NUCLEAR FORENSICS

A COMPUTER VISUALIZATION APPROACH TO A SCIENTIFIC SEARCH PROBLEM

-CHARLES WANG, MIMS 2014

ABOUT

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- **Funding:** National Science Foundation Grant: #1140073
- **Project Title:** Recasting Nuclear Forensics as a Digital Library Search Problem

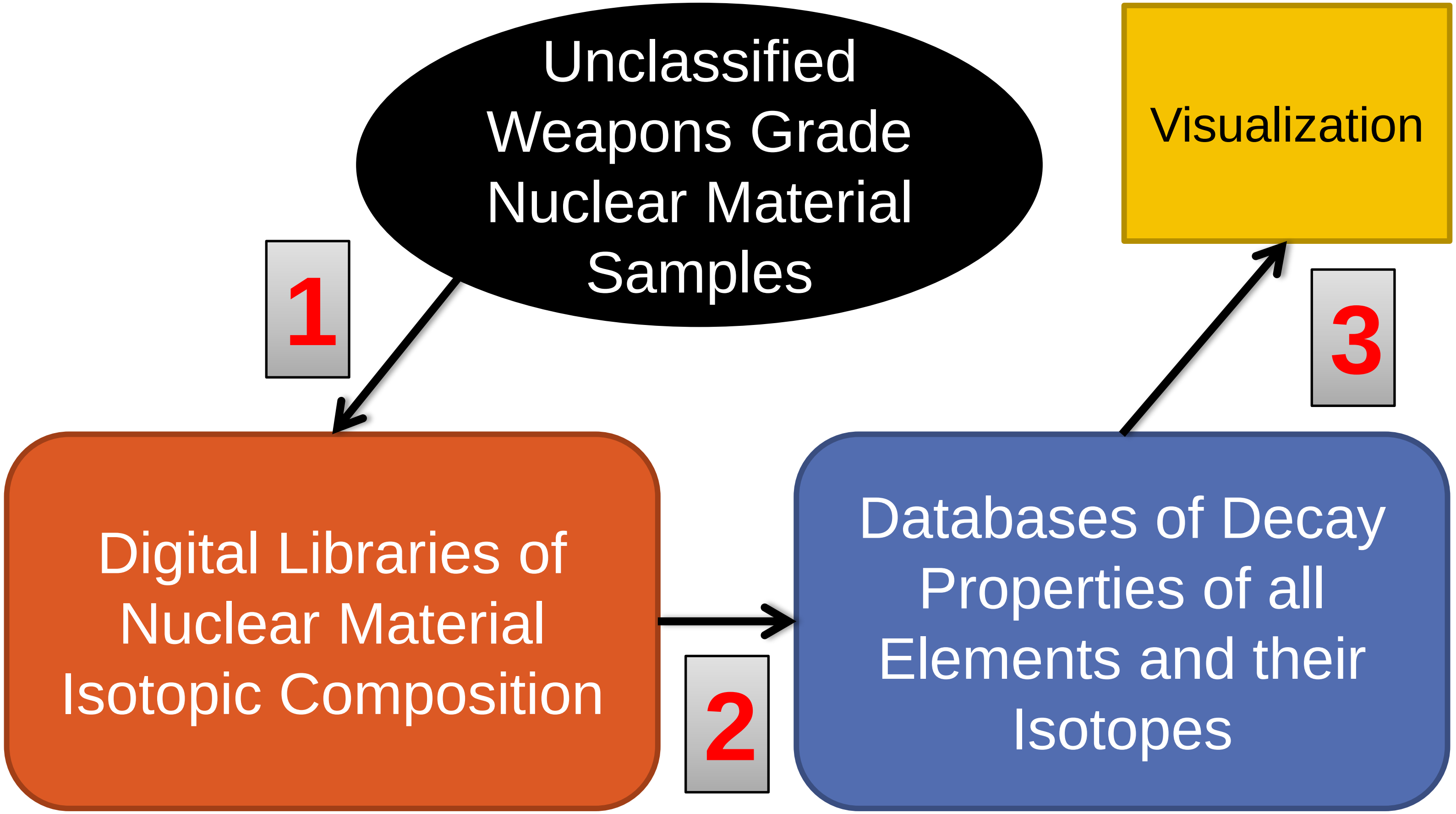
NUCLEAR SAFEGUARDS

- **Criminals or terrorists may obtain illicit nuclear materials from existing nuclear facilities**
- **Currently USA & Russia have 95% of all weapons grade nuclear material**
- **IAEA (International Atomic Energy Agency, Vienna)**
  - Dept. of Nuclear Safety and Security- safety infrastructure
  - Dept. of Safeguards- nuclear material verification

NUCLEAR FORENSICS

- **The science of tracing the sources of smuggled nuclear material**
- **Since 1992, more than 800 incidents of interdicted nuclear material have been reported**
- **Key component of fighting global terrorism**

FORENSIC FRAMEWORK



STEP1: FIND SAMPLE COMPOSITION

Sample X

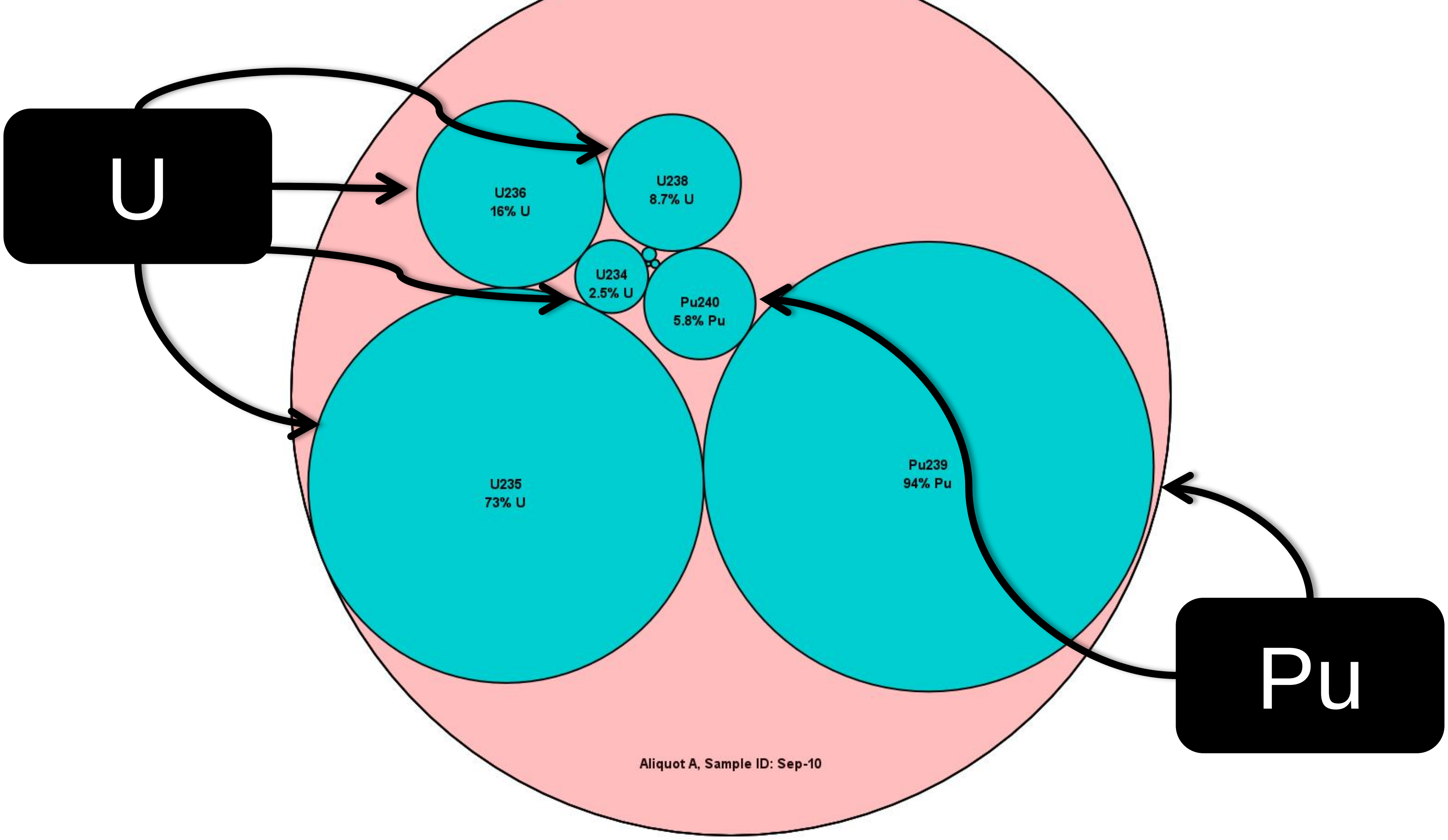
Aliquot A	Aliquot B	Aliquot C	Aliquot D

Aliquot A

Isotope	% Weight Of Element
Pu-242	0.0323
Pu-241	0.0921
Pu-240	5.762
Pu-239	94.1024
Pu-238	0.0112
U-238	8.691
U-236	16.2796
U-235	72.5557
U-234	2.4737

ONE SAMPLE X (W/ 1ST ALIQUOT)

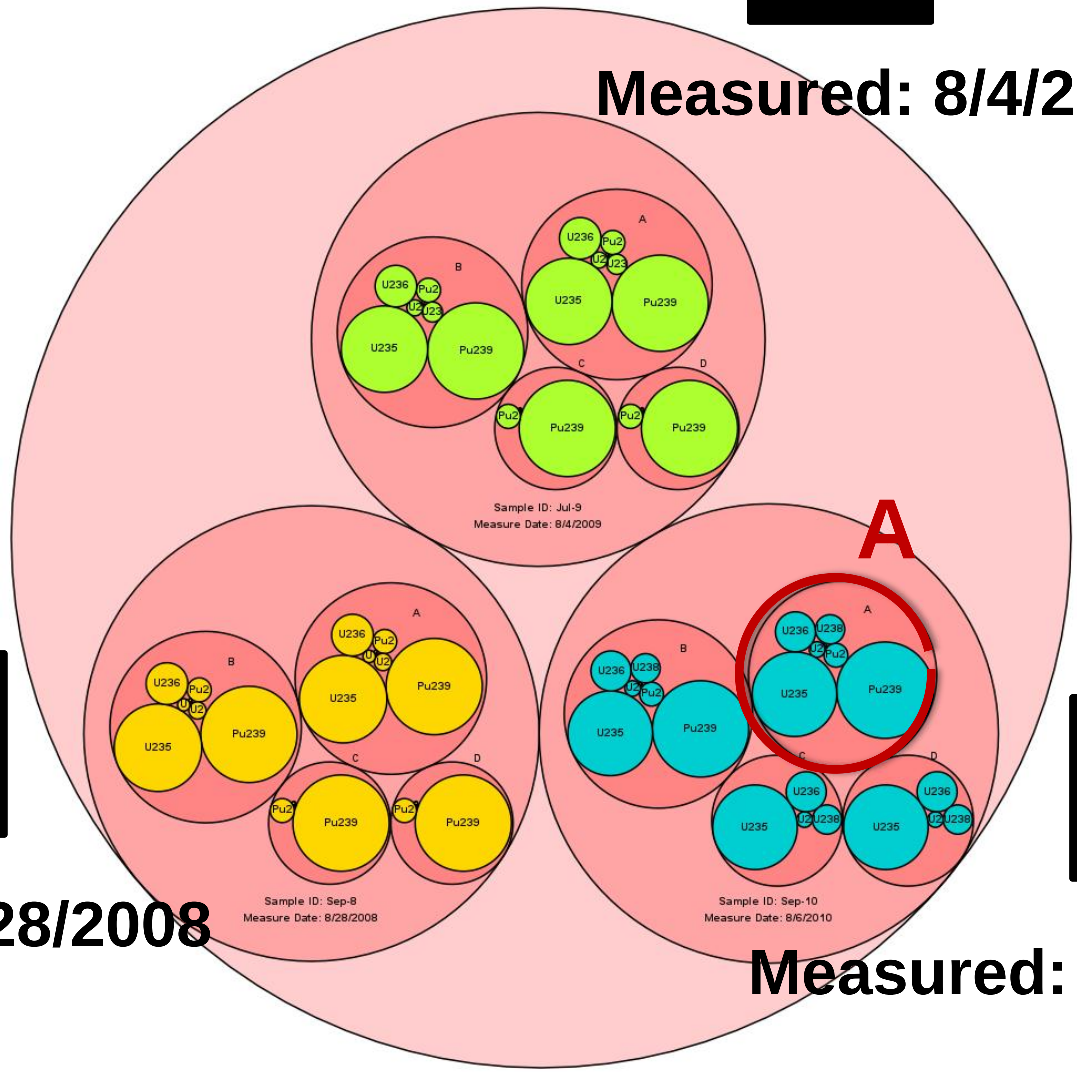
Measured: 8/6/2010



THREE SAMPLES

Z

Measured: 8/4/2009



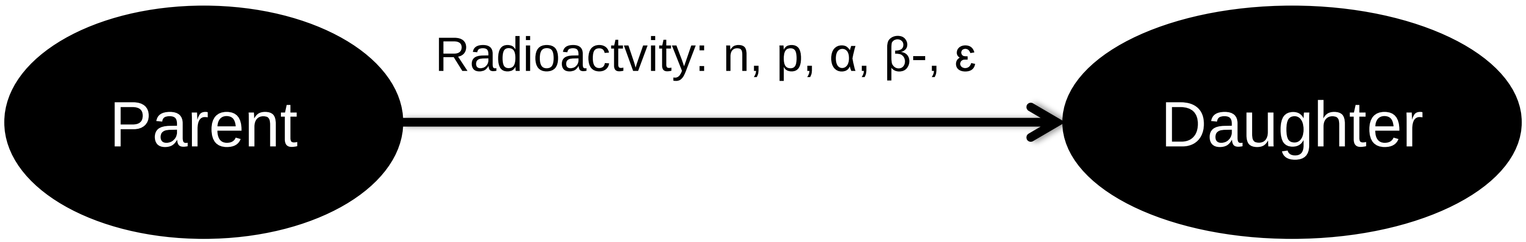
Y

Measured: 8/28/2008

X

Measured: 8/6/2010

STEP2: FIND DECAY CHAINS FOR EACH ISOTOPE COMPONENT



- **Built decay chains (directed-graph approach) from Nuclear Wallet Cards**
- **Wallet Cards:** Catalogues properties for ground and isomeric states of all known nuclides. Published by National Nuclear Data Center, Brookhaven National Laboratory.

NUCLEAR WALLET CARDS

A

Z

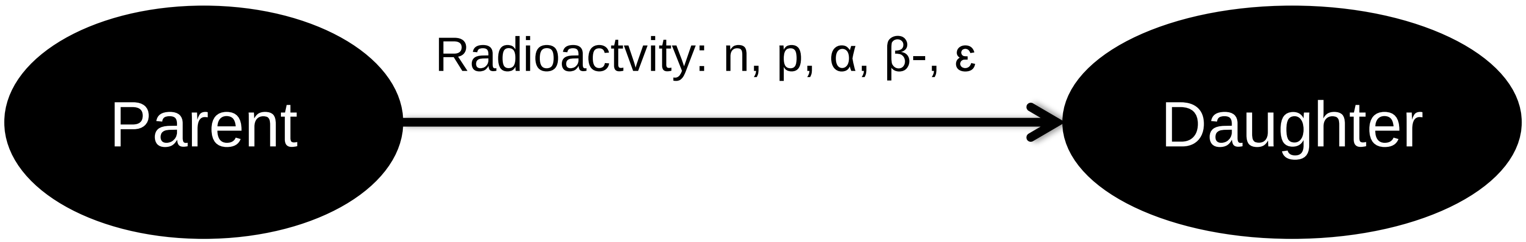
Decay Mode

Half Life

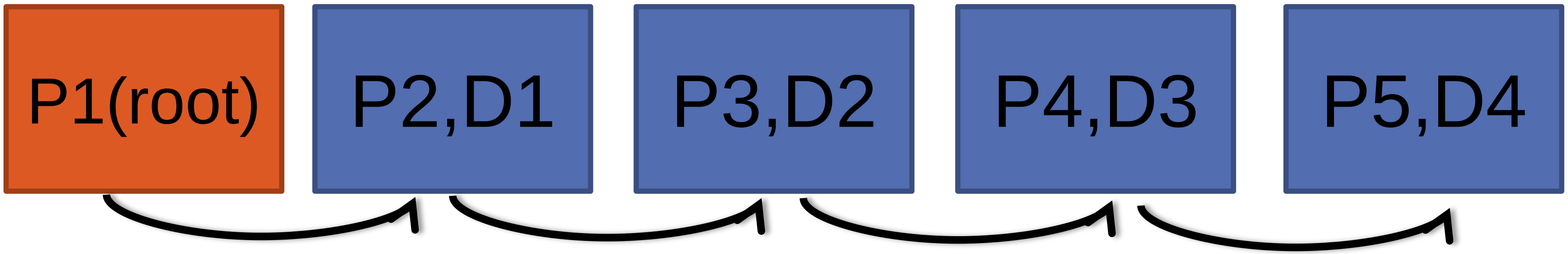
ID

!	A	M	Z	elem	Jpi	Jpi2	decay_mode	decay_note	branch_percent	MeV	MeV_Q-value	half_life_txt	abundance	at_mass	S	dummy	half_life_sec	idwc
	1		1	H	Q	1/2+				0	0	STABLE	99.9885% 70	7.28900	0	200601	0.00E+00	1
	2		1	H	Q	1+				0	0	STABLE	0.0115% 70	13.13570	0	200309	0.00E+00	2
	3		1	H	Q	1/2+	B-		100	0	0.019	12.32 Y 2		14.94980	0	200007	3.89E+08	3
	4		1	H	Q	-2	N		100	0	2.88			24.62100	0.1	199807	0.00E+00	4
	5		1	H	W	(1/2+)	2N		100	0	1.8	5.7 MEV 21		32.89200	0.089	NUBASE	8.33E-23	5
	6		1	H	Q	(2-)	N		100	0	0.9	1.6 MEV 4		41.87500	0.254	200212	2.97E-22	6
	7		1	H	W	(1/2+)	2N?				0	29E-23 Y 7		47.93500	0.351	03KO11	9.15E-15	7
	3		2	HE	Q	1/2+				0	0	STABLE	0.000134% 3	14.93120	0	870312	0.00E+00	8
	4		2	HE	Q	0+				0	0	STABLE	99.999866% 3	2.42490	0	199807	0.00E+00	9
	5		2	HE	Q	3/2-	A		100	0	0.89	0.60 MEV 2		11.23100	0.02	840808	7.91E-22	10
	5		2	HE	Q	3/2-	N		100	0	0.89	0.60 MEV 2		11.23100	0.02	840808	7.91E-22	11
	6		2	HE	Q	0+	B-		100	0	3.508	801 MS 10		17.59200	0	09RA33	8.01E-01	12
	7		2	HE	Q	(3/2)-	N			0	0.435	150 KEV 20		26.06700	0.008	200302	3.16E-21	13
	8		2	HE	Q	0+	B-		100	0	10.651	119.1 MS 12		31.60900	0	200505	1.19E-01	14
	8		2	HE	Q	0+	BN		16	0	8.619	119.1 MS 12		31.60900	0	200505	1.19E-01	15
	9		2	HE	Q	1/2+	N		100	0	1.27			39.78000	0.06	200602	0.00E+00	16
	10		2	HE	Q	0+	N		100	0	-0.202	300 KEV 200		48.80900	0.07	200705	1.58E-21	17
	3		3	LI	W		P	?			0	unbound		28.66700	2.0000 S		0.00E+00	18
	4		3	LI	Q	-2	P		100	0	3.103	6.03 MEV		25.32300	0.212	980707	7.87E-23	19
	5		3	LI	Q	3/2-	P		100	0	1.965	1.5 MEV AP		11.67800	0.05	840808	3.16E-22	20
	5		3	LI	Q	3/2-	A		100	0	1.965	1.5 MEV AP		11.67800	0.05	840808	3.16E-22	21
	6		3	LI	Q	1+				0	0	STABLE	7.59% 4	14.08690	0	200212	0.00E+00	22
	7		3	LI	Q	3/2-				0	0	STABLE	92.41% 4	14.90710	0	200302	0.00E+00	23
	8		3	LI	Q	2+	B-		100	0	16.005	839.9 MS 9		20.94500	0	200505	8.40E-01	24
	8		3	LI	Q	2+	BA		100	0	0	839.9 MS 9		20.94500	0	200505	8.40E-01	25
!	8	M	3	LI	Q	1+	IT		100	0.9808	0.981	8.2 FS 23		21.92580	0	200505	8.20E-15	26
	9		3	LI	Q	3/2-	B-		100	0	13.607	178.3 MS 4		24.95400	0	200602	1.78E-01	27
	9		3	LI	Q	3/2-	BN		50.8	0	11.941	178.3 MS 4		24.95400	0	200602	1.78E-01	28
	10		3	LI	Q	(1-,2-)	N		100	0	0.025			33.05200	0.012	200705	0.00E+00	29

STEP2: FIND DECAY CHAINS FOR EACH ISOTOPE COMPONENT



- **Built decay chains (directed-graph approach) from Nuclear Wallet Cards**
- **Wallet Cards:** Catalogues properties for ground and isomeric states of all known nuclides. Published by National Nuclear Data Center, Brookhaven National Laboratory.
- **Decay chain generation**: Given parent isotope, find daughters based on decay type.



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═════ Compute Parent-Daughter Pair (PU-241) ═════
***** (A,Z,elem),(d_A,d_Z,d_elem),decay_mode,branch_percent,half_life_sec ****
TOP LEVEL: (241,94,PU),(241,95,AM),B-,100,452000000
CHAIN COMPUTATION: (241,95,AM),(237,93,NP),A,100,13700000000
CHAIN COMPUTATION: (237,93,NP),(233,91,PA),A,100,67700000000000
CHAIN COMPUTATION: (233,91,PA),(233,92,U),B-,100,2330000
CHAIN COMPUTATION: (233,92,U),(229,90,TH),A,100,5020000000000
CHAIN COMPUTATION: (229,90,TH),(225,88,RA),A,100,250000000000
CHAIN COMPUTATION: (225,88,RA),(225,89,AC),B-,100,1290000
CHAIN COMPUTATION: (225,89,AC),(221,87,FR),A,100,864000
CHAIN COMPUTATION: (221,87,FR),(217,85,AT),A,100,286
CHAIN COMPUTATION: (217,85,AT),(213,83,BI),A,99.99,0.0323
CHAIN COMPUTATION: (213,83,BI),(213,84,PO),B-,97.8,2740
CHAIN COMPUTATION: (213,84,PO),(209,82,PB),A,100,3.72e-006
CHAIN COMPUTATION: (209,82,PB),(209,83,BI),B-,100,11700
CHAIN COMPUTATION: (209,83,BI),(0,0,),,,0
CHAIN COMPUTATION: (213,84,PO),(213,84,PO),IT,,9.3e-011
CHAIN COMPUTATION: (213,83,BI),(209,81,TL),A,2.2,2740
CHAIN COMPUTATION: (209,81,TL),(209,82,PB),B-,100,130
CHAIN COMPUTATION: (209,82,PB),(209,83,BI),B-,100,11700
CHAIN COMPUTATION: (209,83,BI),(0,0,),,,0
CHAIN COMPUTATION: (217,85,AT),(217,86,RN),B-,7.00E-03,0.0323
CHAIN COMPUTATION: (221,87,FR),(221,88,RA),B-,0.1,286
CHAIN COMPUTATION: (221,88,RA),(217,86,RN),A,100,28
CHAIN COMPUTATION: (217,86,RN),(213,84,PO),A,100,0.00054
CHAIN COMPUTATION: (213,84,PO),(209,82,PB),A,100,3.72e-006
CHAIN COMPUTATION: (209,82,PB),(209,83,BI),B-,100,11700
CHAIN COMPUTATION: (213,84,PO),(213,84,PO),IT,,9.3e-011
CHAIN COMPUTATION: (213,84,PO),(209,82,PB),A,100,3.72e-006
CHAIN COMPUTATION: (209,82,PB),(209,83,BI),B-,100,11700
CHAIN COMPUTATION: (209,83,BI),(0,0,),,,0
CHAIN COMPUTATION: (213,84,PO),(213,84,PO),IT,,9.3e-011
CHAIN COMPUTATION: (213,84,PO),(209,82,PB),A,1.00E-03,9.3e-011
CHAIN COMPUTATION: (209,82,PB),(209,83,BI),B-,100,11700
CHAIN COMPUTATION: (209,83,BI),(0,0,),,,0
COMPUTATION: (221,88,RA),(0,0,),14C,1.00E-12,28
COMPUTATION: (225,89,AC),(0,0,),14C,4.00E-12,864000
COMPUTATION: (229,90,TH),(229,90,TH),IT,,120
CHAIN COMPUTATION: (233,92,U),(0,0,),24Ne,9.00E-10,5020000000000
CHAIN COMPUTATION: (237,93,NP),(0,0,),SF,2.00E-10,67700000000000
CHAIN COMPUTATION: (241,95,AM),(0,0,),SF,4.00E-10,13700000000
Time Elapsed: 2 secs
```

P1

D1

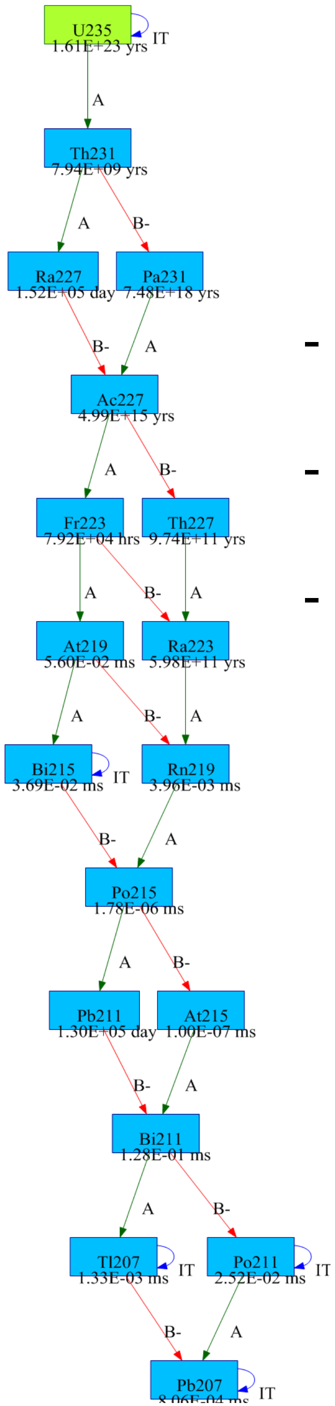
P2

D2

P3

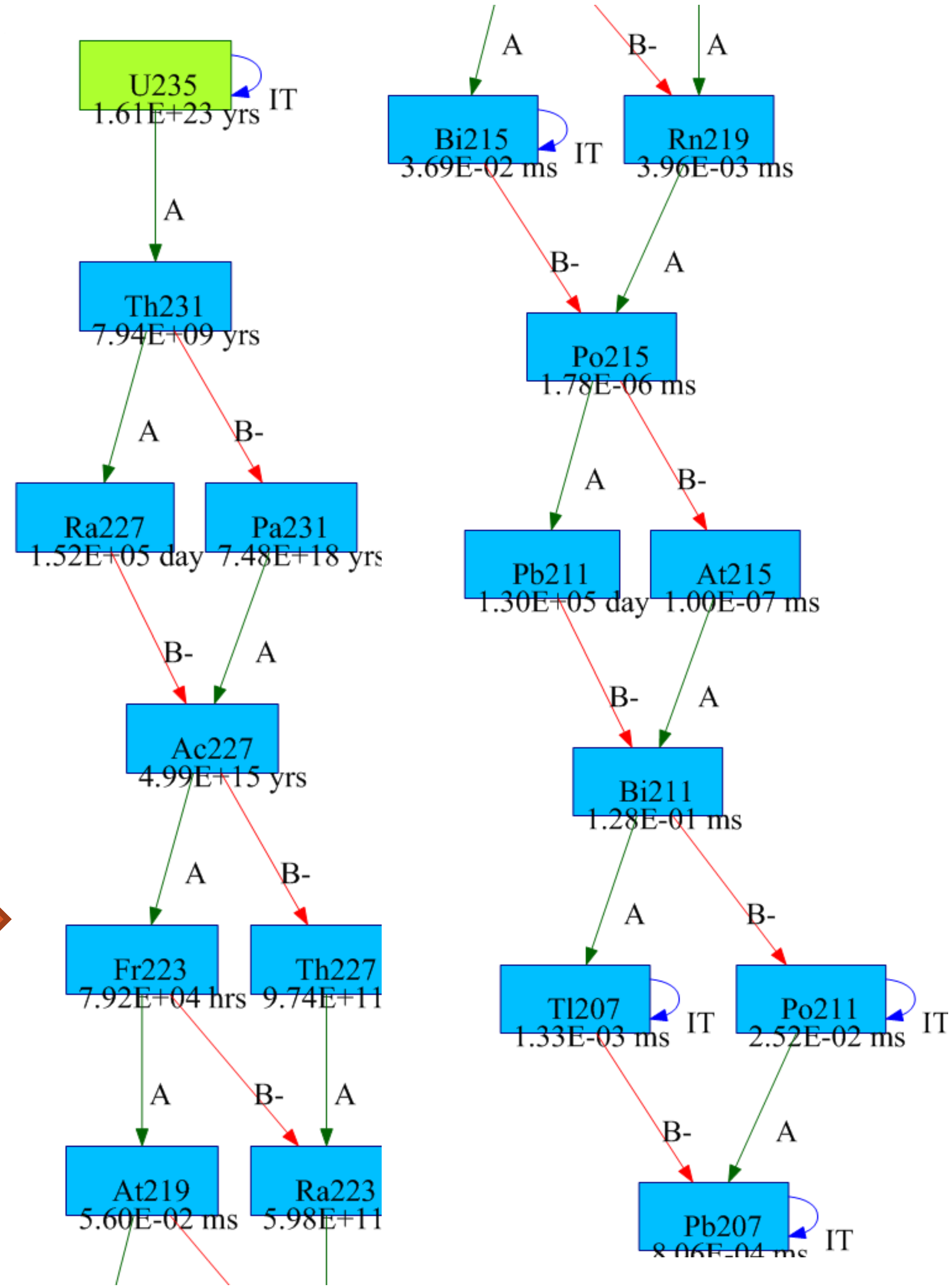
D3

Pu-241



U-235

- Only 0.72% Natural Abundance
- Little Boy, Aug. 6, 1945 (Hiroshima)
- Weapon grade: U-235 > 85%



PUTTING ALL TOGETHER

Decay Activities of Sample X, Aliquot A

Isotope Composition	% Weight Of Element
Pu-242	0.0323
Pu-241	0.0921
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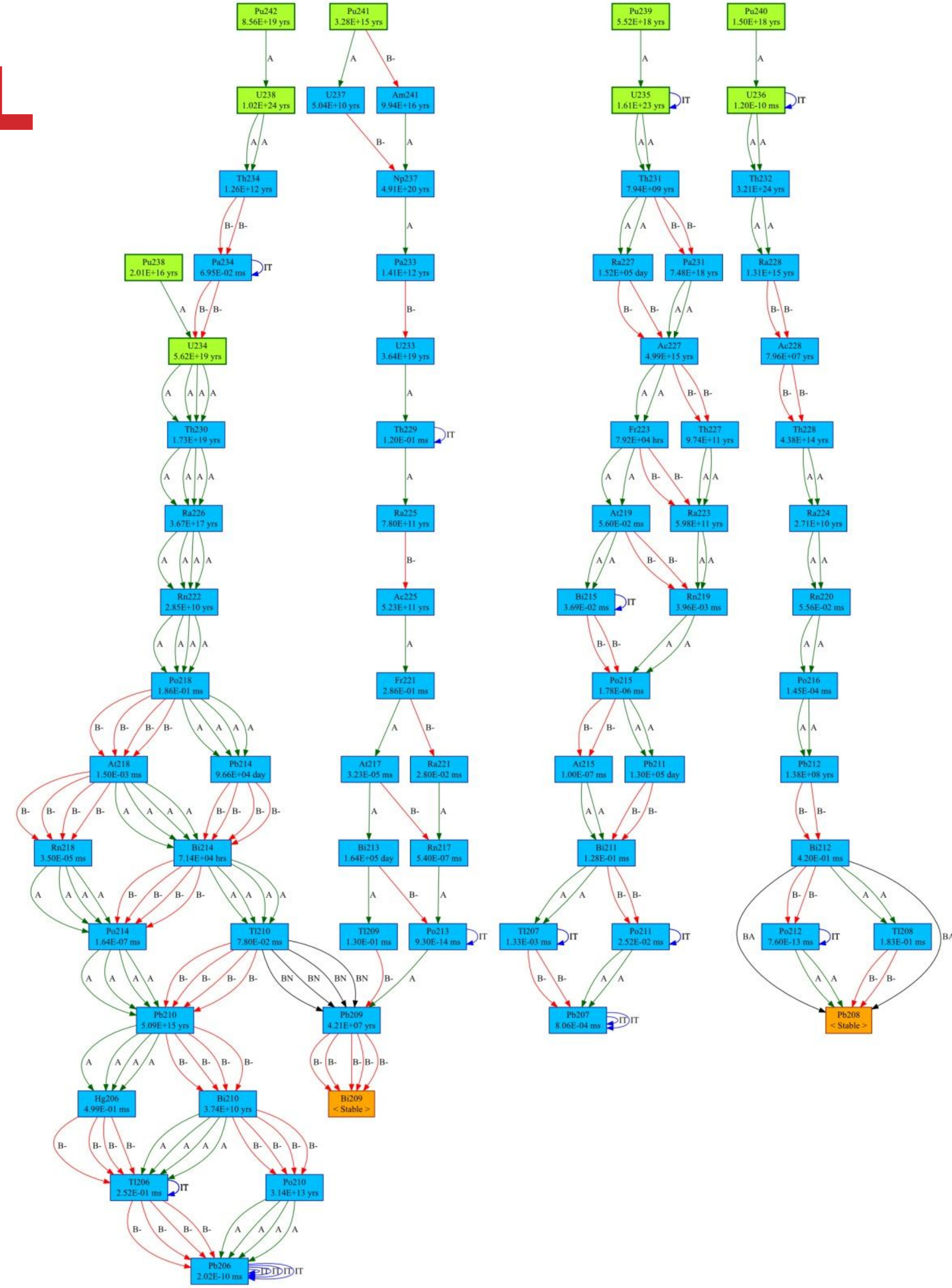

IMPLEMENTATION STANDARD AND FRAMEWORK

- **Scalable Vector Graphics (SVG)**

Our graphs are generated in SVG format, which is often used to define vector-based graphics for the Web. SVG is a W3C recommendation and integrates with other W3C standards such as the DOM and XSL. SVG images can be searched, indexed, scripted, and are scalable.

- **Data-Driven Documents (D3.js)**

D3.js is a Javascript library for manipulating documents based on data. D3, successor of the previous Protovis framework, employs largely available SVG, JavaScript
and CSS languages for data visualization. The D3 framework is used to illustrate the circle packing visualization approach.

FUTURE WORK

- **Want to know how much is left for certain isotopes after a given time T (isotopic fingerprint)**
  - Use Bateman's Equation (transient equilibrium):

$$A_d = ([A_P(0)\frac{\lambda_d}{\lambda_d - \lambda_P} \times (e^{-\lambda_P t} - e^{-\lambda_d t})] \times BR) + A_d(0)e^{-\lambda_d t},$$

  - Ad: Daughter Activity
  - Ap: Parent Activity
  - ג: Decay Constant
  - T: Half Life
- **Expand collaboration to forensics and data groups at LLNL and ORNL**
- **Begin to create nuclear forensics educational materials in collaboration with the UCB Nuclear Engineering Department**