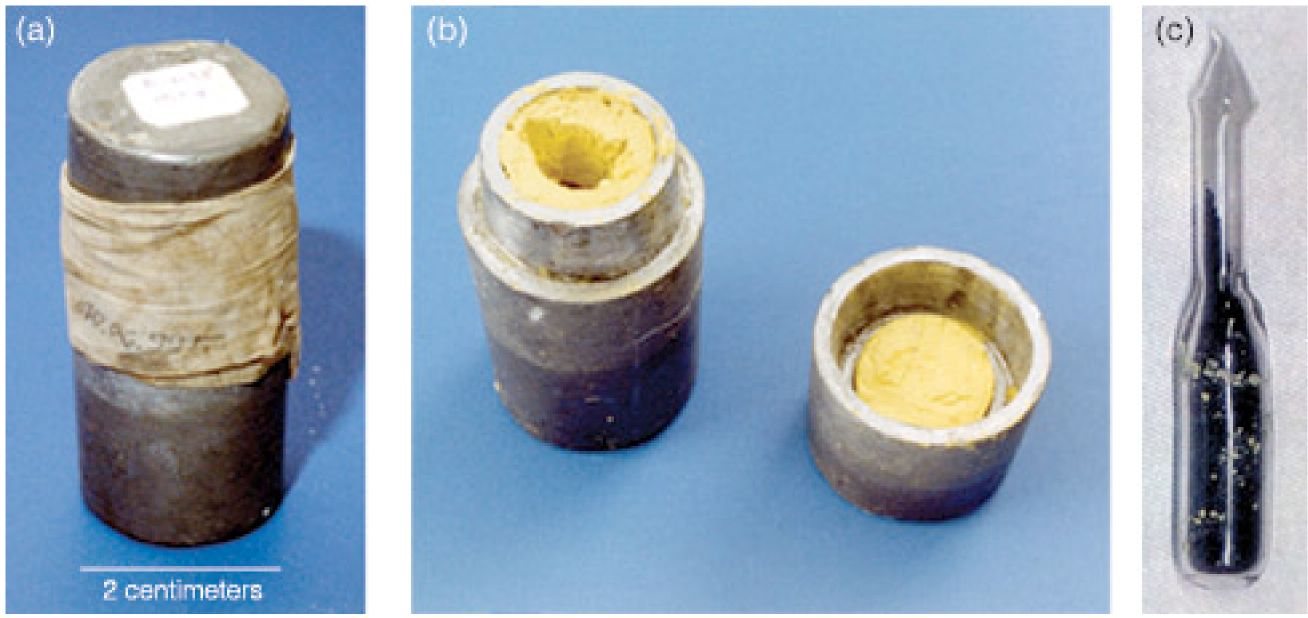
Intercepted at Munich Airport in August 1994 on a Lufthansa flight from Moscow

- 363 grams of plutonium (87% Pu-239) and 122 grams of uranium (560 grams of plutonium and uranium oxide)
- In addition: 210 grams of enriched lithium metal (89.4% Li-6)

"Most likely, the plutonium was a mixture of different spent fuels (e.g., a low-burn-up or weapons-grade plutonium and a high-burn-up fuel) and had no direct connection with the uranium present."

K.-R. Lützenkirchen, *CSI: Karlsruhe,* Actinide Research Quarterly, 2007

1999 Bulgarian HEU



Intercepted at Turkish-Bulgarian border in May 1999

- 10 grams of HEU (72% U-235)
- High U-236 content (13%)

Findings of 9-month forensic analysis:

- Reprocessed uranium from high-burnup fuel
- Original U-235 content: 90%

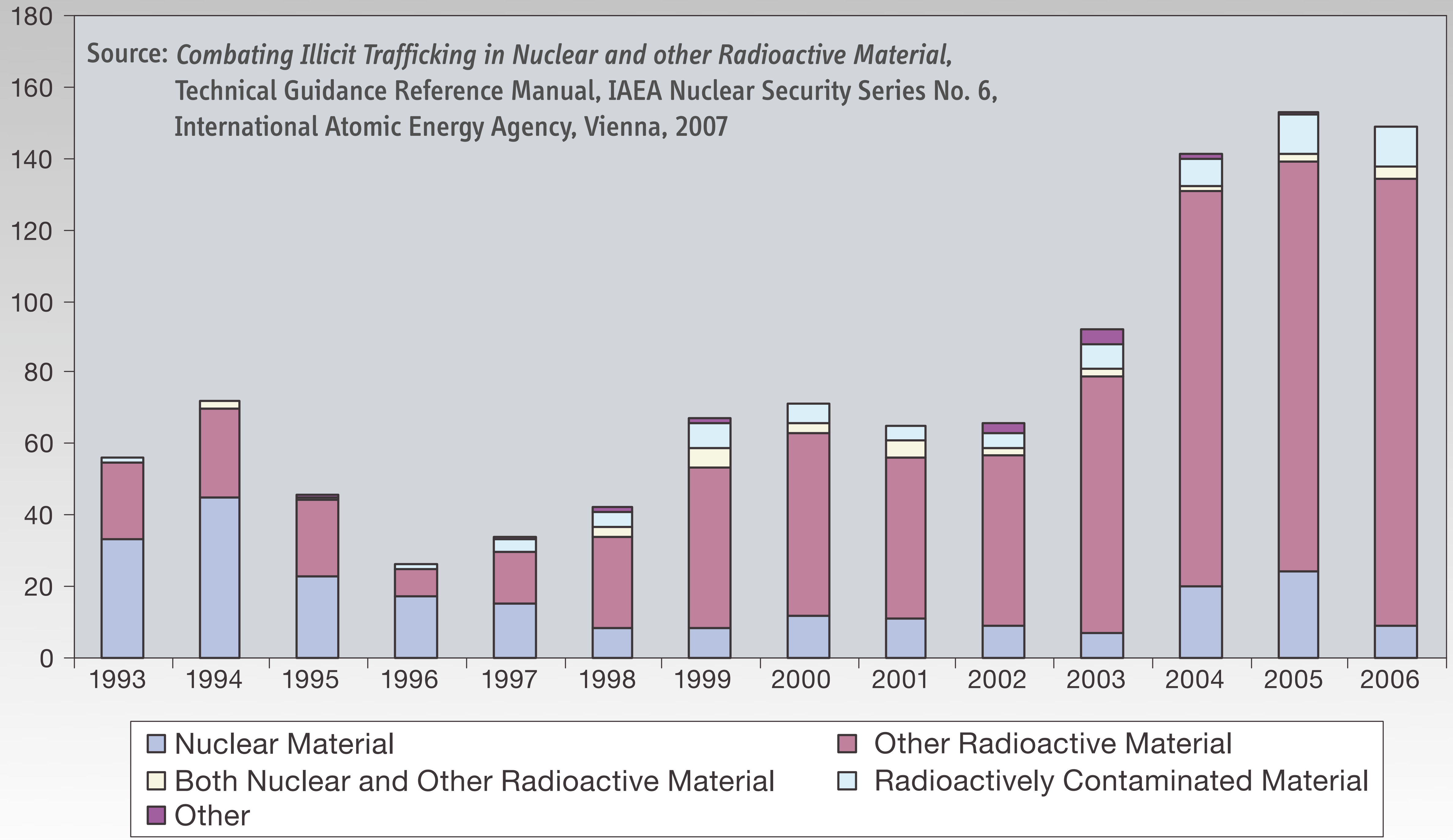
"[This investigation] was the most thorough and far-reaching analysis of illicit nuclear material ever conducted."

"The attribution of the Bulgarian HEU [...] remains incomplete. Despite the comprehensive forensic investigation and wealth of data, neither the original source of the HEU nor the point at which legitimate control was lost has yet been unambiguously identified."

Moody, Hutcheon, and Grant, 2005, p. 402 and p. 418

Confirmed Incidents

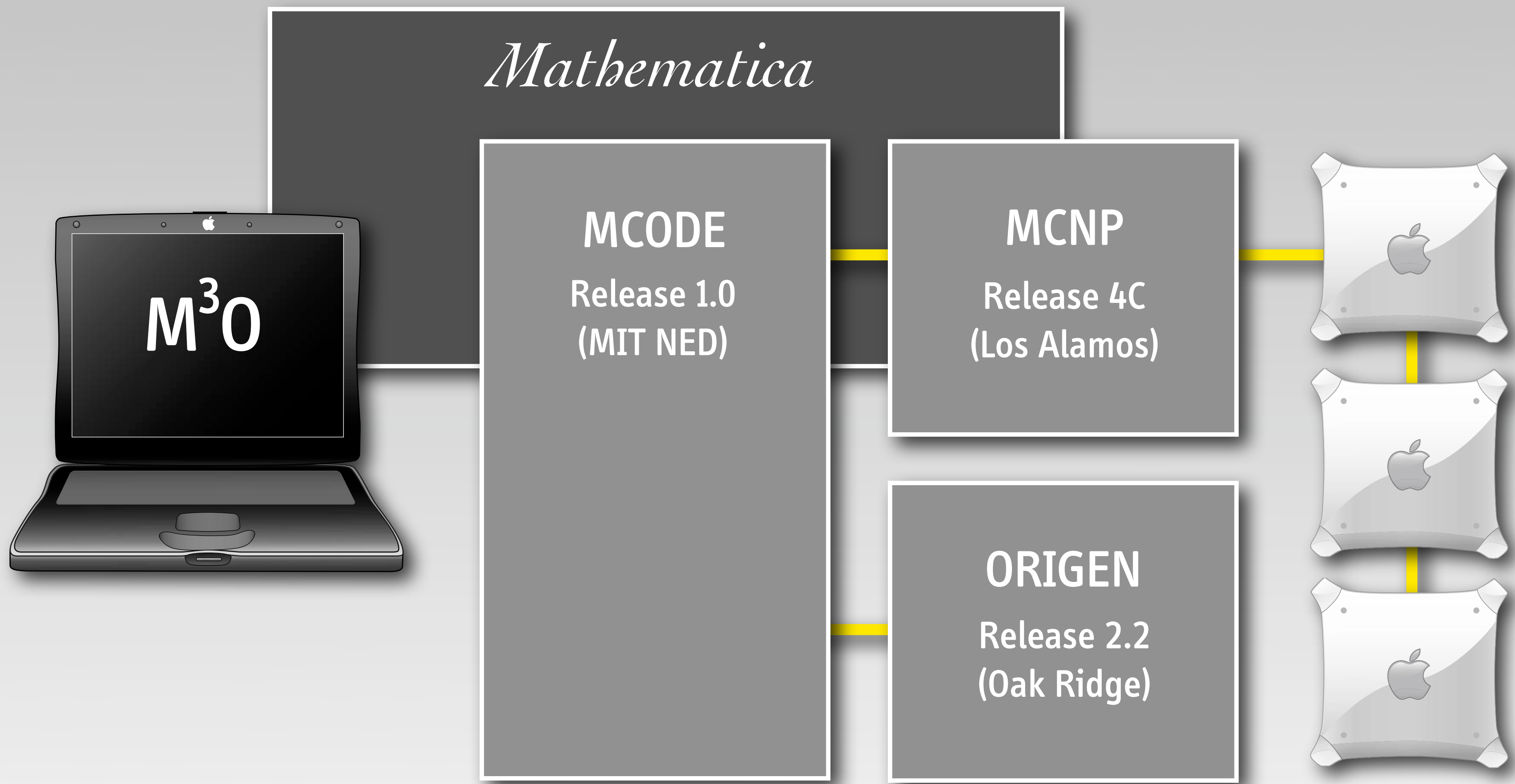
(1993-2006)



Pre- vs Post-Explosion Isotopics

(highly simplified)

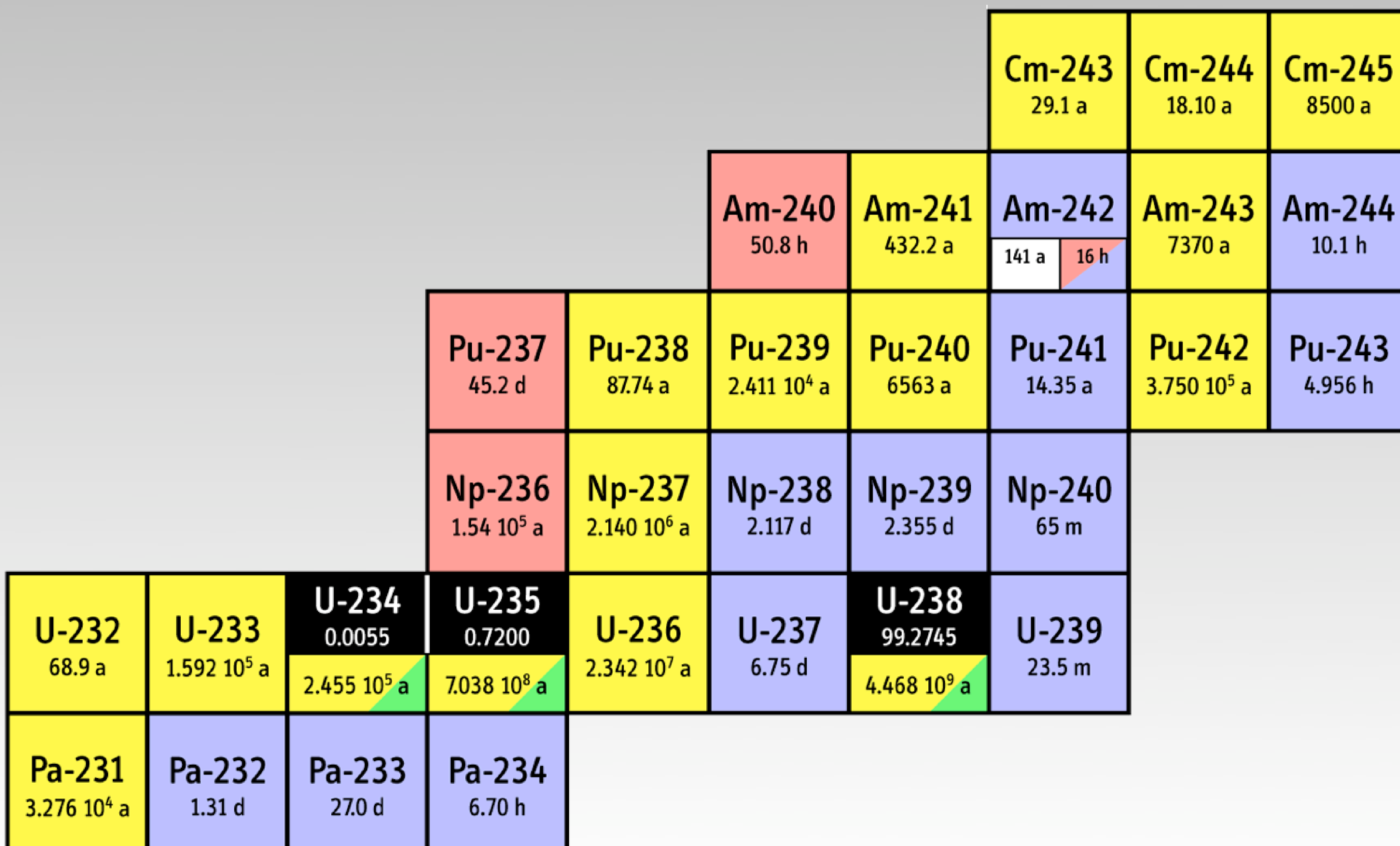
System for Neutronics Calculations



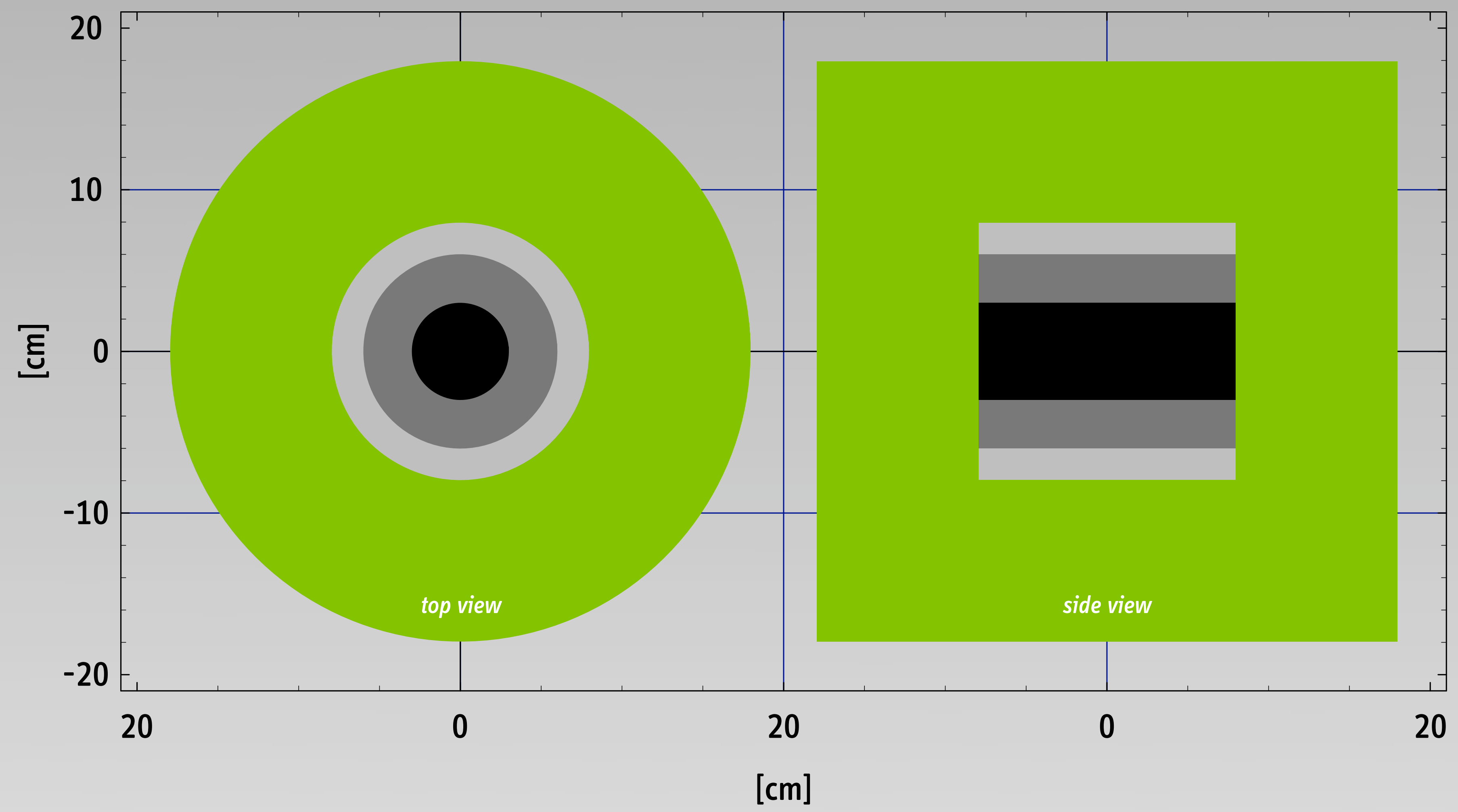
A. Glaser, *Neutronics Calculations Relevant to the Conversion of Research Reactors to Low-Enriched Fuel*
Ph.D. Thesis, Department of Physics, Darmstadt University of Technology, April 2005

Nuclides in Burnup Calculations

(tracking 1300 unique nuclides)



Hypothetical Gun-Type Device



60 kg of HEU in a tungsten tamper of 10 cm thickness

20 kt released in 100 ns (last ten neutron generations of the fission chain reaction)

Geometry fixed, time rescaled (x 10^{14}) to guarantee functionality of ORIGEN

Uranium Mass Balance and Isotopics

(for reference HEU composition)

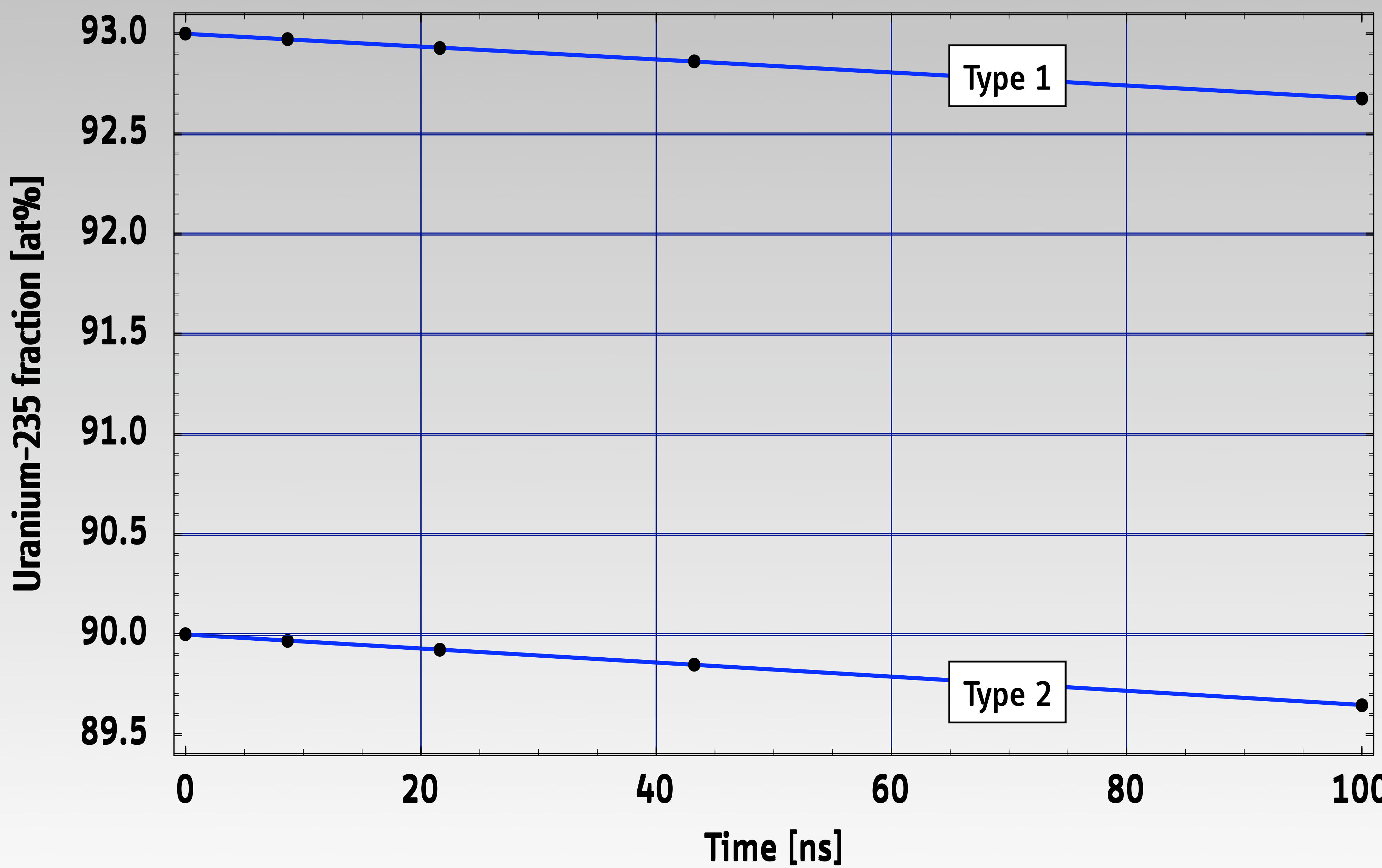
	Initial		Final		Delta M
U-234	0.60 kg	1.0 at%	0.59 kg	1.0 at%	-0.004 kg
U-235	55.76 kg	93.0 at%	54.62 kg	92.7 at%	-1.135 kg
U-236	-	-	0.14 kg	0.2 at%	+0.138 kg
U-238	3.64 kg	6.0 at%	3.63 kg	6.1 at%	-0.014 kg
U-239	-		*(5.5 g)*		
TOTAL	60.00 kg		58.99 kg		-1.010 kg

The uranium isotopics in a gun-type device shift very little (0.1-0.3%) during the explosion

In practice, the phenomena are much more complex,
but this simple analysis suggests why determination of pre-explosion isotopics is feasible
(if weapon-codes and weapon-test data are accessible)

U-235 Content During Explosion

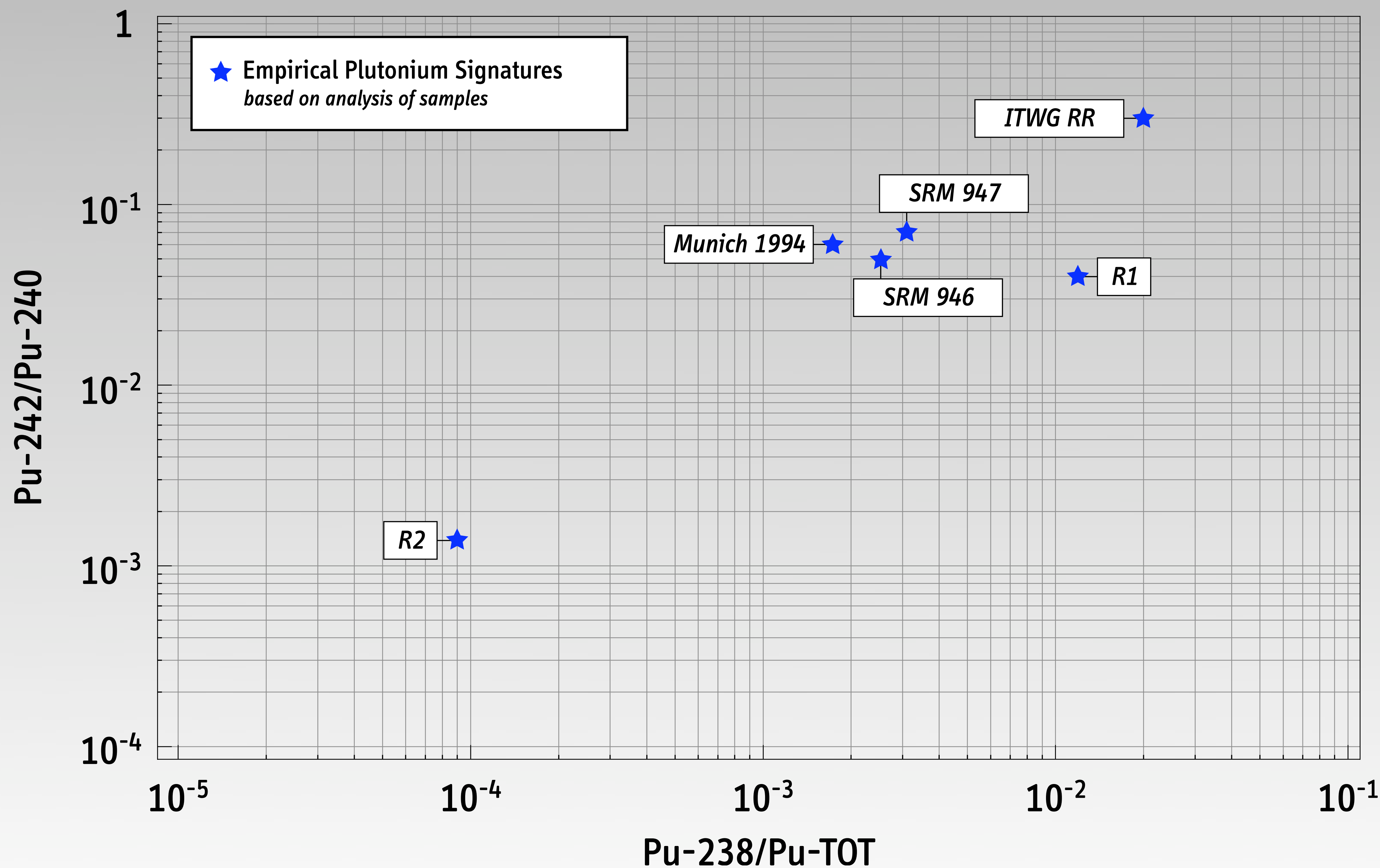
(averaged over debris)



Signatures of Plutonium Compositions

(for pre-explosion analysis)

Isotope Ratio Correlations



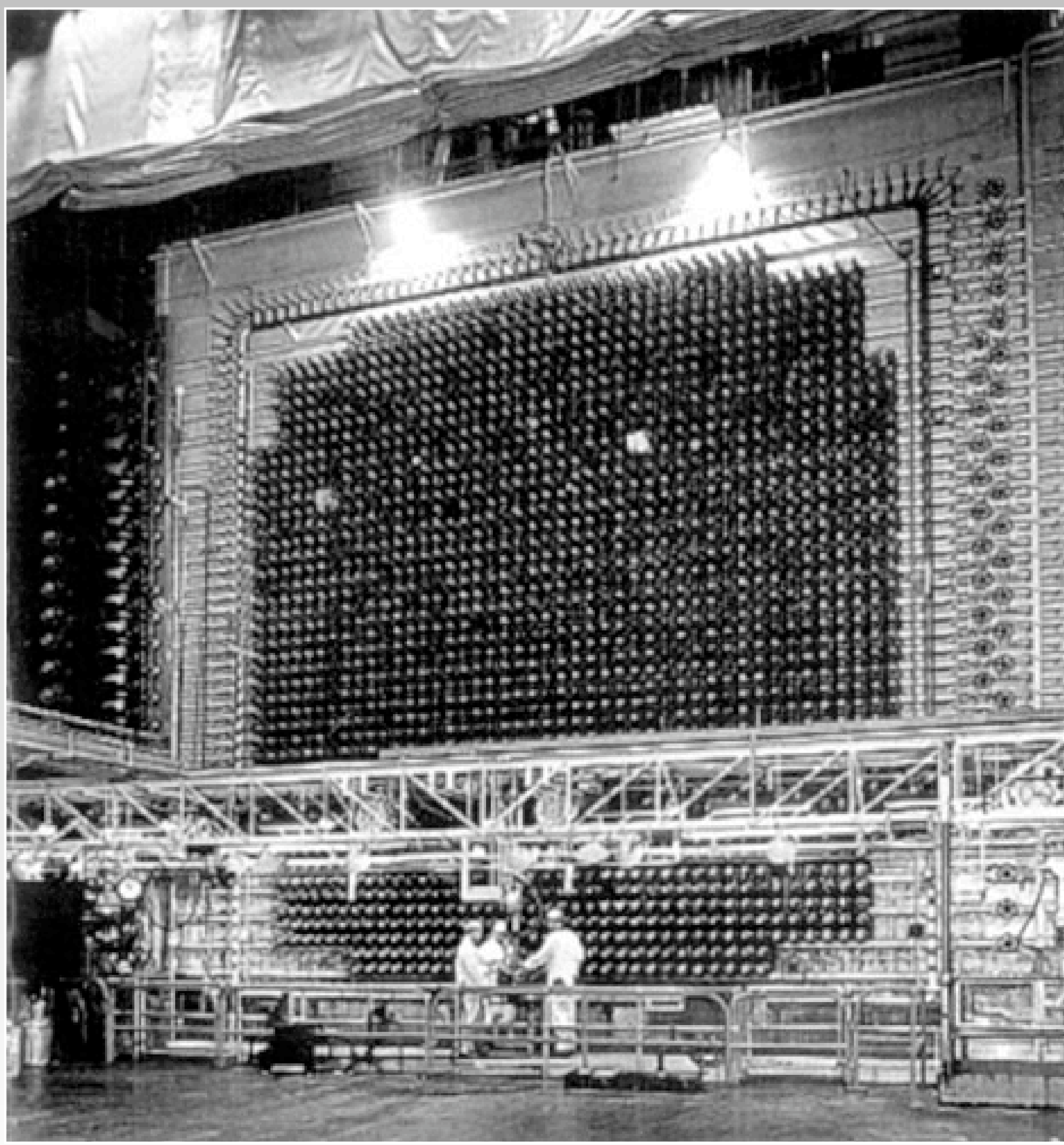
K. Mayer, M. Wallenius, and I. Ray, "Nuclear Forensics – A Methodology Providing Clues on the Origin of Illicitly Trafficked Nuclear Materials," *Analyst,* Royal Society of Chemistry, 130 (2005), pp. 433–441

Production Reactor Types

	Graphite moderated		Heavy-water moderated		Driver fuel with external DU targets
	H_2O cooled	CO_2 cooled	H_2O cooled	D_2O cooled	
United States	Hanford				Savannah River
Russia	"Tomsk-7"				
U.K.		Calder Hall			
France		G-Series			Célestin
China	"Jiuquan"				
Israel				Dimona	
India			Cirus/NRX	Dhruva	
Pakistan			Khushab		
DPRK		Yongbyon			

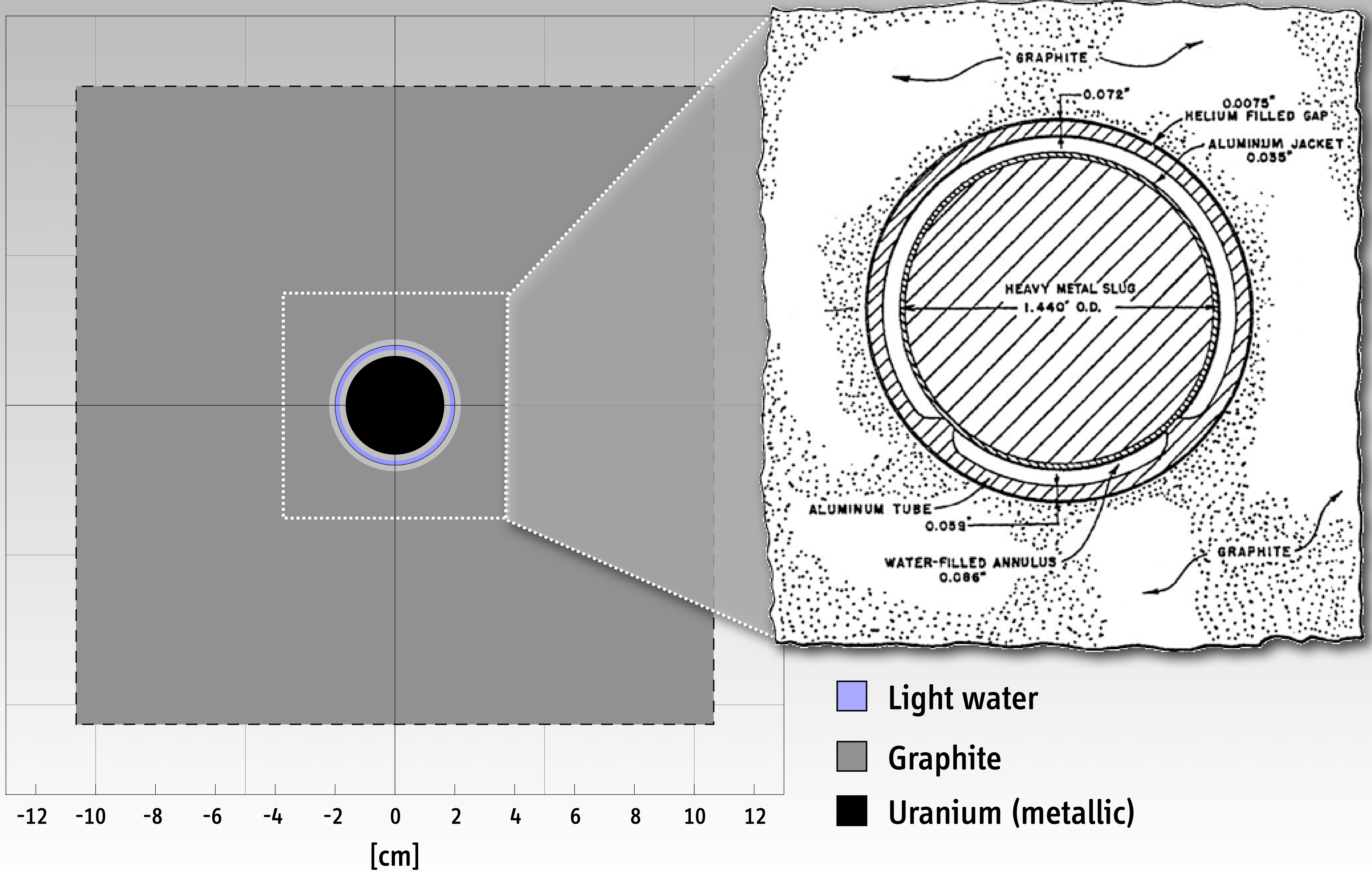
Hanford B Reactor

(United States, 1944-1968)



B-Reactor in 1998

Unit Cell of Hanford B Reactor

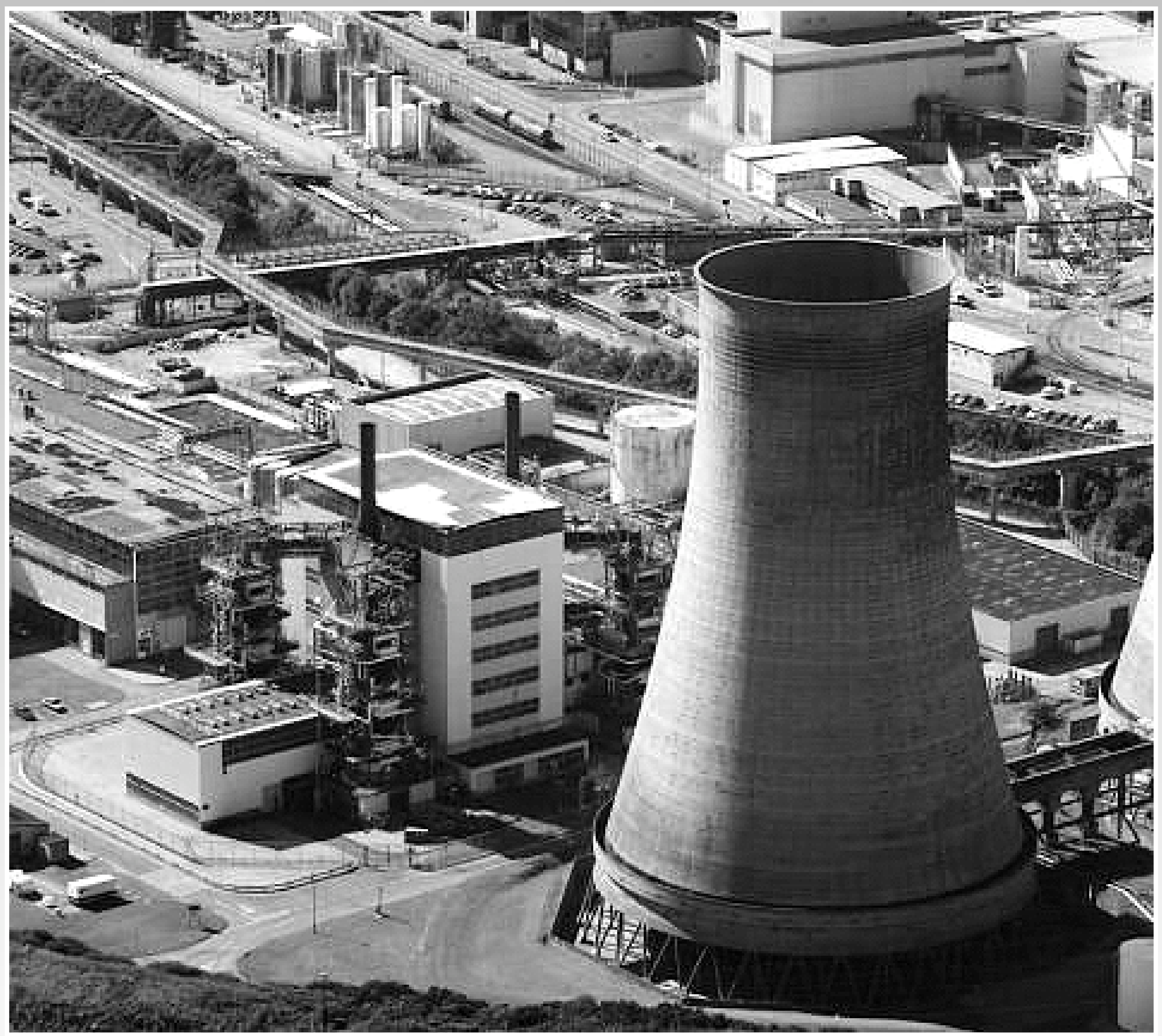


NRX / Cirus Reactor

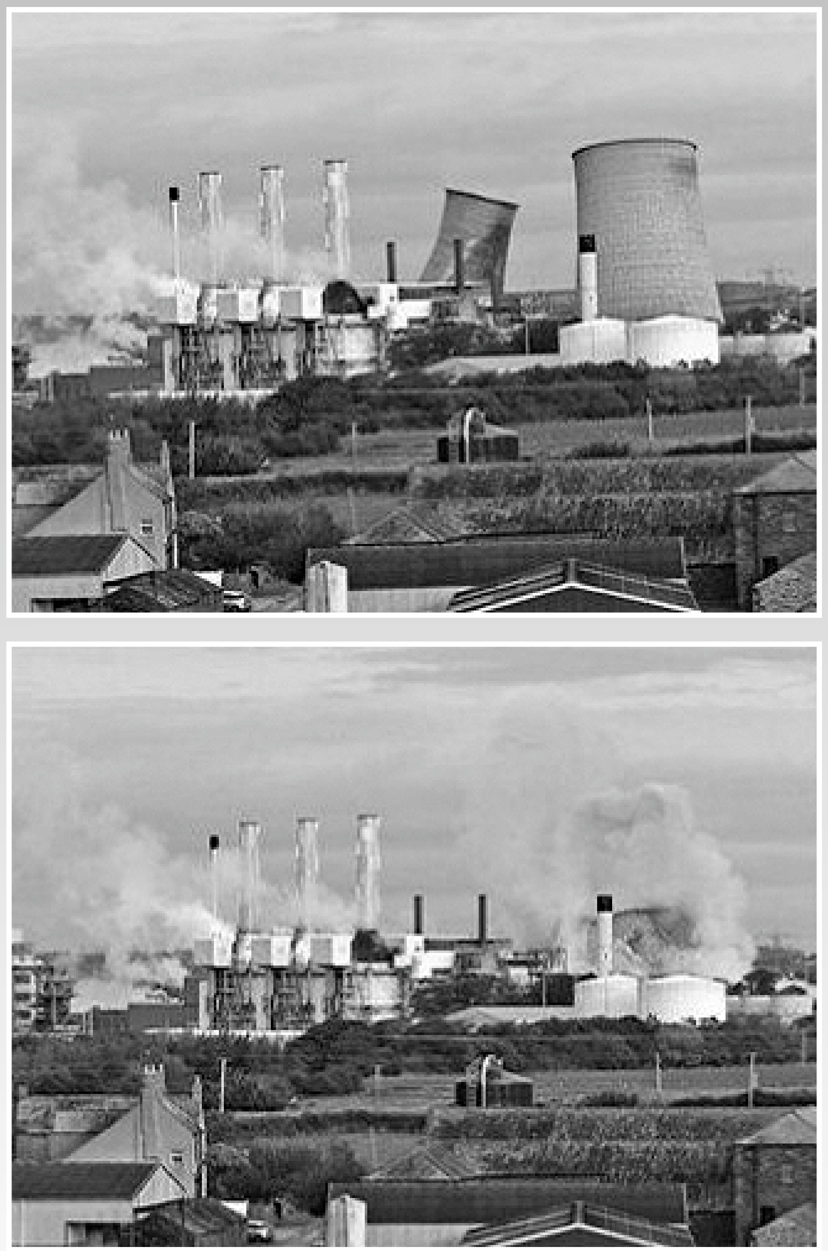
(Canada / India)

Calder Hall Reactor

(United Kingdom)



Source: BNFL



Demolition of Calder Hall (A) Towers
September 29, 2007

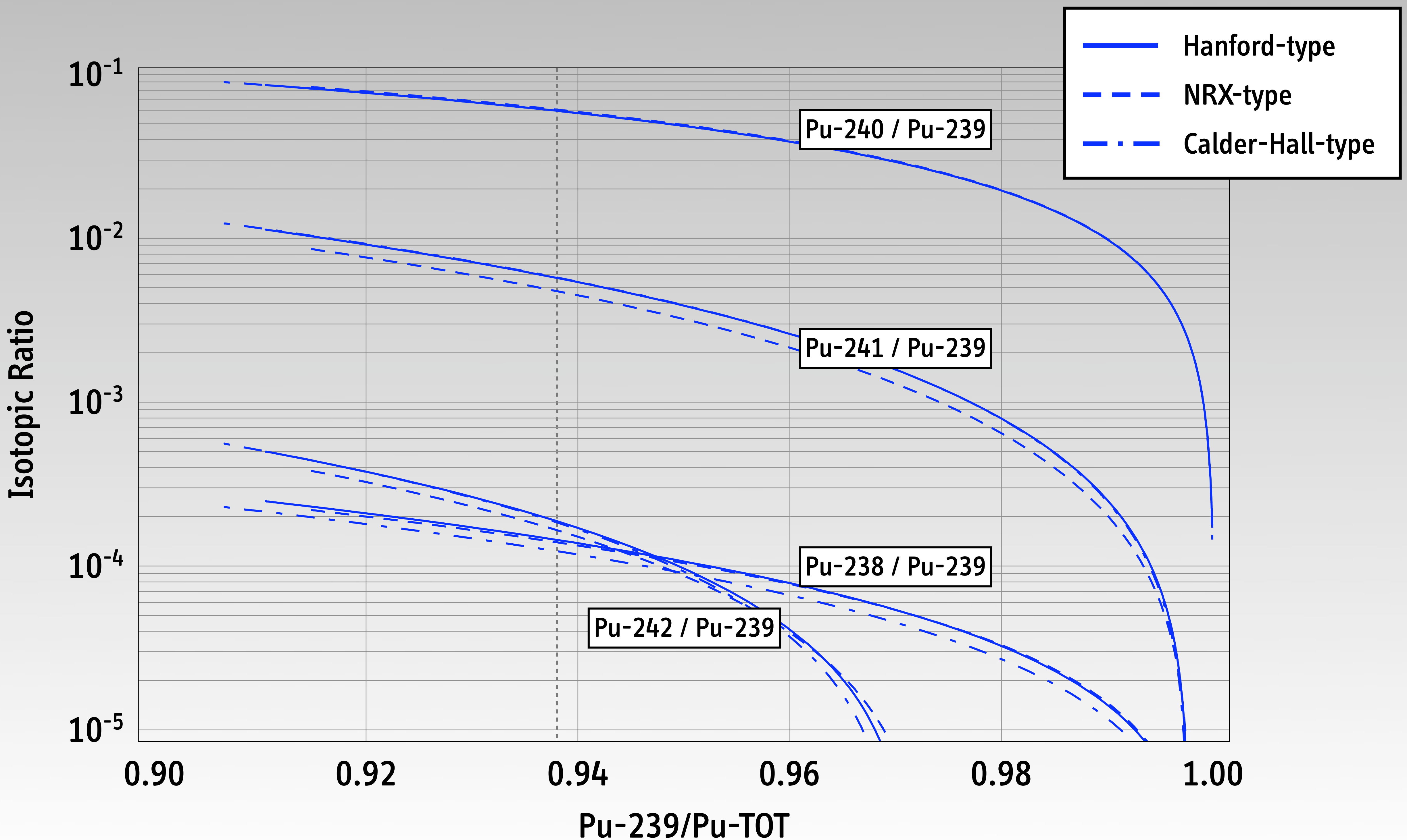
Yongbyon Reactor

(North Korea)

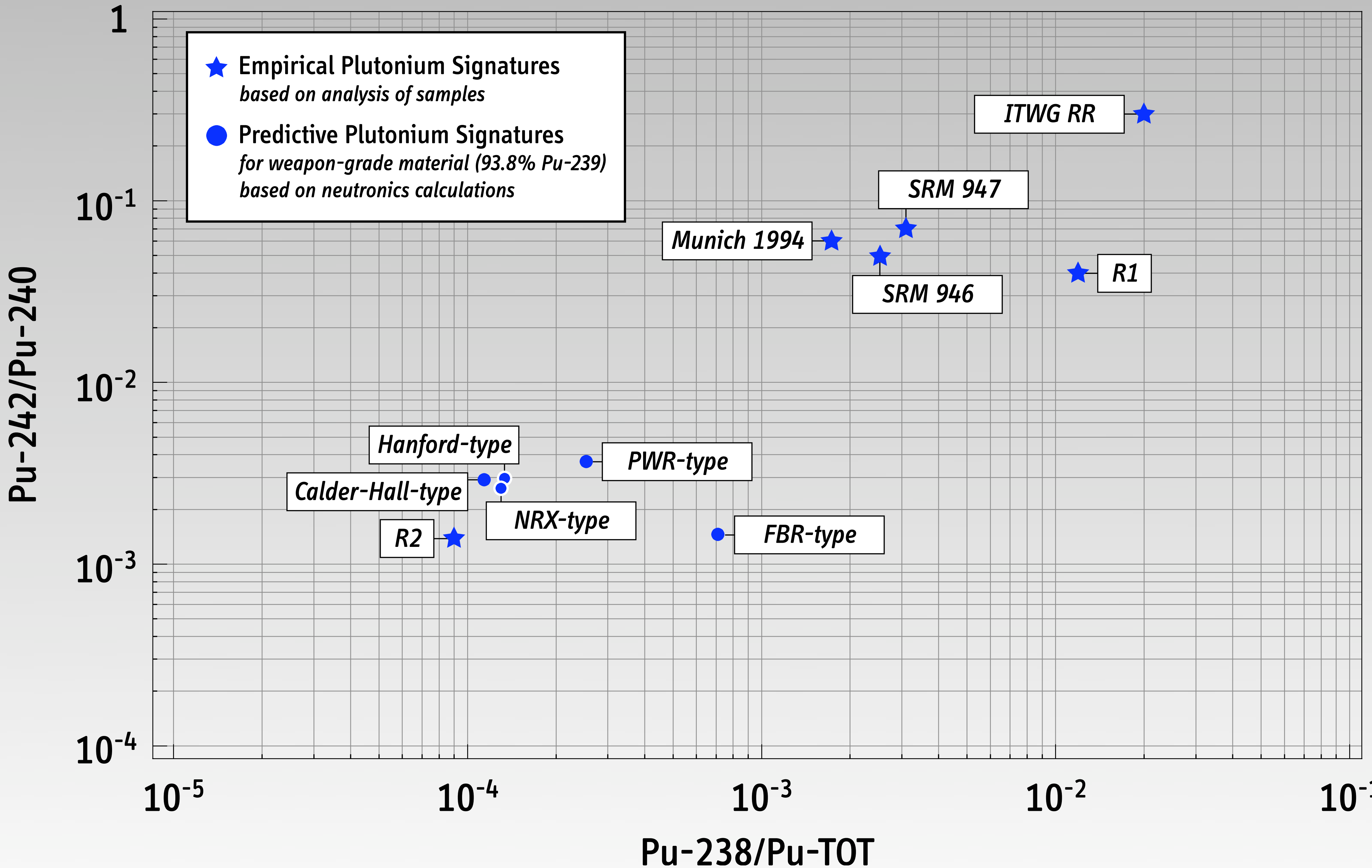
Photo: Keith Luse

Demolition of cooling tower, June 26, 2008

Plutonium Isotope Ratio Correlations



Isotope Ratio Correlations



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Summary

Isotopic Signatures and Nuclear Forensics

Predictive signatures of nuclear materials are generally too weak for a robust nuclear forensic analysis (if source-attribution is pursued)

To perform task with confidence, empirical signatures (samples) are required

Importance of comprehensive (international) databases for nuclear forensics

Pre- vs Post-explosion Forensics

Fewer signatures in post-explosion scenario

Determination of pre-explosion isotopics (to guide attribution process) feasible for some weapon states – *and impossible for all others*

What Can (or Should) Be the Role of Nuclear Forensics Today?

Nuclear Forensics for Fissile Material Control

Combatting Illicit Trafficking

Assisting response to criminal or unauthorized acts
involving nuclear or other radioactive material

Global Campaign Leading to Unambiguous Physical Protection Standards

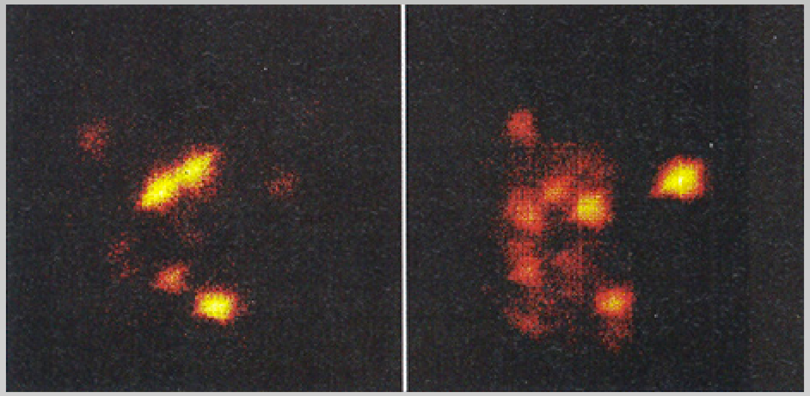
"supported and enforced by the promise of pre-detonation nuclear attribution"
(Chivers et al., Arms Control Today, July/August 2008)

"If such material should escape a state's control, the state should be forced to establish truly effective physical protection measures or face international condemnation and corrective action. Weapons-usable fissile material found outside of state control would present clear evidence that robust physical protection measures are not in place."

Nuclear Forensics for IAEA Safeguards

Environmental Sampling Techniques

(e.g. absence of HEU production in declared enrichment facilities)



Images of micron-sized uranium particles made with a Secondary Ion Mass Spectrometer

Left: U-235 Concentration
Right: U-238 Concentration

Undeclared plutonium separation in North Korea (from samples taken in 1992)

HEU particles on Iranian centrifuges (discovered in June 2003)*

HEU particles on aluminum tubings found in North Korea (revealed in July 2008)**

*IAEA GOV/2003/63, 26 August 2003

** Not an IAEA analysis, reported in *Nuclear Fuel*, 14 July 2008

Nuclear Forensics for Arms Control

Treaty Verification Support

Source of material used in an unattributed nuclear test (CTBT)

Age-determination of material samples (FMCT)

"Nuclear Archaeology"

Documentation of past nuclear weapons activities to "lay a firm foundation for verifiable nuclear disarmament"

S. Fetter, *Science & Global Security*, 1993

Nuclear Forensics for National Security

("New Deterrence")

"The transfer of nuclear weapons or material by North Korea to states or non-state entities would be considered a grave threat to the United States, and we would hold North Korea fully accountable for the consequences of such action."

George W. Bush, Oct. 9, 2006

"Kim [Jong-il] must be convinced that American nuclear forensics will be able to identify the molecular fingerprint of nuclear material from his Yongbyon reactor. He must feel in his gut the threat that if a nuclear weapon of North Korean origin explodes on American soil or that of a U.S. ally, the United States will retaliate precisely as if North Korea had attacked the United States with a nuclear-armed missile: with an overwhelming response that guarantees this will never happen again."

Graham Allison, Washington Post, Oct. 27, 2006

Nuclear Forensics for National Security

("New Deterrence")

Rationale

Terrorist groups cannot be deterred
Instead, deter state sponsors, which could provide fissile material for "indirect" attack

Relies on credible attribution capability

Numerous Problems

"N=1 problem"
Duration of forensic analysis
Database issues
...
Establishing intent (vs negligence)

What kind of forensic evidence "justifies" what kind of response?

About Databases

Since 1995, joint database owned by the European Union and Russia

(Karlsruhe/Moscow)

Most weapon states have their own databases
with data from nuclear weapon tests

528 atmospheric tests (plus more than 1,500 underground tests)

United States now has also bilateral agreements with some other states (e.g. Kazakhstan)

Proposal for an International Database (May, Davis, Jeanloz)

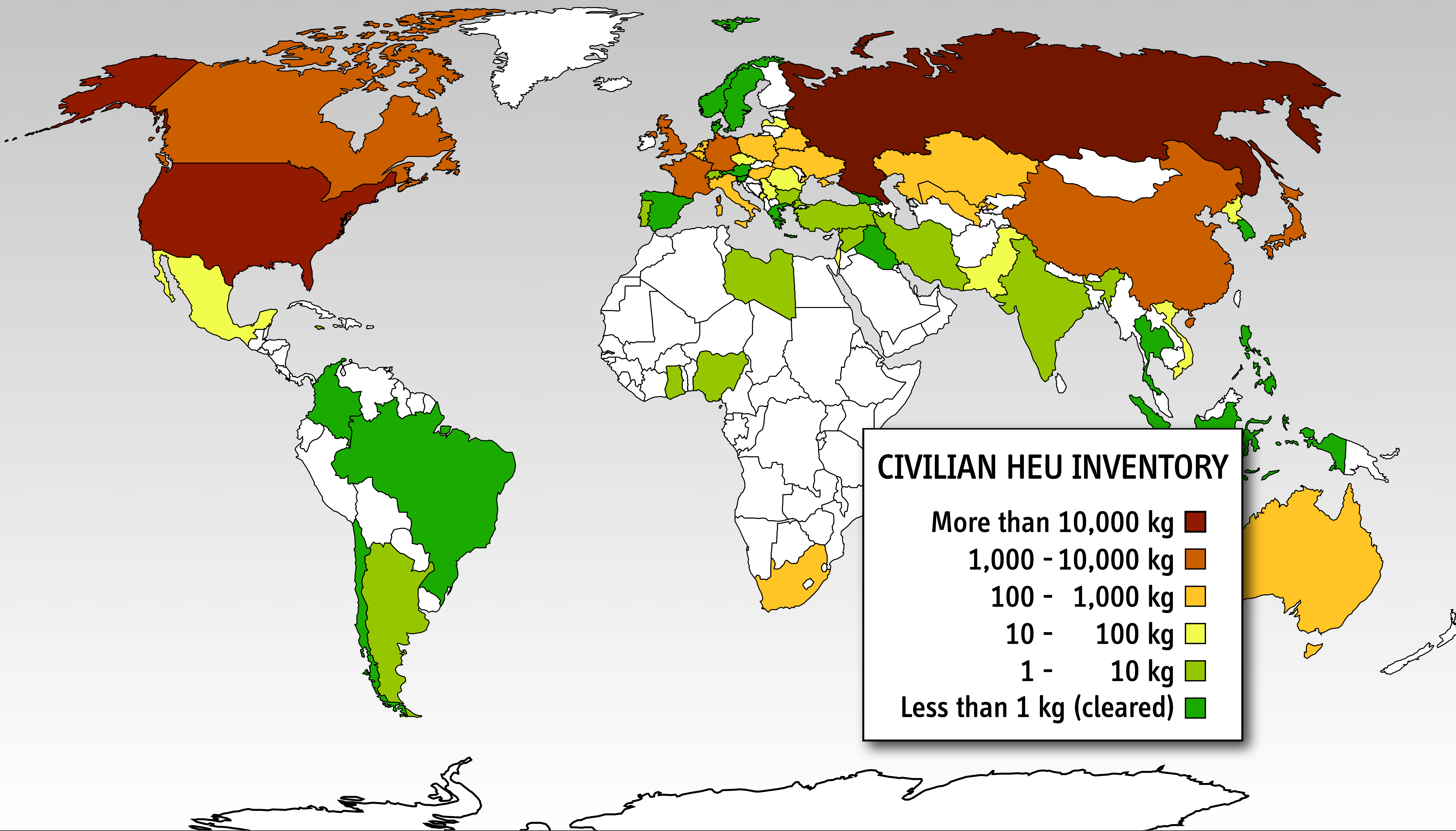
Issues

Commercially (and militarily) sensitive nature of material compositions and isotopics
Authentication and completeness of submitted data
Access to database

Why should states join when the consequences are unclear?

Beyond Nuclear Forensics

e.g., A Global Cleanout of Nuclear Weapon Materials



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