Characterization of Gamma Radiation Fields at the University of Wisconsin Nuclear Reactor Lab – 1 MW TRIGA

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Research goals

- ✓ Photon exposure in BP 2 at 1 MW (experimentally). Reason: quantify the gamma induced radiolysis in our supercritical water loop.
- ✓ Normalize MCNP5 model to experimental measurements. Develop flexible tool for determining gamma exposure.
- ✓ Profile radiation levels from photons around UWNR at shutdown

What we actually did

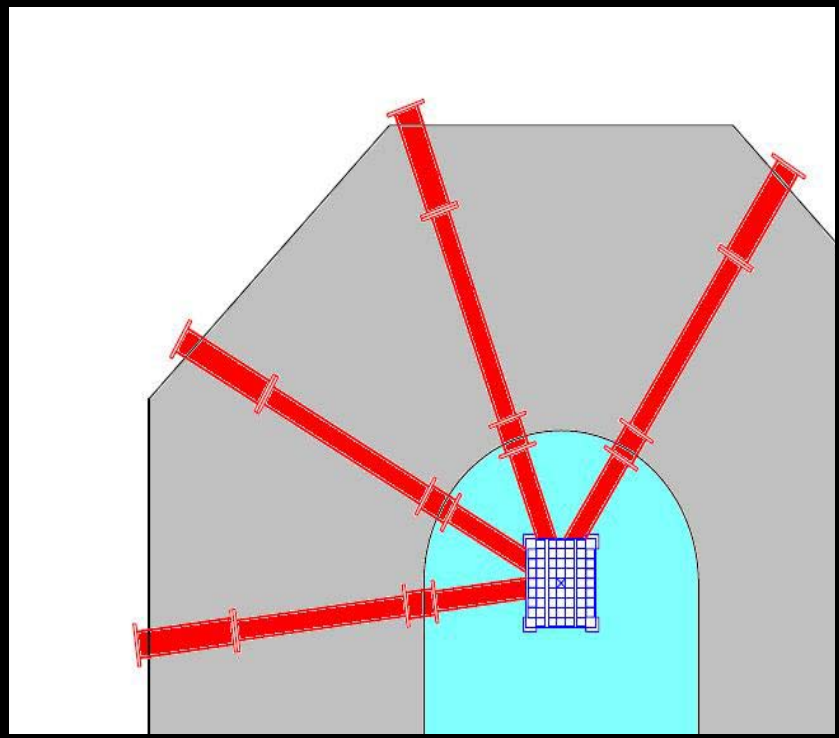
- Results
  - Photon exposure in P-Tube (just below BP2) experimentally determined with CaF:MN dosimeters.
    - 10.1 MR/hr at 1MW
    - Radiation levels scale linearly above 1 kW. Below 1kW the background is significant.
  - MCNP5 model used to simulate Rads-TLD in P-Tube. Model normalized to experimental results. (Factor of 1.3)
  - Profiled photon exposure (reactor shutdown) with GM detector. 20 minutes to 63 days after shutdown.
  - BP Input File: Replaced core with detailed source. Used to design shielding for Spring 2006 radiography experiments in BP1.

Outline

- Introduction to facility
- Shutdown measurements
- Power measurements with CaF:Mn dosimeter
  - Results
  - Accounting for neutrons
- Benchmark MCNP5 model
  - Calibration ratio of 1.3
- Radiography shielding design
  - Replace Core with Detailed Source
- Conclusions
- Acknowledgements

Intro: irradiation facilities

- Beam Ports
  - Long cylindrical tube extending from grid box to outside the biological shield
  - Size
    - 13 Feet Long
    - Inner section: 6 in diameter
    - Outer section: 8 in diameter
  - Irradiation Time
    - Extended length irradiations



UWNR Beam Ports

Intro: irradiation facilities

- Pneumatic Tube
  - Fast response pressurized tube system
  - Small capsule
    - Diameter: ~1.25”
    - Length: ~5.5”
  - Irradiation time:
    - Few seconds to several minutes.

“Rabbit”

Shutdown measurements: equipment

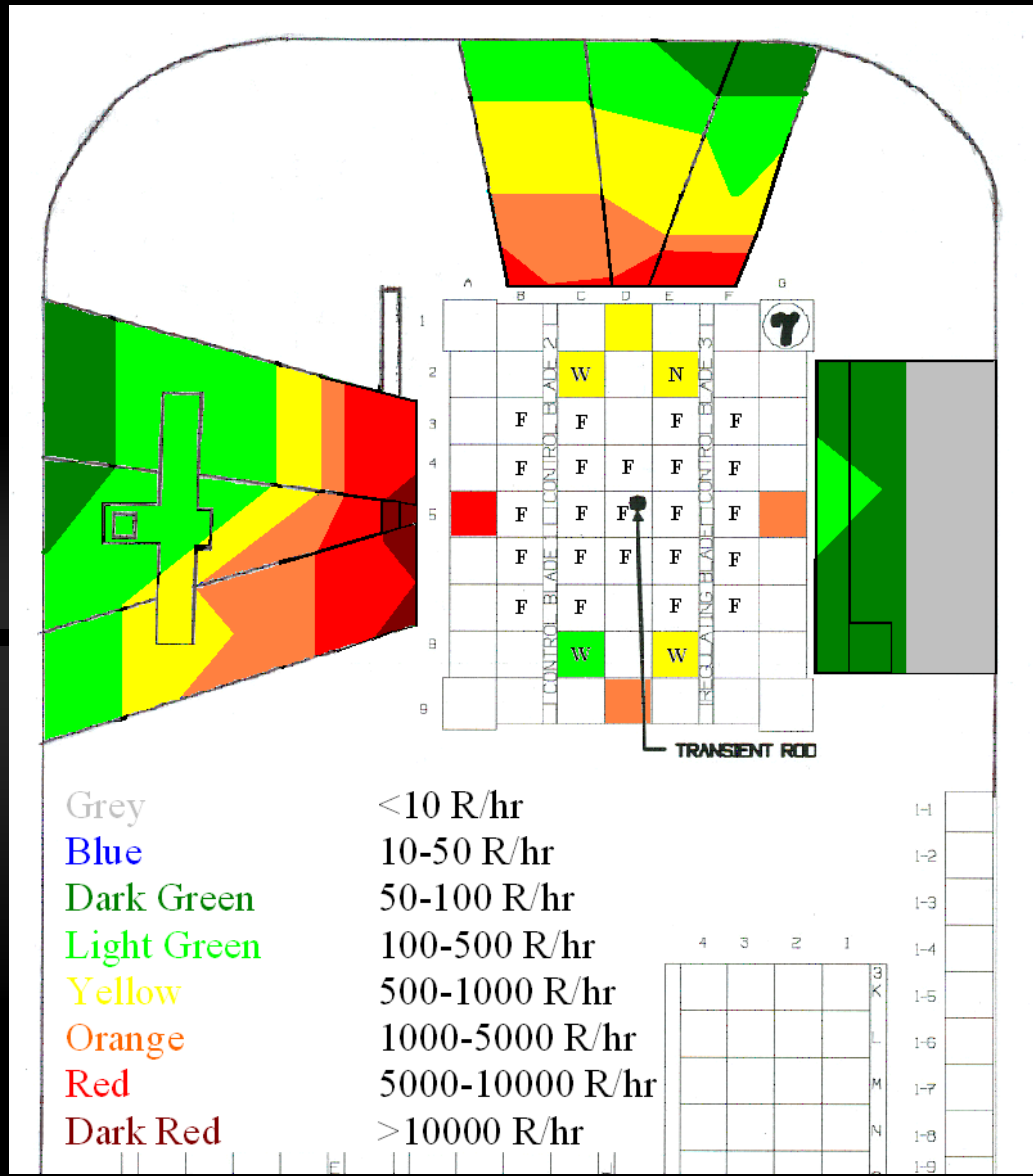
- Thermo Electron Underwater Ion Chamber
  - (UWDS FHZ 312, SN#: 42540/44)
- Depth of 65 Feet
- Exposure rates up to 10,000 R/hr

Underwater Detector w/ Readout Device

Shutdown measurements

- ✓ Pool locations
  - ✓ 50 Locations
    - ✓ BP, Grid Box, Thermal Column
  - ✓ This figure: 16 hours after reactor shutdown

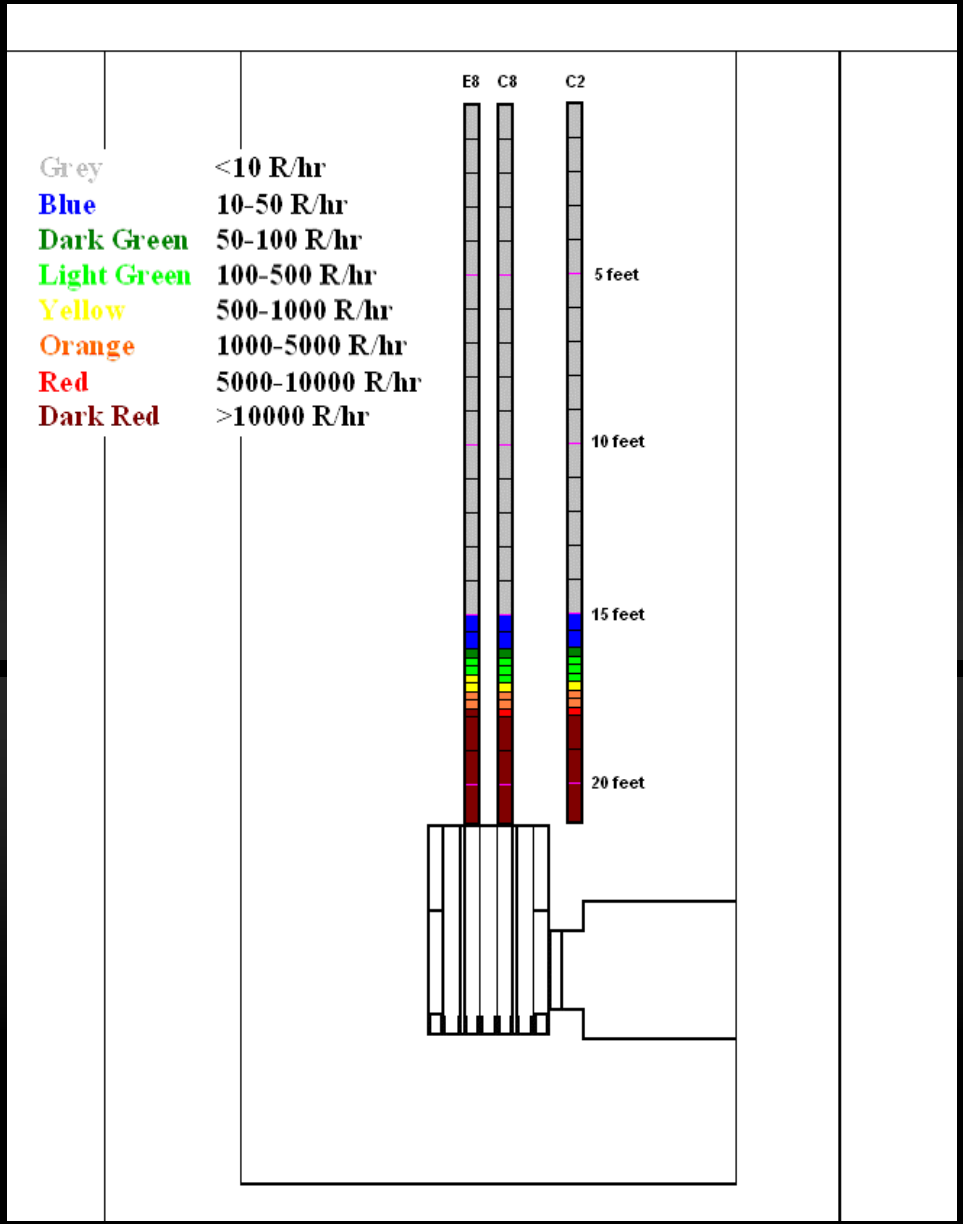
* Measurements taken 30 min after shutdown to 63 days after shutdown



Shutdown measurements

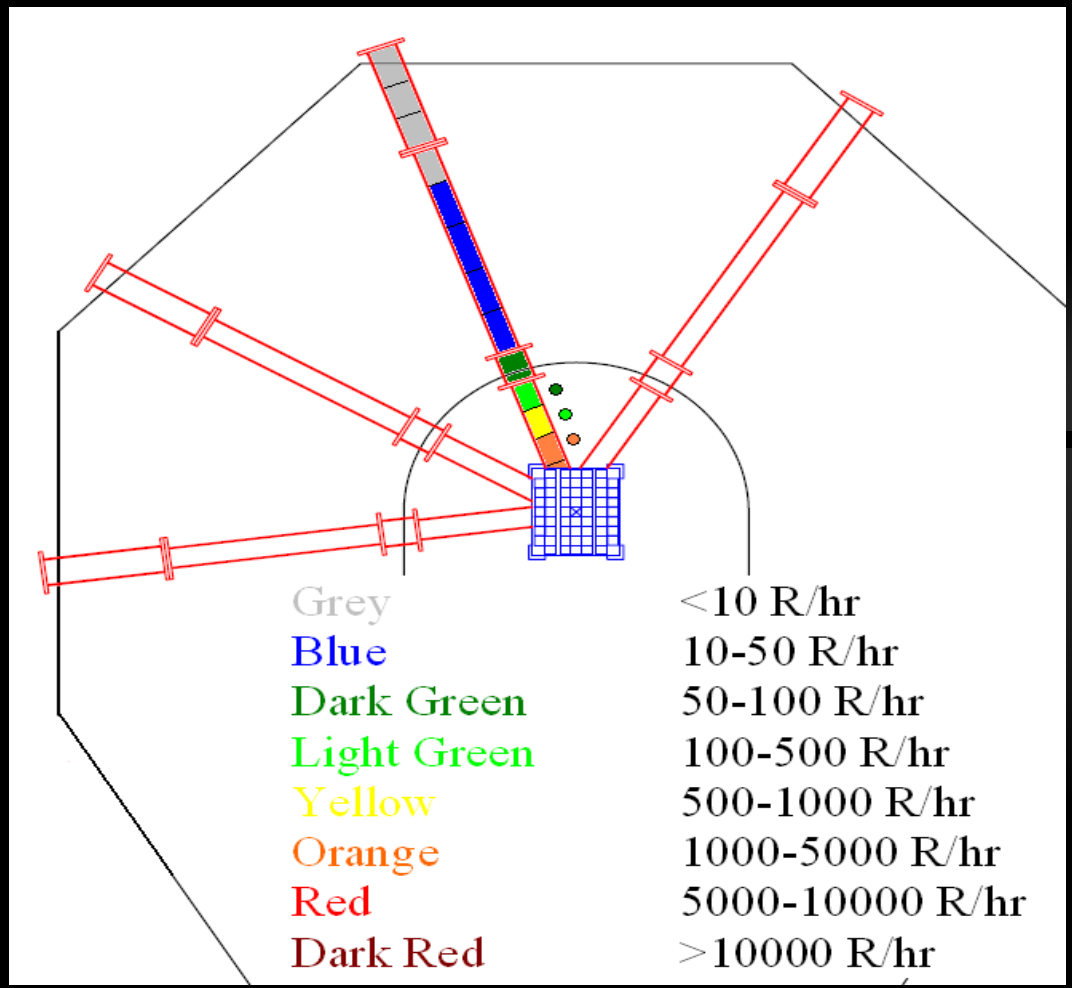
- Whale tubes
  - C2, C8, E8
  - This figure: 16 hours after reactor shutdown

* Measurements taken 30 min after shutdown to 63 days after shutdown



Shutdown measurements

- Beam port 3
  - This figure: 6 days (typical) after reactor shutdown
  - Matching pool readings



* Measurements taken 30 min after shutdown to 63 days after shutdown

CaF:Mn TLDs
Exposure measurements with reactor operating

- TLD Package
  - Consist of four CaF_2:Mn TLD crystals (0.3 x 0.3 x 0.09 cm, density of 3.1 g/cm$^{3)}$
  - Housed in Al6061 aluminum alloy casing (0.8x0.8x0.55 cm, density of 2.71 g/cm3)

CaF2:Mn TLD Package

- Saturation limit of 500,000 R. Ideal conditions of < 10,000 R
  - Forced use of P Tube
  - Dictated exposure times (4-240 seconds) and power levels (1.5kW - 100kW)

CaF:Mn TLDs
Results

Sample #	Power (kW)	Time (s)	Dose (kR)	kR/hr
1	1.5	180	1.80	36.0
2	1.5	210	2.08	35.7
3	1.5	240	2.25	33.8
4	4	60	1.09	65.4
5	4	75	1.34	64.3
6	4	90	1.66	66.4
7	10	25	1.00	144
8	10	32	1.23	138
9	10	40	1.57	141
10	30	8	0.91	410
11	30	10	1.19	428
12	30	12	1.47	441
13	100	4	1.55	1395
14	100	6	2.14	1284
15	100	8	3.05	1372

CaF:Mn TLDs
Neutron response

- Neutron Contribution (Ni foil as neutron monitor)
  - Effective Neutron Kerma
  - Secondary gammas
  - Activation of the TLD
  - Activation of the Al casing
  - Charged particles produced in the Al casing

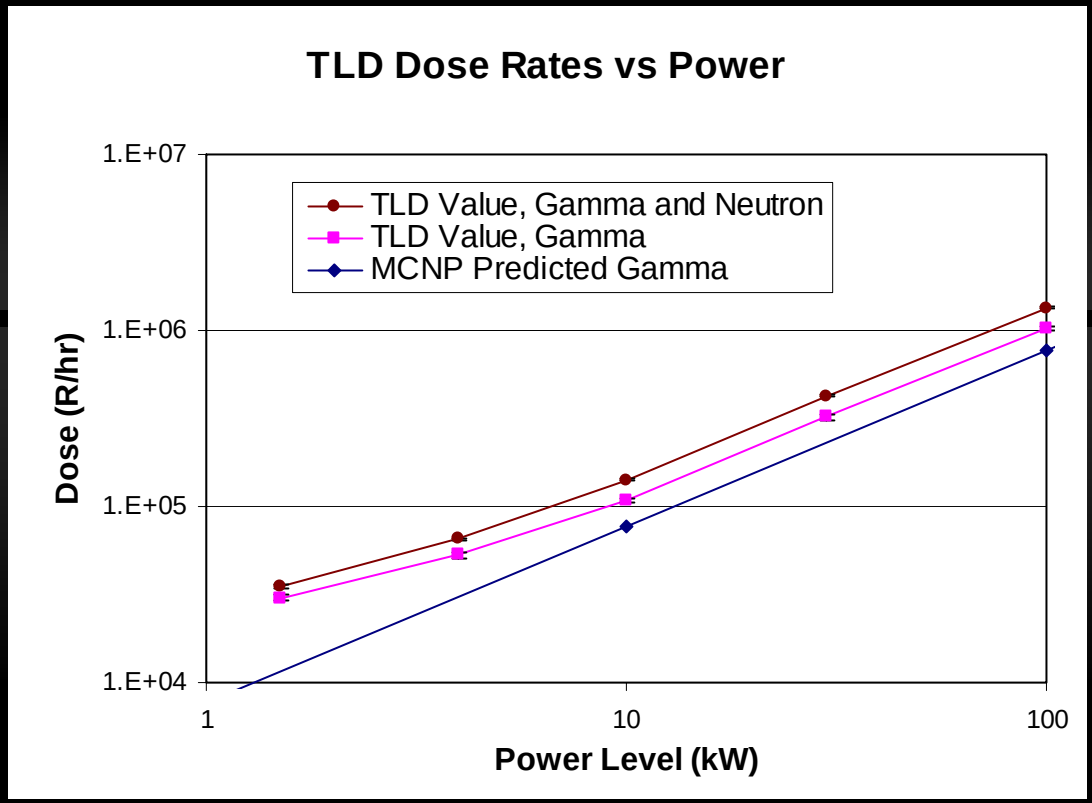
CaF:Mn TLDs
Neutron Response

Power (kW)	Combined Dose Rate (R/hr)	Neutron Only Dose Rate (R/hr)	Gamma Only Dose Rate (R/hr)
1.5	3.51E+04	4.90E3	**3.02E+04**
4	6.53E+04	1.25E4	**5.28E+04**
10	1.41E+05	3.29E4	**1.09E+05**
30	4.26E+05	1.06E5	**3.21E+05**
100	1.35E+06	3.29E5	**1.02E+06**

UWNR Dose Rates at Varying Power Levels

- ✓TLD Full Power (1 MW) Prediction: 10.1 MR/h

CaF:Mn TLDs Results



Gamma only, Combined, and MCNP Predicted Dose Rates of TLDs

CaF:Mn TLDs Results

Results show a linear relationship (*R2*=0.9999) between gamma radiation and the power level within the reactor. This linear fit to the dose rate results gives:

$$\dot{D}\left[kR/h\right] = 10.08\left[\frac{kR/h}{kW}\right] \cdot P\left[kW\right] + 13.2\left[kR/h\right]$$

where is the dose rate in *kR/h* and *P* is the reactor power level in *kW*. This suggests a shutdown dose rate, due to fission product decay, of 13.2 kR/h, and a full power (1 MW) dose rate of 10.1 MR/h.

UWNR Dose Rates at Varying Power Levels

✓TLD Full Power (1 MW) Prediction: 10.1 MR/h

Benchmark MCNP5 simulation

- TLD was created in MCNP5 UWNR Model
  - Identical geometry, materials, placement
  - Hot temperature cross sections

Tally	Dose [Rad(TLD)/hr]	Error (%)
CaF_2:Mn TLD	7.76E+06	3.30

Benchmark MCNP5 Simulation Calibration Ratio

- ✓ TLD Full Power Prediction: 10.1 MR/h
- ✓ MCNP5 Full Power Prediction: 7.76 MR/h
- ✓ Offset Ratio (TLD/MCNP5): 1.301

Beam Port Input File

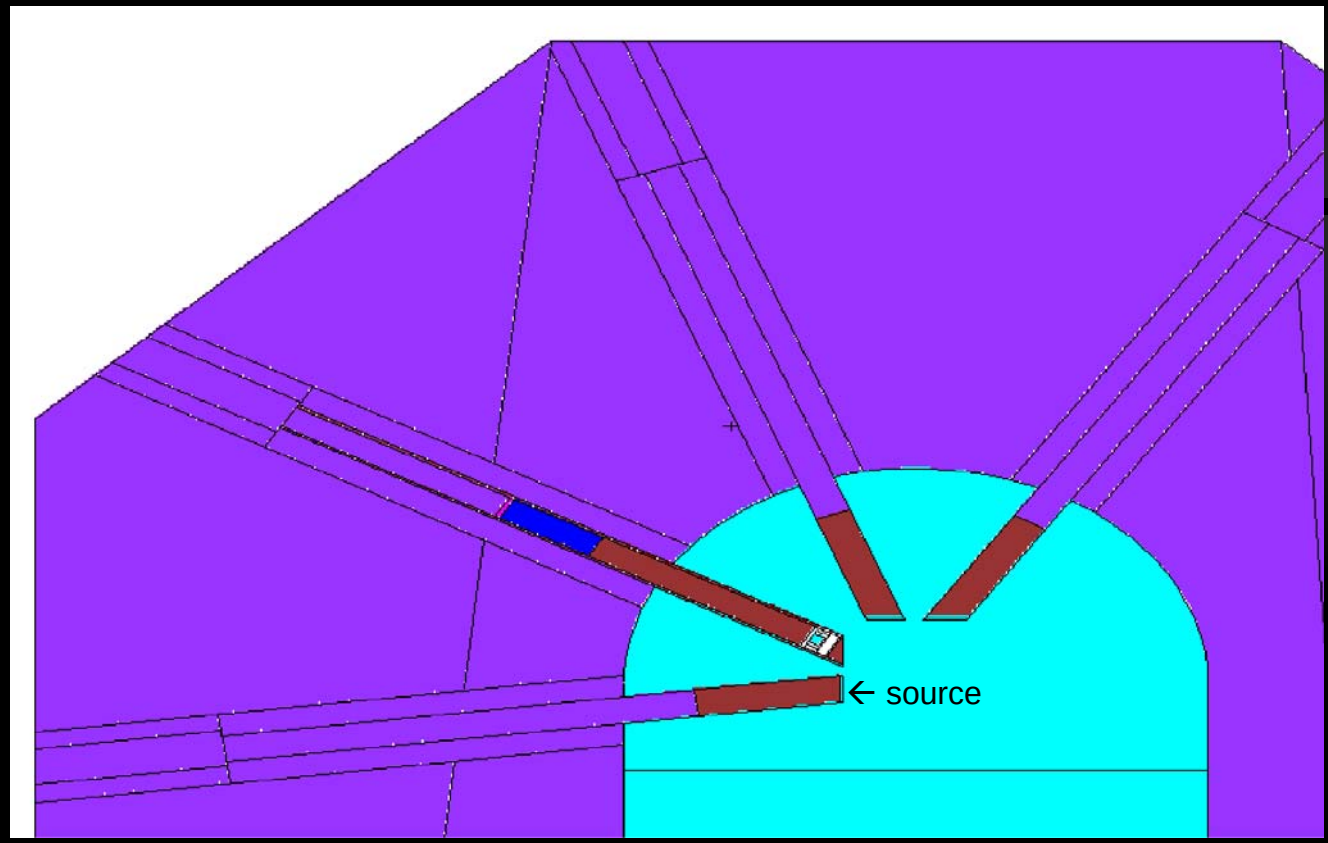
Reason

- MCNP5 UWNR Model
  - Simulates core w/ emphasis on criticality
  - Good for determining dose rates very close to the core
  - Bad for determining dose rates far from the core
    - Dose Rate (<3% Error) outside of Biological Shield takes many years

Beam Port Input File

Geometry

- ✓ UWNR Model w/out Core



MCNP5 Beam Port Model

Beam Port Input File

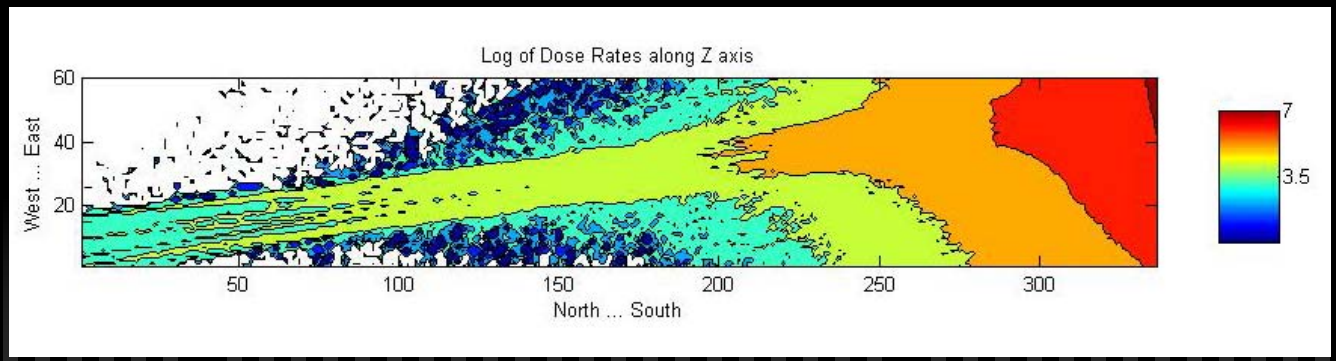
Source

- Source needed to mimic core
  - Simple Source
    - Quick and efficient first order approximation
    - Average fission information
  - Detailed Source
    - In-depth precise analysis
    - UWNR specific photon information

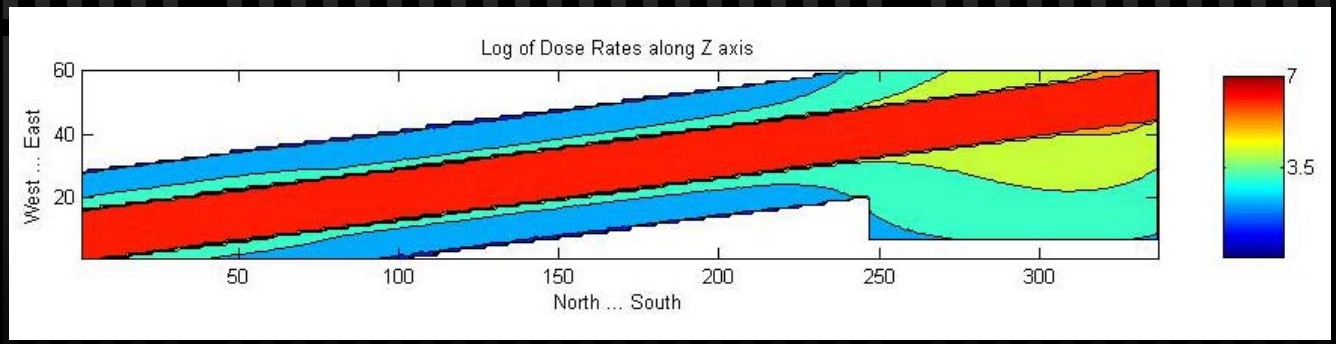
Beam Port Input File

Validation of Results

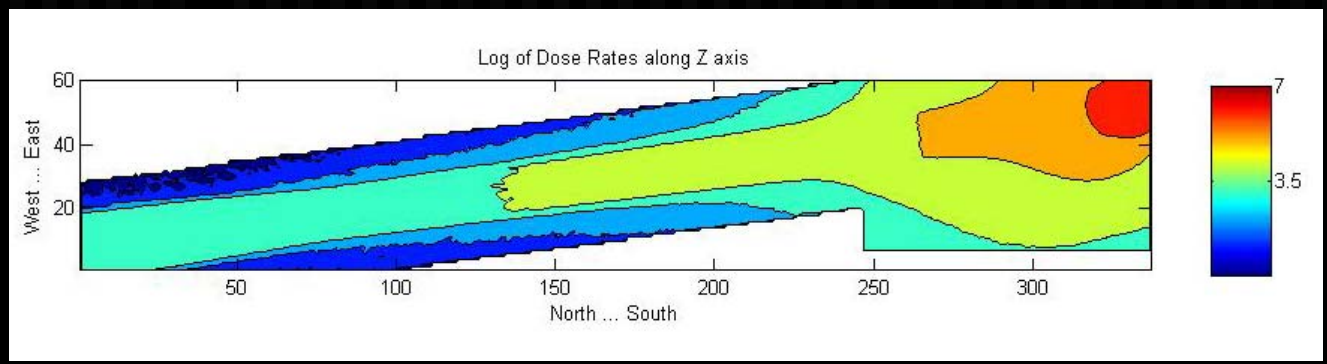
Full Core



Simple Source



Detailed Source



Beam Port Input File

Calibration Ratio

- Simple Source
  - Not Valid: Incorrect Photon Behavior
- Detailed Source partially valid
  - Correct photon behavior
  - Nearly accurate dose rate magnitude
    - Normalized to MCNP5 model / CaF dosimeters

Conclusions

- Accurately mapped shutdown radiation with GM detector (good agreement with CaF dosimeter)
  - 20mins – 63 days after last reactor operation
- Determined dose rates in P Tube for operating conditions
  - Dose Rates (1.5 kW – 100kW): 30.2 kR/hr to 1020 kR/hr
  - Predicted Dose Rates (1 MW): 10.1 MR/hr
- Normalized MCNP5 model to experimental results for gamma exposure in P-Tube.
  - Calibration Factor of 1.3
- Developed computational model of photon radiation external to the beam ports at full power. Used to design shielding for Spring 2006 radiography experiment.
  - Corrects for replacing core with a disk source: MCNP5 to disk source conversion
  - Normalizes MCNP5 to experimentally measured dose rates (CaF)
  - 3-4 day computer time for <5% results (compared to several years with MCNP5 model)

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