Radio-assay of Materials via Neutron Activation Analysis

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NSSC Research/Training Program (UCD/LBNL/Sandia)

- Applications:
  - Radio-pure materials for physics experiments
  - Trace analysis for reactor monitoring & treaty verification
  - Environmental monitoring
- Techniques:
  - Neutron Activation Analysis
  - Low background gamma counting
  - Atom Trapping Trace Analysis
- Facilities:
  - MNRC reactor and Counting Labs at UC Davis
  - Low Background Counting Facilities at Oroville and LBNL
  - Cold Atom Lab at Sandia
- Three tiered training: Postdocs, Grads & Undergrads
  - Round the year training with students/postdocs spending 3-6 month stints at the Labs
  - Summer schools organized jointly by UCD and Labs.

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Neutron Activation Analysis

- Measure concentration of radioactive contaminants in materials via exposure to neutrons, followed by gamma counting.
  - Source of neutrons is the MNRC reactor
- Long lived isotopes of Uranium, Thorium, and Potassium are activated into short lived ones
- Example:
  - Potassium-40 has a 1 billion year half life
    - Difficult to measure concentration in material
  - Activate Potassium-41 into Potassium-42
    - Potassium-42 has a 12 hour half life
  - Use gamma ray spectrum to look for Potassium-42
    - From measured amount of Potassium-42 one can reconstruct how much Potassium-40 is in material

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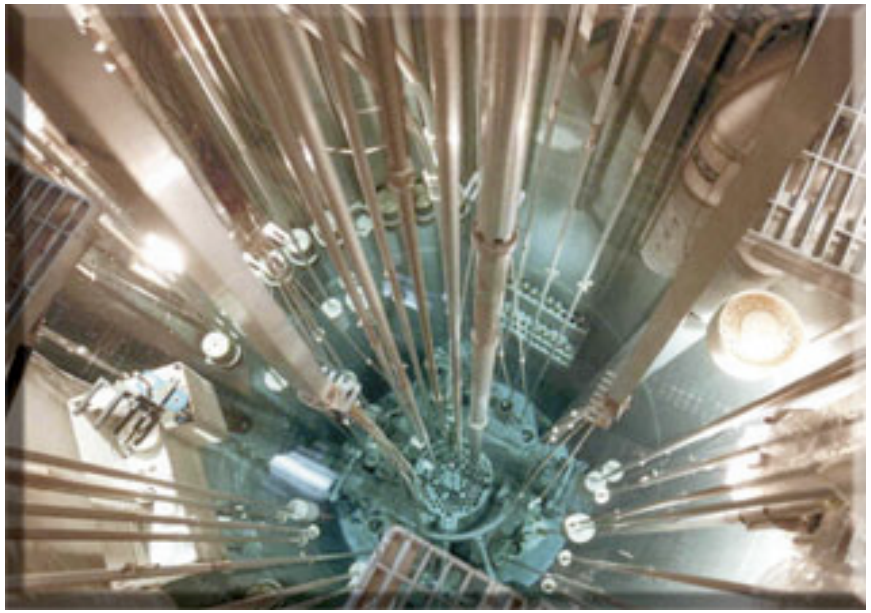
- Training, Research and Isotope Production reactor built by General Atomics (TRIGA Mark II)
- 2 MW max, 1.5 MW typical, ~1000 MW for 20 ms pulsed
- Operated by UCD since 2003



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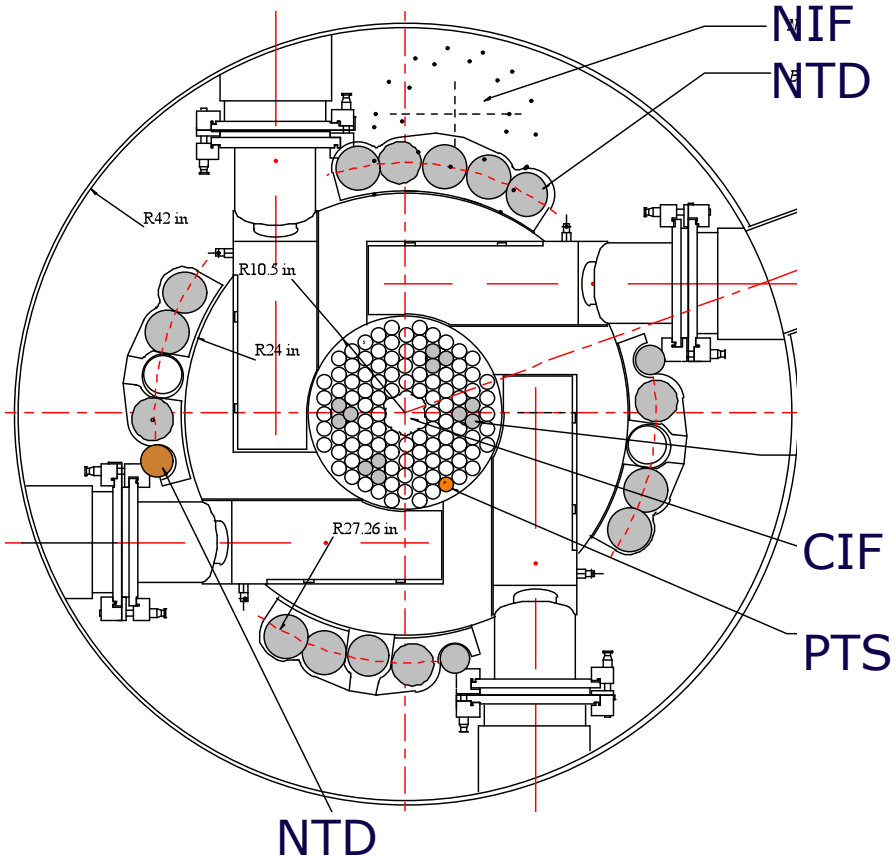
Irradiation Facilities



	Φ_{th} (n/cm²s)	Φ_{fast} (n/cm²s)
CIF	**1.0×10^{13}**	**5.2×10^{12}**
PTS	**5.2×10^{12}**	**5.2×10^{12}**
NTD	**3.1×10^{11}**	**1.2×10^{10}**
NIF	**1.5×10^{8}**	**1.5×10^{10}**

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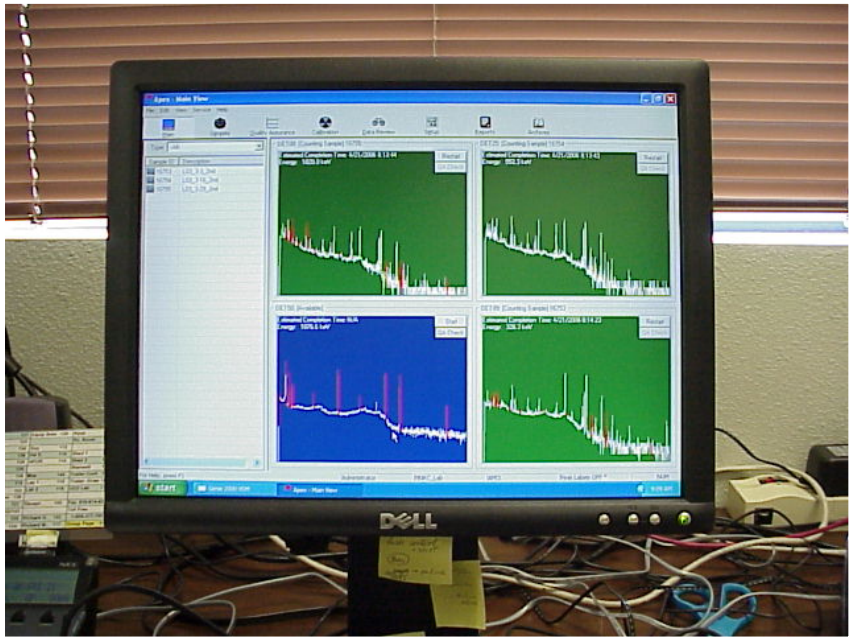
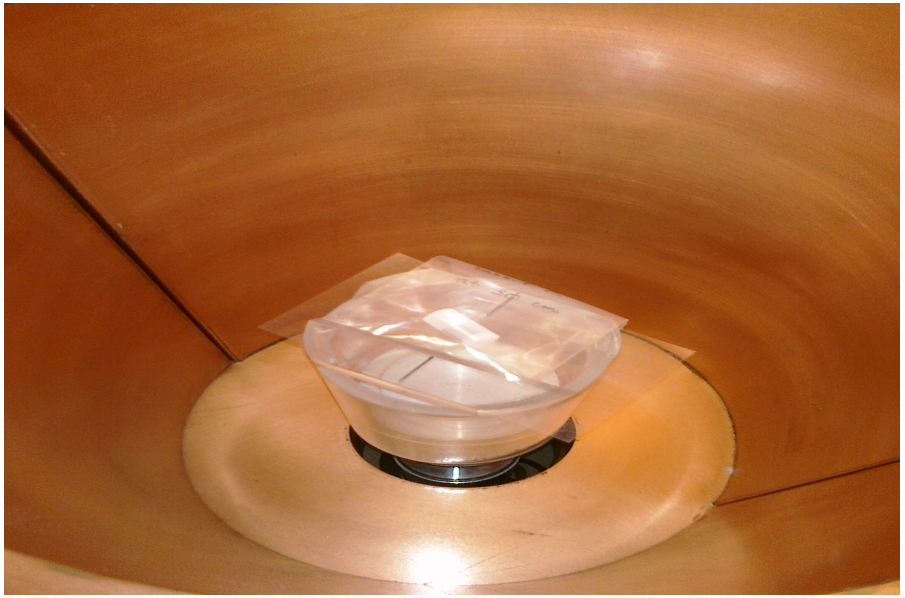
Counting Laboratory



- Four high purity Ge detectors (Canberra)
  - 8,25,50,99% efficient
- Digital readout (LYNX MCA's with Ethernet connectivity)
- Lines detected/indexed by the analysis software package.
- α-β Counter


50
CANBERRA




CANBERRA

Why Titanium? Material Properties

	Density (g/cc)	Tensile Strength (MPa)	Weldability
Titanium	4.5	434	yes
Stainless Steel	8.03	860	yes
Copper	8.94	220	no

Material	Size	Uranium		Thorium		Potassium	
		ppb	mBq/kg	ppb	mBq/kg	ppm	mBq/kg
Titanium	3/8” Plate	< 0.2	< 2.5	< 0.4	< 1.6	< 0.2	< 6.2
Titanium	3/16” Plate	< 0.3	< 3.8	< 0.7	< 2.8	< 0.3	< 9.3
Titanium	3/16” Plate	< 0.03	< 0.4	< 0.2	< 0.8	< 0.05	< 1.6
S Steel 316L	3/4” Plate	0.07	0.9	0.71	2.9		1.8
S Steel 316L	1/4” Plate	0.17	2.1	0.57	2.3		3
S Steel 316L	1/8” Plate	< 0.03	< 0.4	0.84	3.4		5.1
Copper		< 1		< 1		< 0.001	
Copper		< 0.5		< 0.5		< 0.01	

Stainless Steel data from D. McKinsey. Copper data from UKDM collaboration

Example: NAA of K

- Thermal Activation – signal

$$^{41}K + n_{th} \rightarrow {}^{42}K$$

$$\sigma_{\gamma} = 1.46b$$

$$^{42}K \rightarrow {}^{42}Ca + e^{-} + \gamma_{1524.73}$$

- Fast Activation – the lines are below K-42

$$^{48}Ti + n_{fast} \rightarrow {}^{48}Sc$$

$$\sigma = 0.07b$$

$$^{48}Sc \rightarrow 48Ti + e^{-} + \gamma_{1037.6} + \gamma_{983.5}$$

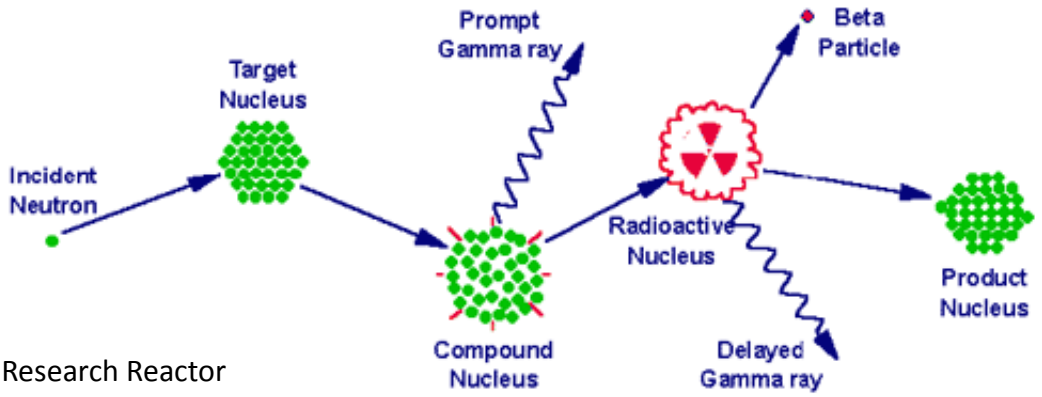
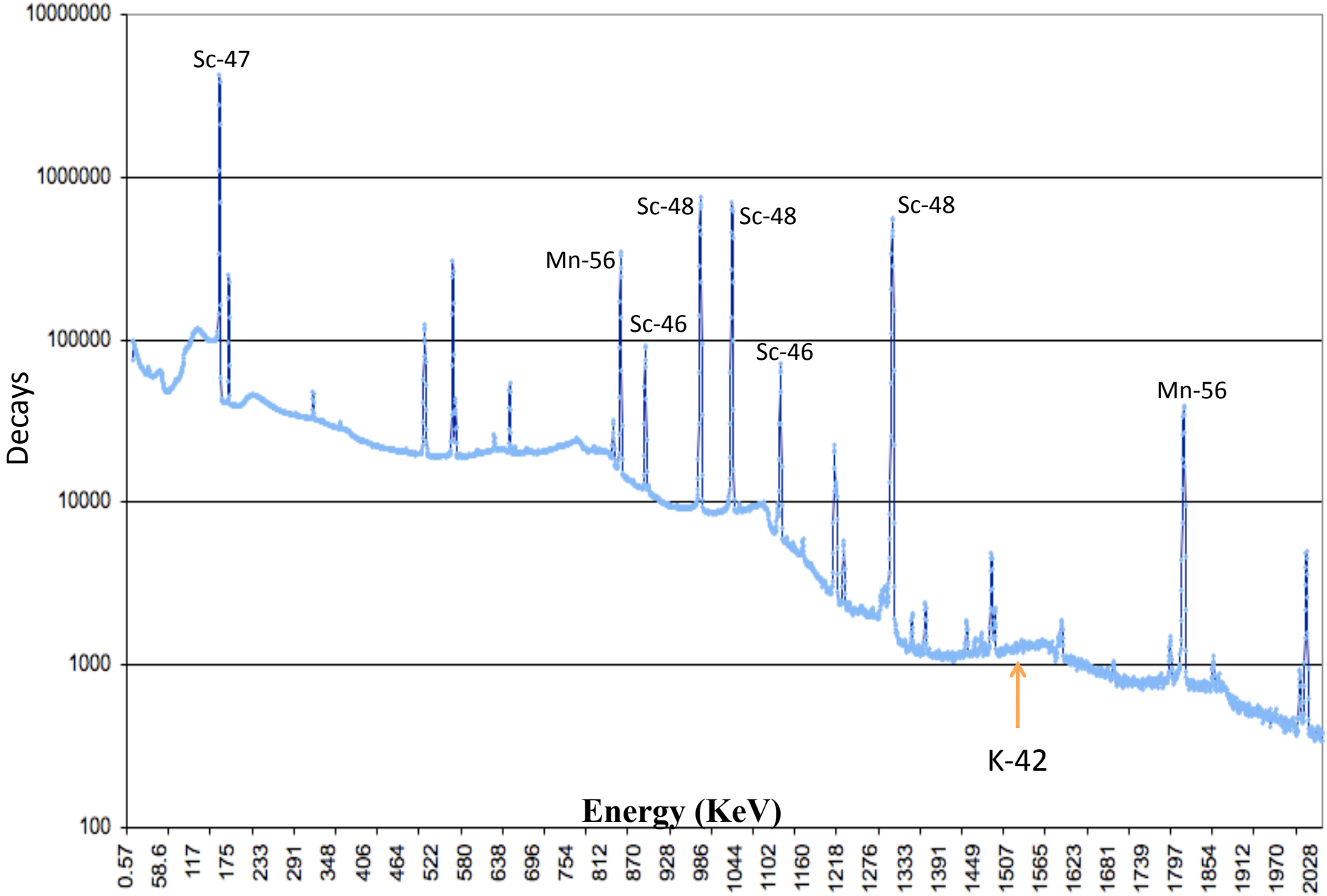


Diagram: University of Missouri Research Reactor

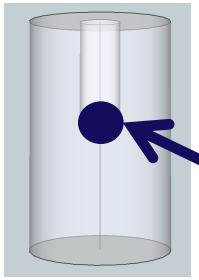
However, Compton background from Mn-56 (Mn-55 present in Ti)



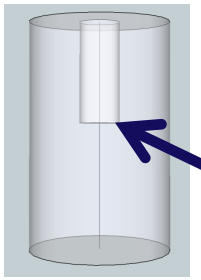
$$N_{K42}(t) \propto \frac{\phi \sigma_{K41} N_{K41}}{\lambda}$$

Reactor Flux

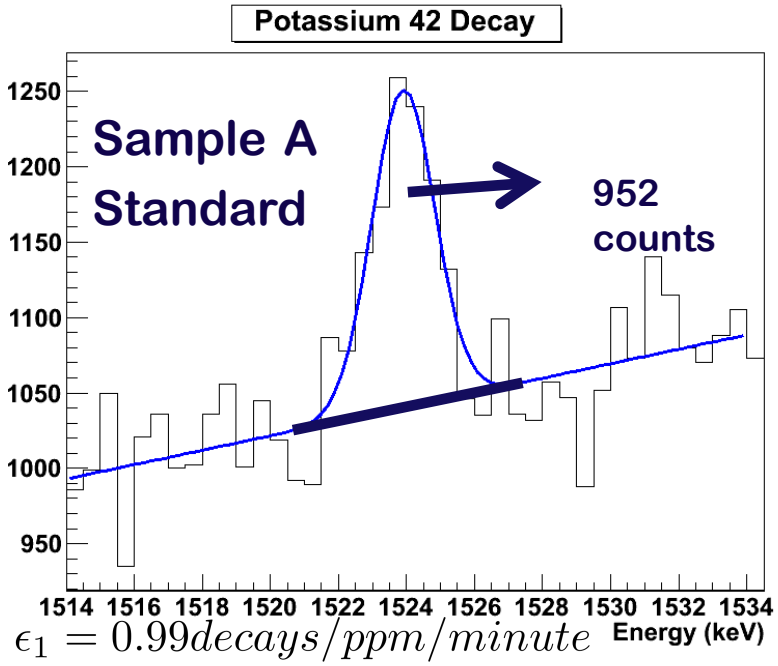
- Number of Potassium-42 produced depends on neutron flux, which is not constant and covers large energy range
  - Large systematic uncertainty
- Remove reactor uncertainty with ratio method
  - Expose two samples simultaneously
  - Sample A is a standard with known contaminant
  - Sample B is unknown
- Use this method to assay Potassium in Titanium

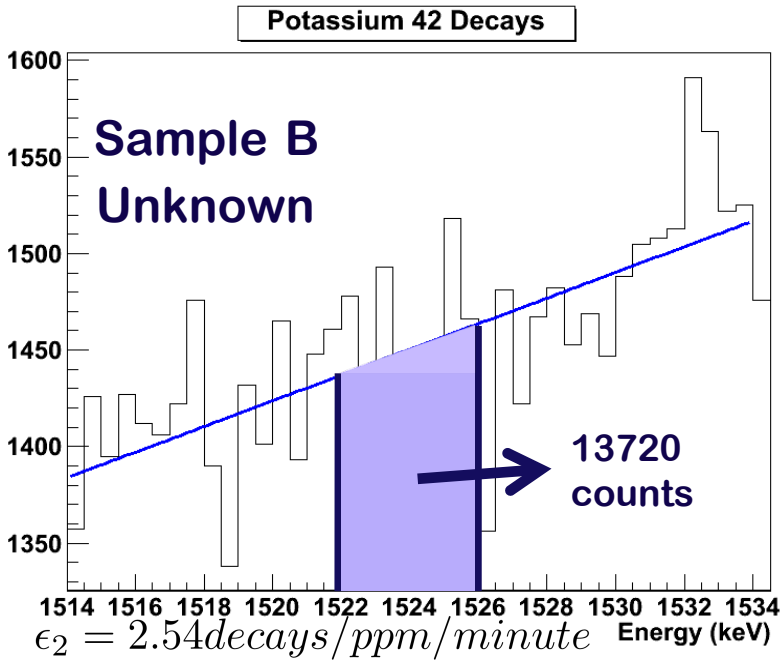


0.3 ppm K



No added K





- Compare Unknown sample to Standard sample
  - < 0.015 ppm potassium contamination
- Compare to < 0.04 ppm from direct counting

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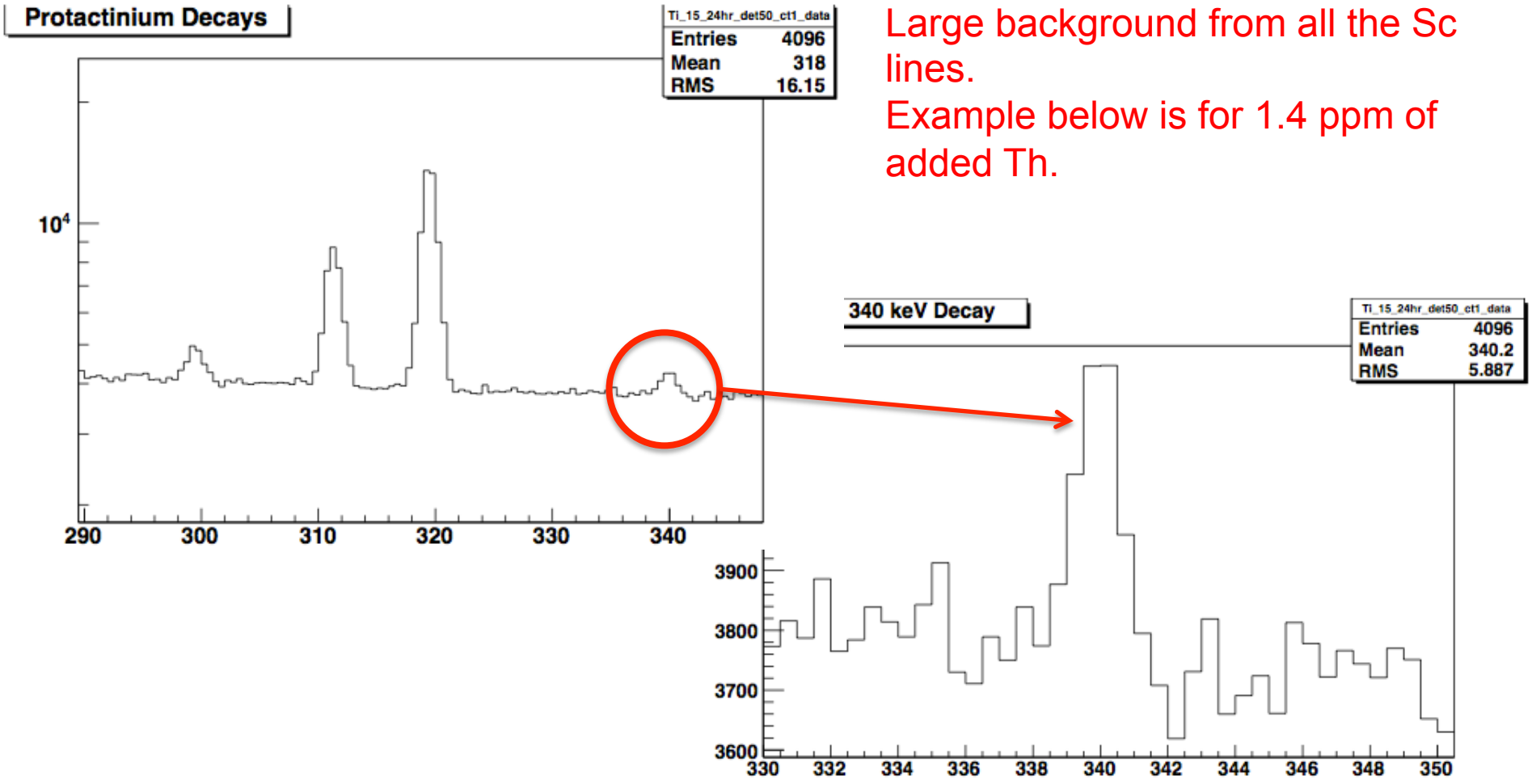
Thorium Assay

Th-232 activated and Pa-233 line at 340 keV measured (half-life ~27 days).
Large background from all the Sc lines.
Example below is for 1.4 ppm of added Th.



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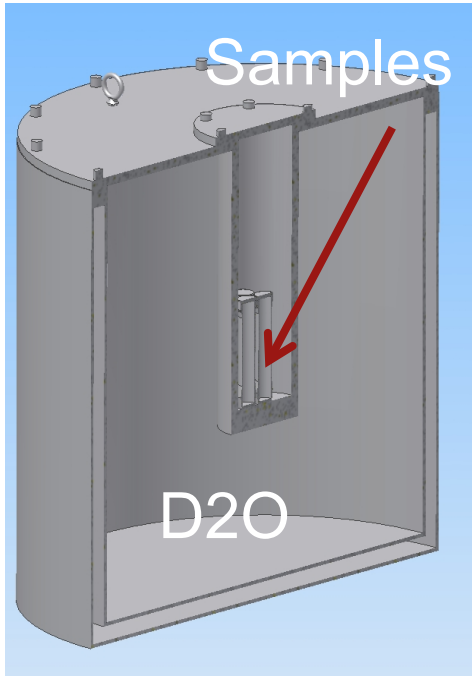
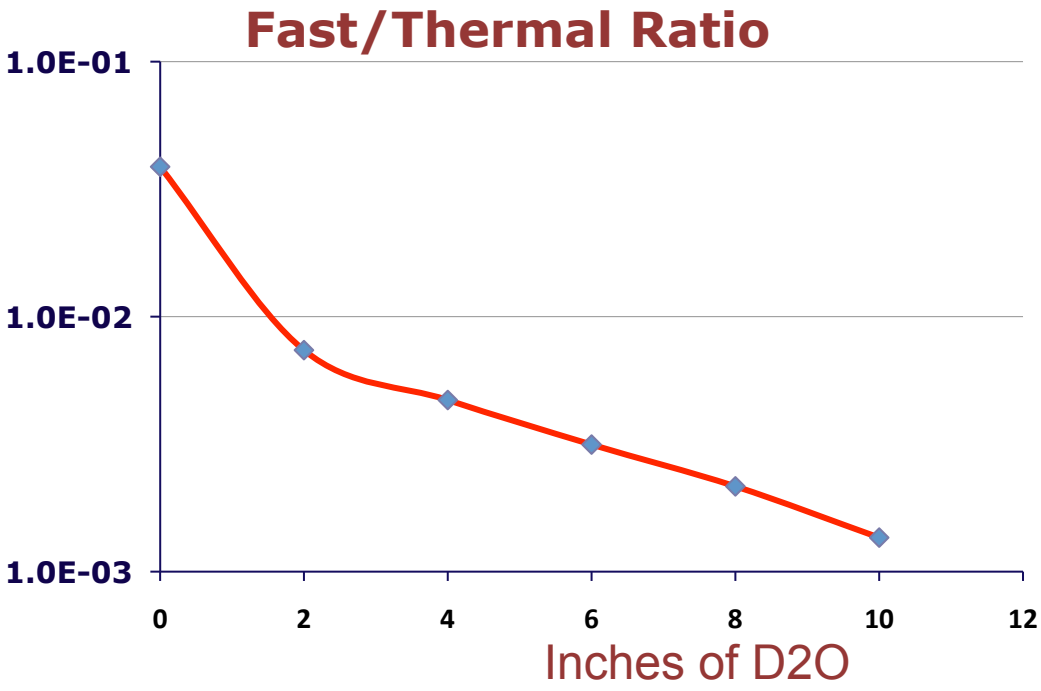
- **Largest background from fast neutron (n,p) activation**
- **Moderate fast neutron flux to enhance signal/ noise**

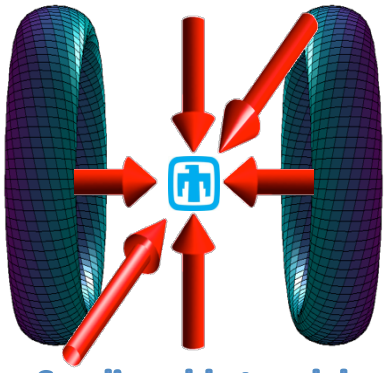
Heavy Water Capsule





Atom trapping trace analysis

Kevin Strecker and Lorraine Sadler
Sandia National Laboratories: *Livermore Campus*


Sandia cold atom lab

ATTA utilizes state-of-art laser cooling and atom trapping techniques to directly measure and quantify trace gasses.

The detection sensitivity and precision can exceed PPT levels through sample preparation . A single atom can be interrogated and measured over 10^9 times.

Observables are photons. No radiological counting. No background shielding. Measurement independent of the lifetime of the isotope.

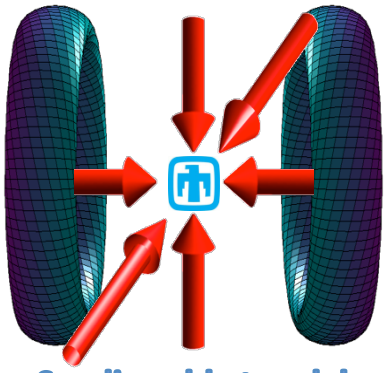
Resonant nature of the process can distinguish between isotopes and even ratio isotopes.

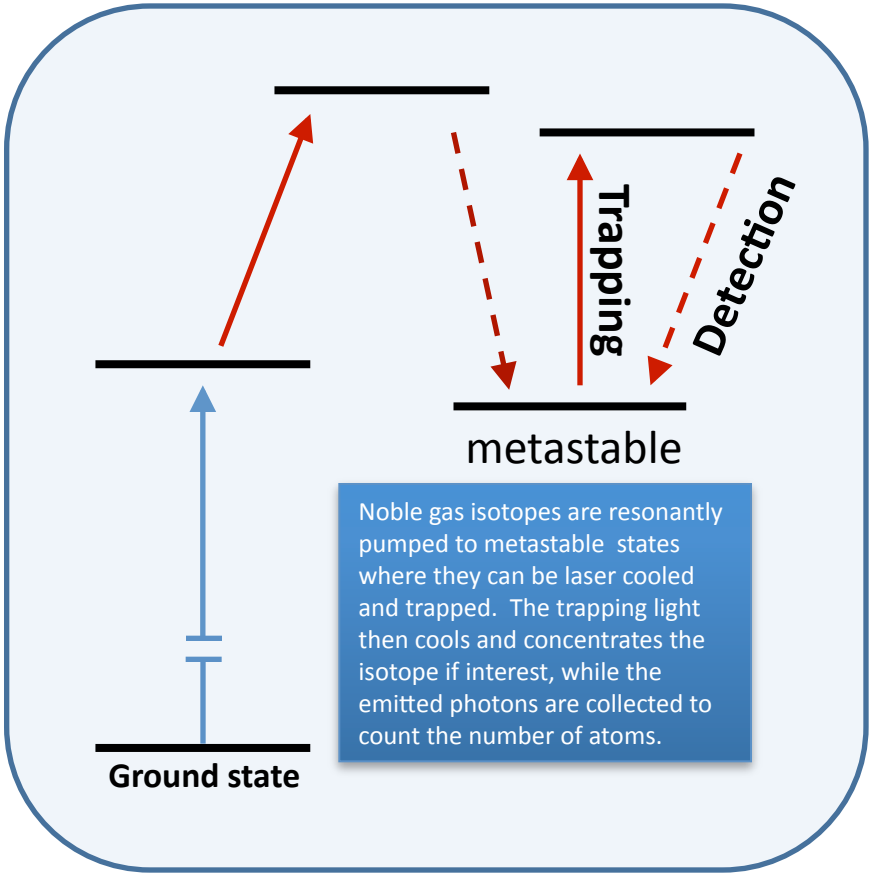
National Nuclear Security Administration

Sandia National Laboratories

Atom trapping trace analysis

Noble Gases





Noble gases are of particular interest for trace analysis. They have application in dating, environmental monitoring, and nuclear treaty verification

Trace amounts of unstable noble gas isotopes are direct byproducts of nuclear fisson. Precision measurements on isotopic ratios can monitor operational conditions of the plant and fuel rod conditions.

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Summary

An effort in NAA has been launched, funded by NA-22.

A measurement of K in Ti shows improvement possible over direct gamma-ray counting.

Measurements of U/Th more challenging. Heavy water module under development.

A survey of plastics underway.

We welcome samples (mg instead of kg).

Summer school ~late June/early July. Will cover a wide range of topics including NAA, reactor operations, reactor core simulation/monitoring, instrumentation, ATTA, neutron imaging etc. Students/postdocs welcome.