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Characterization of Novel Calorimeters in the Annular Core Research Reactor

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* Presenter

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Objectives

To investigate the responses of a set of elemental calorimeter materials including Si, Zr, Sn, Ta, W, and Bi to pulsed irradiation inside the central cavity of ACRR.

Of particular interest is the measured heating component due to secondary radiation produced within the calorimeters themselves, since this would be highly localized and, consequently, could impact test environment characterization efforts.

Specific goals are to:

- Examine differences in response behavior among the various materials, including that portion attributable to neutron capture reactions within the calorimeters
- Assess the fidelity of an MCNP model in replicating the observed responses
- Survey the apportionment and origin of significant radiative dose contributions

ACRR Description

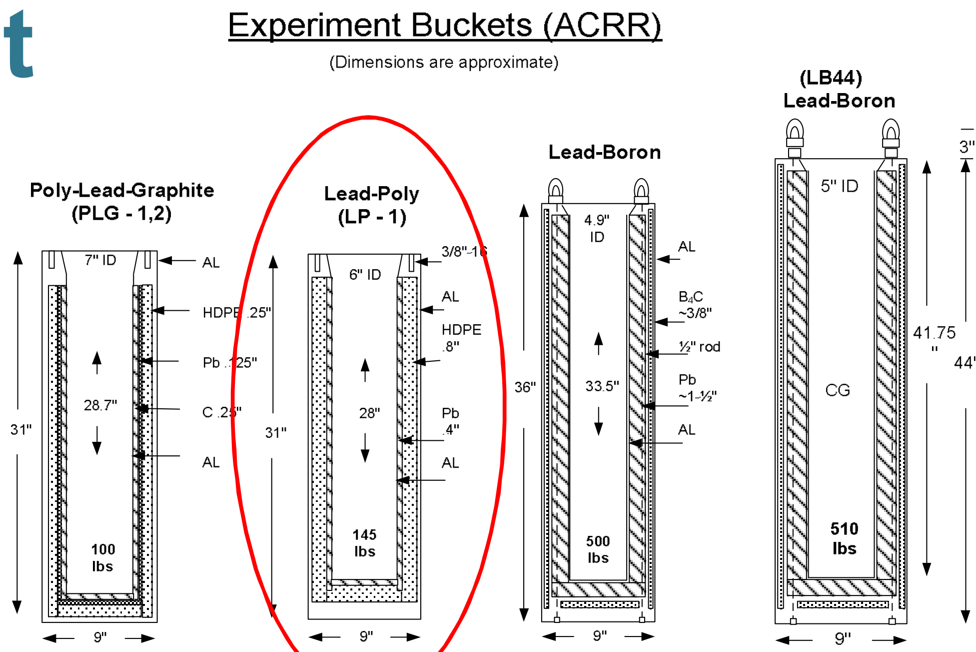
ACRR w/ FREC-II

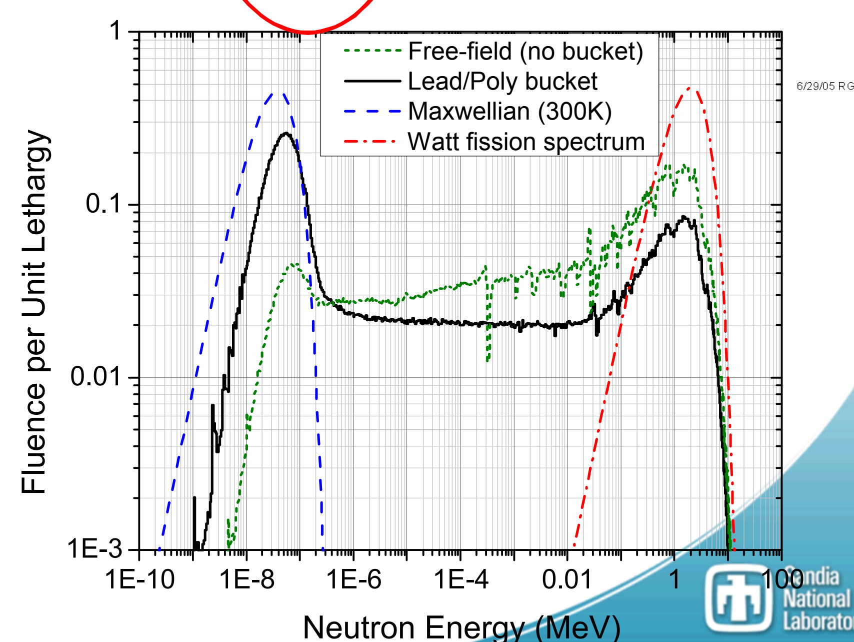
- 236 UO_2-BeO fueled elements (1.5 in dia. x 20 in) (3.8 cm dia. x 51 cm) – 100 g U-235 per element – 35% enr.
- Operating Power level
  4 MW_{th} Steady State Mode
  250 MJ Pulse Mode (6 ms FWHM)
  300 MJ Transient Mode (Programmable)
- Dry cavity 9 in (23 cm) diameter
  Extends full length of pool through core
  Neutron Flux 4E13 n/cm^2-s at 2 MW
  56% > 10 keV, 45% > 100 keV
- Epithermal Spectrum
  Flux in cavity can be tailored for desired energy spectrum
  Poly, B4C
- Open-pool type reactor
  Fuel elements cooled by natural convection
  Pool cooled by HX and cooling tower
- FREC-II uses previous ACPR fuel
  TRIGA type (UZrH) – 20 in (51 cm) dia. dry cavity
- Fuel burnup is minimal
  Reactor used for short duration power runs, pulses, and transients

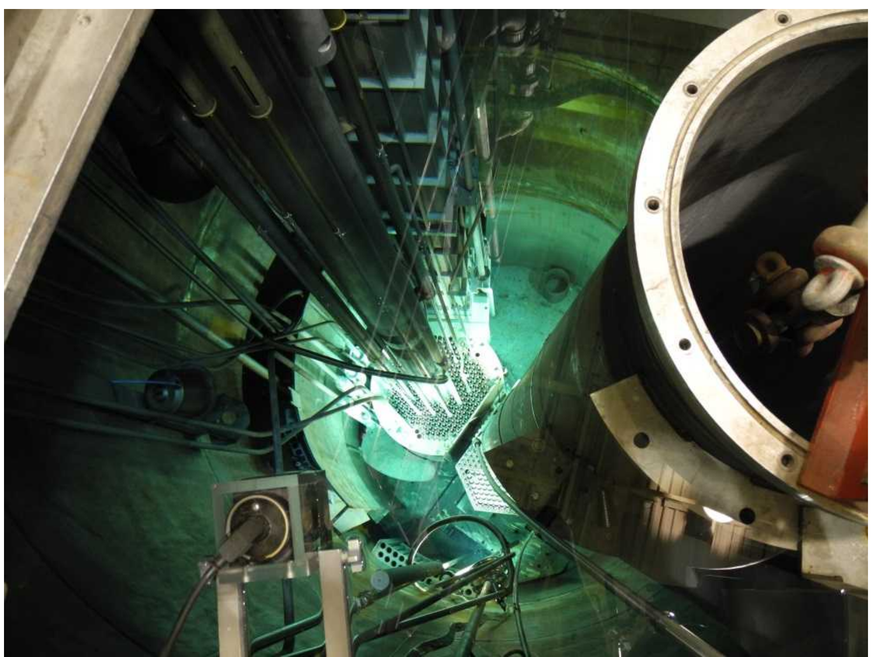
ACRR environment

Four spectrum-modifying buckets are in common use at ACRR. The analysis herein shall focus on the lead-poly bucket (highly moderating) and the free-field cavity.

For reference, the poly-lead-graphite bucket would be intermediate between the above two environments, and the lead-boron bucket would feature fewer gammas and a much harder neutron spectrum.







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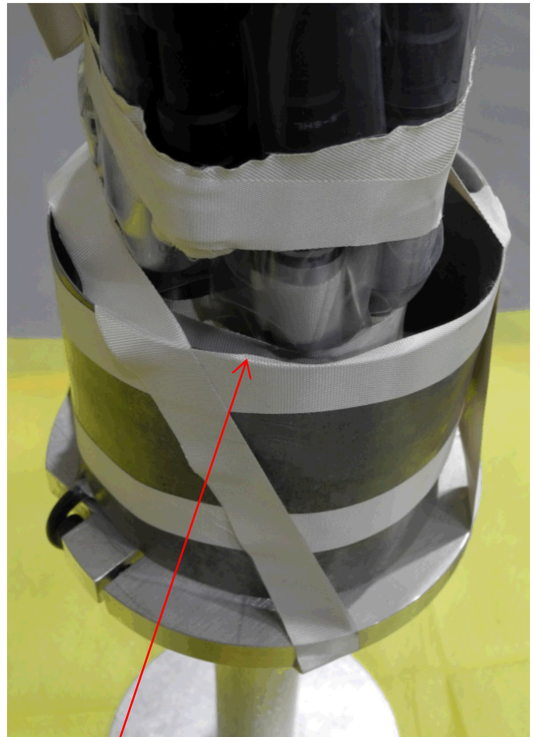
Experimental Setup

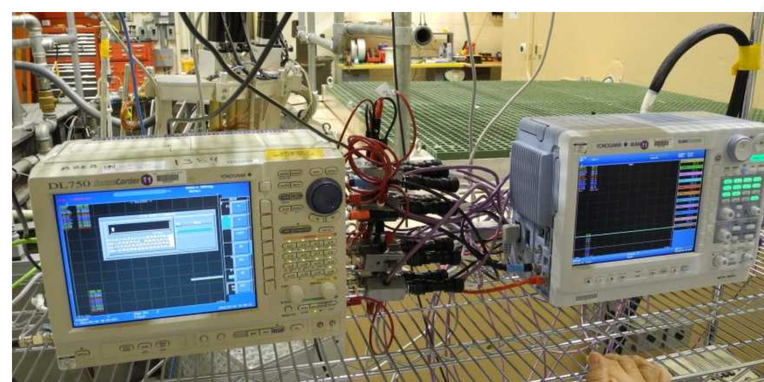
Aluminum stand

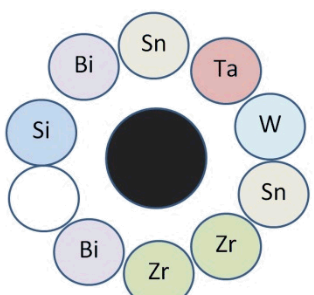
Bare calorimeter array



Cd-covered array

Bucket loading & data acquisition

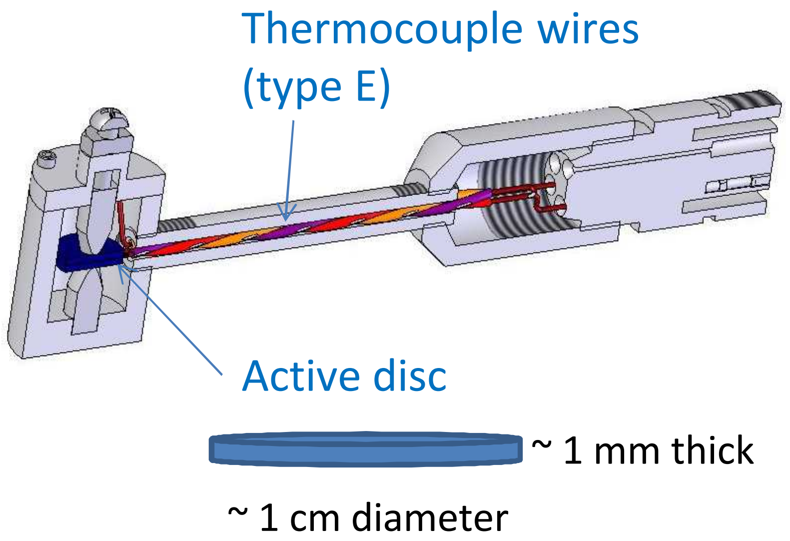


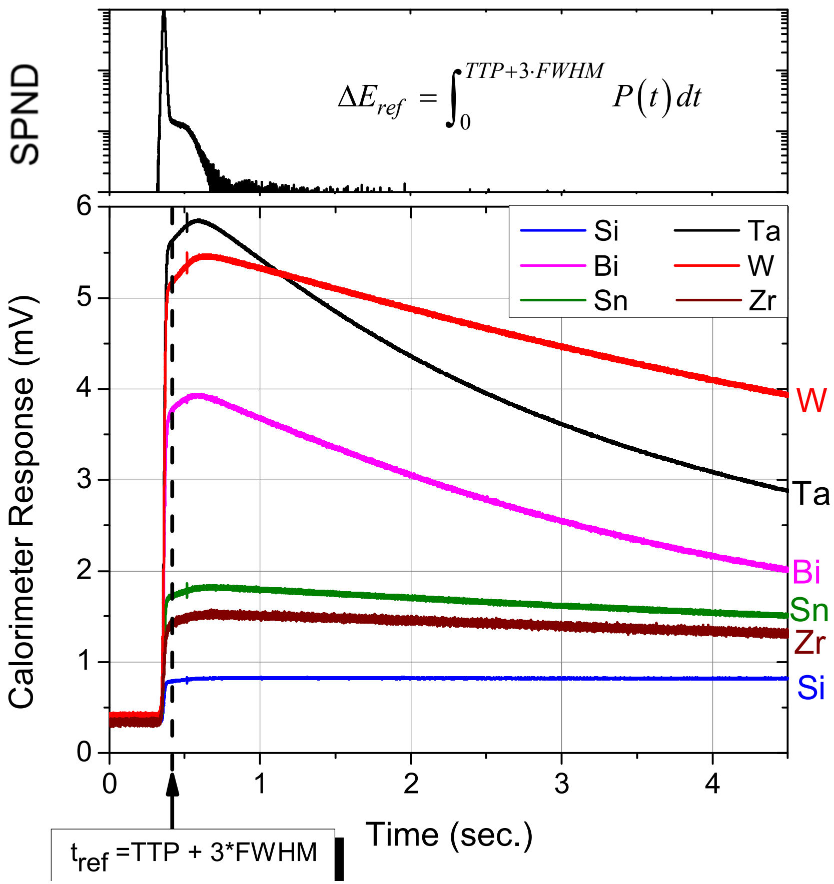


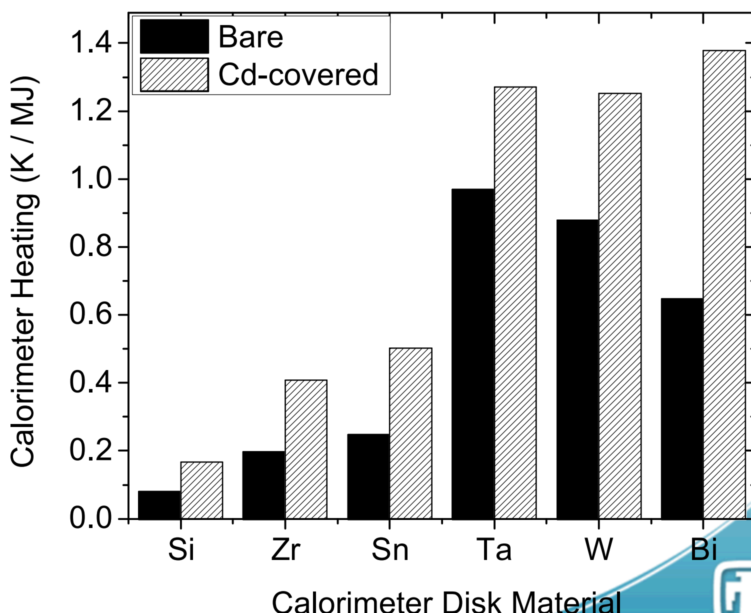
Calorimeters

Signal (in mV) converted to heating (in K) by means of tabulated conversion factors for type E thermocouple

Conversion =~ 0.06 mV/K near room temperature



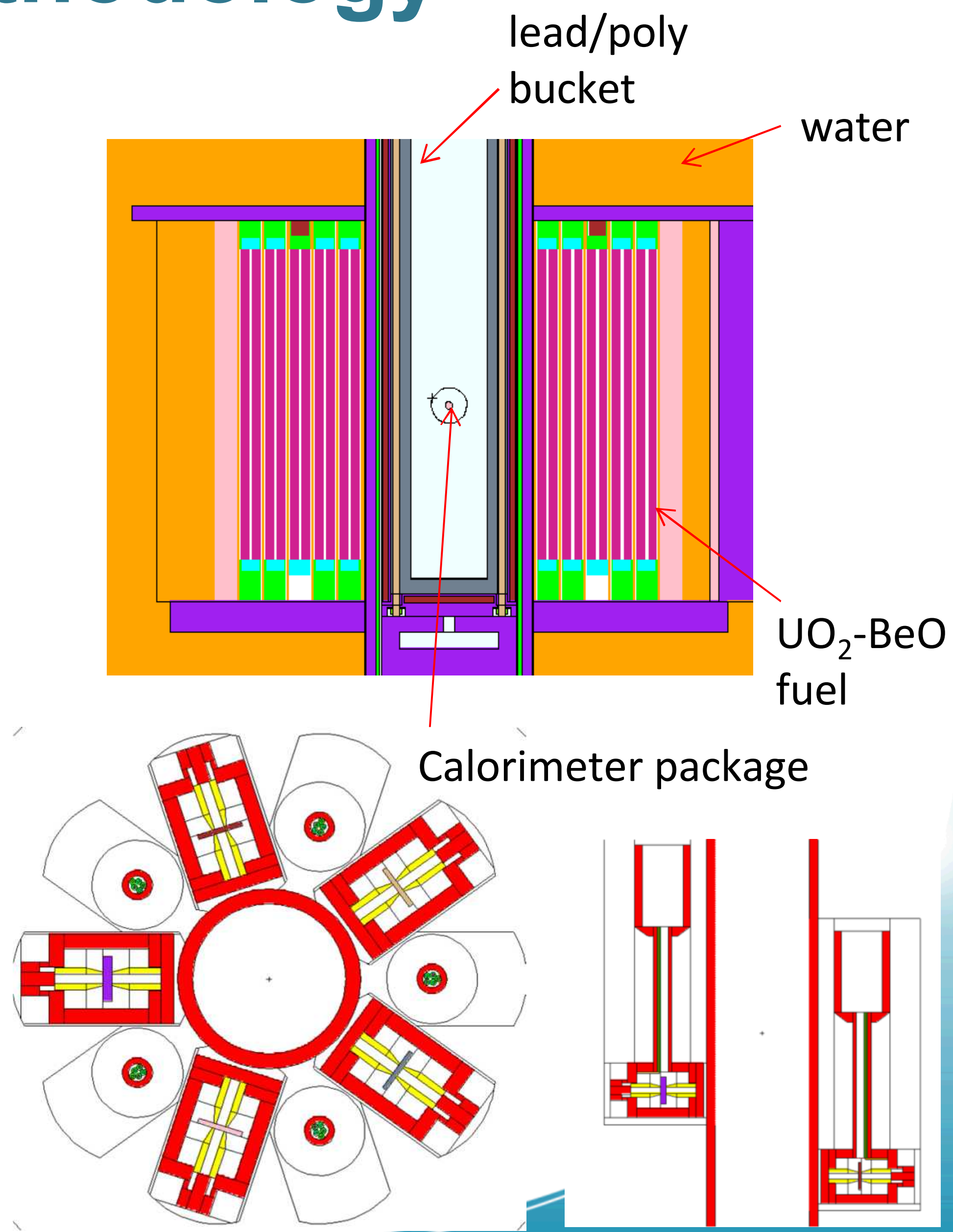




Computational Methodology

- Reactor and experimental package modeled in MCNP
- ENDF/B-VII cross sections used except where gamma production data was lacking (e.g. cadmium).
- Temperature set to 300 K for cross section evaluation purposes
- Heating in the active discs was computed from energy deposition tallies in conjunction with appropriate heat capacities.
- Result was normalized to the pulse energy (in MJ) via:

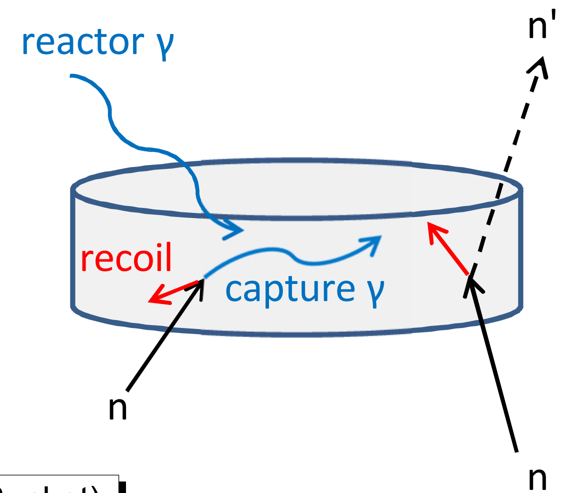
$$\frac{1 \ rad}{source-n} \cdot \left(\frac{2.4 \ source-n}{fission}\right)\left(\frac{fission}{180 \ MeV}\right)\left(\frac{1 \ MeV}{1.6 \times 10^{-19} \ MJ}\right) = 8.33x10^{16} \ \frac{rad}{MJ}$$



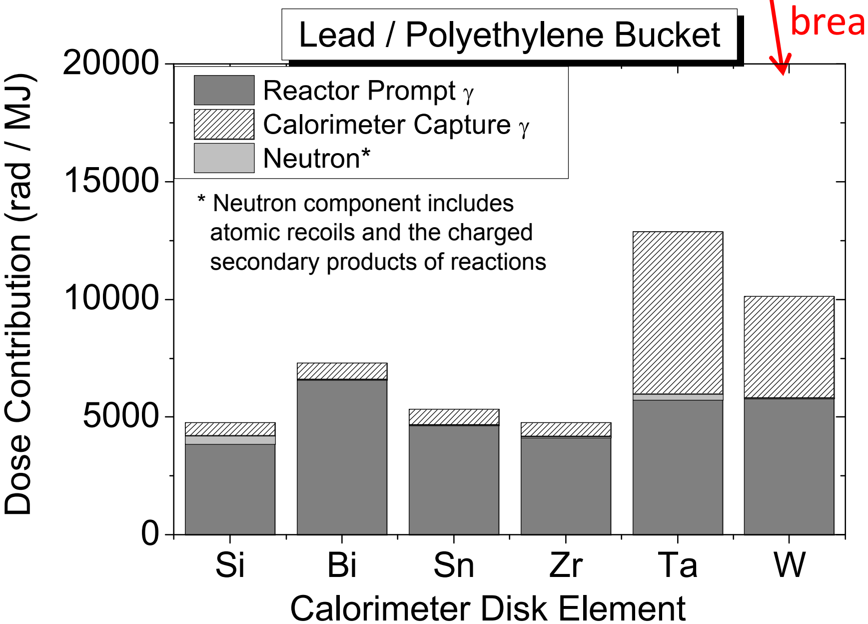
Calculated vs. Experimental Heating

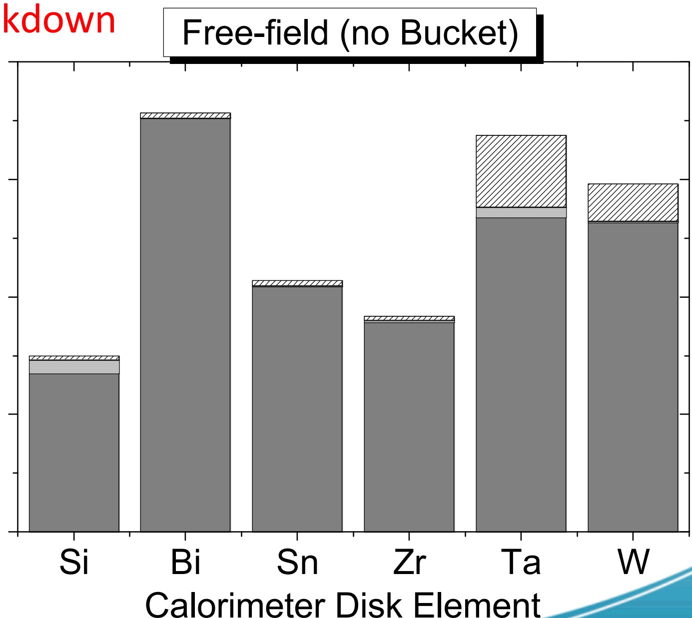
Dose was evaluated using *f8 pulse height tally + electron transport. The kerma was found to overestimate dose substantially due the assumption of charged particle equilibrium.

Disk type	EXPT Heating (K/MJ)			CALC. Heating (K/MJ)		
	Bare	Cd-wrapped	Ratio	Bare	Cd-wrapped	Ratio
Si	0.081	0.167	2.1	0.075	0.158	2.1
Zr	0.198	0.408	2.1	0.185	0.407	2.2
Sn	0.248	0.501	2.0	0.228	0.510	2.2
Ta	0.970	1.270	1.3	1.002	1.244	1.2
W	0.878	1.252	1.4	0.806	1.222	1.5
Bi	0.648	1.378	2.1	0.654	1.402	2.1



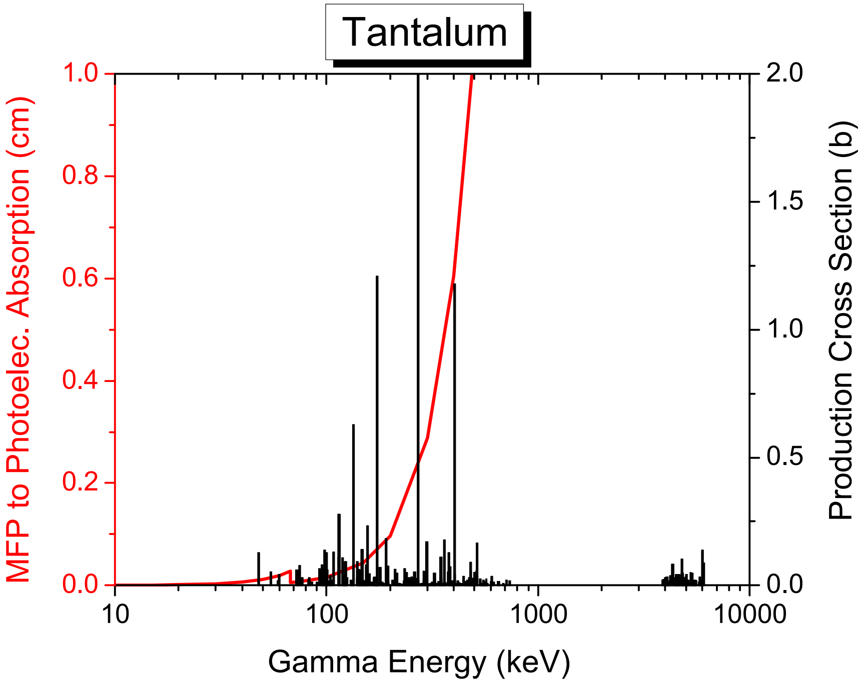
Component breakdown



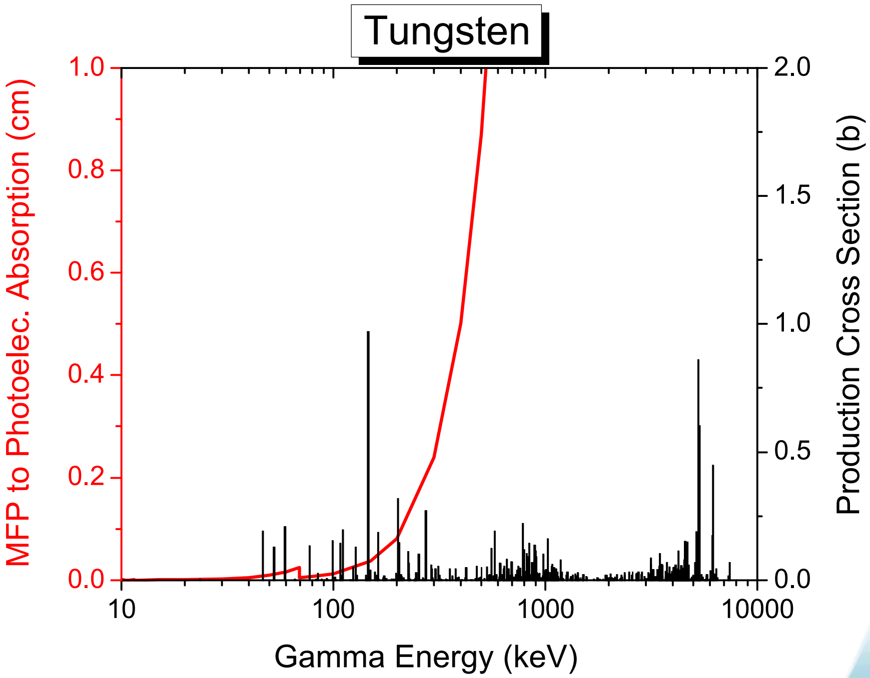


Prompt Capture γ – Range in Disc

A significant dose contribution from disc-generated prompt gammas is plausible in tantalum and tungsten given the prompt γ energy spectrum and range.



67% of gammas produced below 300 keV



26% of gammas produced below 300 keV

Photon cross sections from: NIST XCOM photon database

Prompt gamma data from: R.B. Firestone at al., *Database of Prompt Gamma Rays from Slow Neutron Capture for Elemental Analysis*, IAEA STI/PUB/1263, 251 pp (2007).

Non-disc Contributions

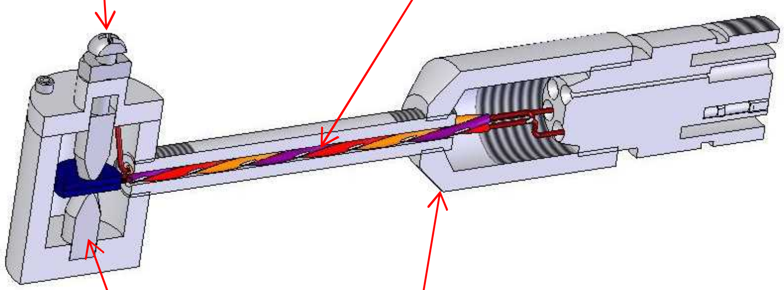
Percent contribution to total response in bismuth:

Steel screw

0.3% lead/poly
< 0.1% free-field

Thermocouple wires

1.8% lead/poly
0.2% free-field



Alumina spacers + Aluminum body

4.3% lead/poly
0.7% free-field

Stand

Not considered (introduces nearly identical perturbation to all test articles)

Conclusions

- Prompt capture gammas generated within the active disc elements can be a major contributor to the measured response.
    - **Pb-poly bucket**: up to 50% of total
    - **Free-field**: up to 20% of total

  with (n,γ) reactions in auxiliary, non-disc components adding an additional several percent in the Pb-poly bucket.

- Simulated heating factors (K/MJ) agree with measured values to within 10% when the dose / kerma offset is taken into account. In particular, comparison of the Cd-wrapped vs. bare response indicates that the model correctly captures secondary radiation effects.

- The results suggest that care must be taken to account for the prompt (n,γ) dose when utilizing certain calorimeter types for dosimetry purposes, since the measured dose can reflect localized perturbations that would not impact other test articles.

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Future Work

- Examine response in other buckets (PLG and Pb-B) and test additional disc materials of interest -- especially gold, cadmium, and indium. The latter two elements, in fact, have already been tested successfully.

- Incorporate nickel foils and/or sulfur pellets into the dosimetry package for each pulse, so that the pulse energy reported by the reactor ops staff can be corroborated independently.

- Further investigate the validity an the isotropic, spherical source approximation in the MCNP model of the central cavity (used herein only to partition radiative dose contributions in the bare package). There is evidence that this approximation introduces an error of up to ~ 10% in the total dose.

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Questions?