PREDICTING ACTIVATION OF EXPERIMENTS INSIDE THE ANNULAR CORE RESEARCH REACTOR

Master's Thesis Defense Presentation

by Joseph Greenberg – Reactor Engineer and Operator

SAND2015-9845PE

Exceptional service in the national interest

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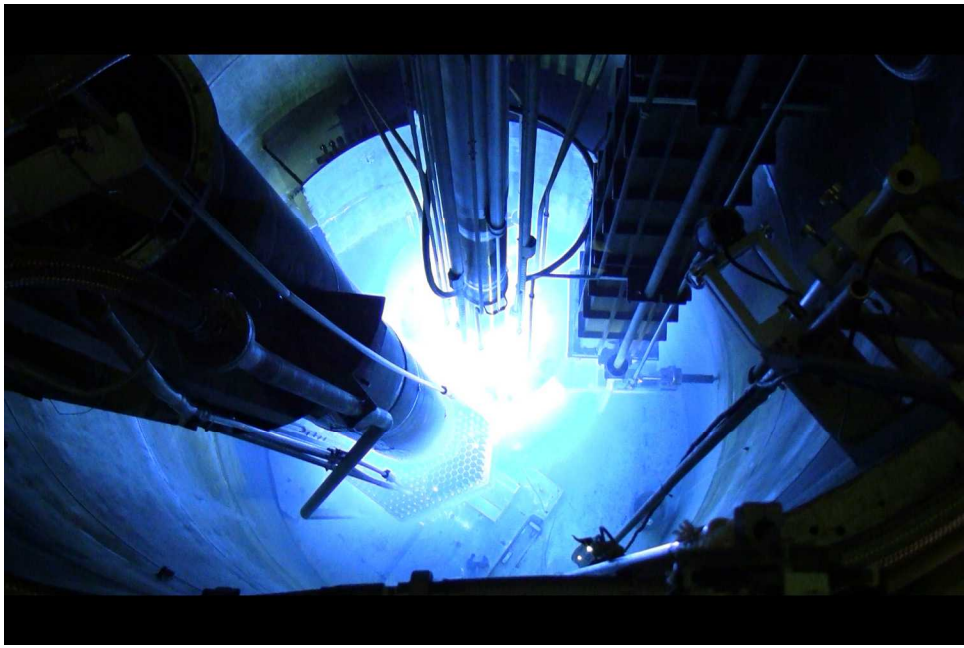

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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  - CINDER2008
  - Dose Rate Estimator for Activation and Decay
- Empirical Approach
  - Detectors
  - Methodology
  - Administrative Limitations
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- Conclusions
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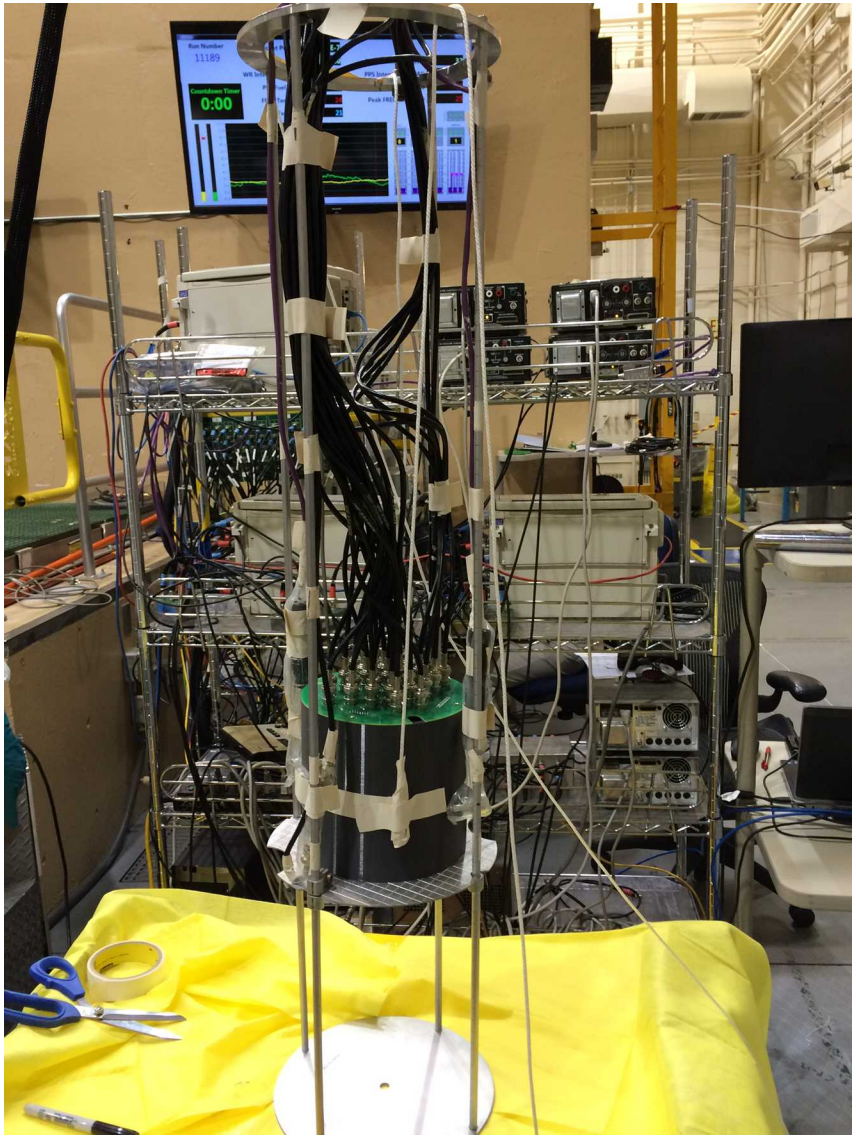

Preface

- BS in ChemE from UNM
- KAPL Shielding Engineer
  - Detector studies
  - Submarine new shield modeling
- KAPL Nuclear Plant Engineer
  - EOOW, Drill coordinator, Training instructor
- Sandia Labs Nuclear Operator and Engineer at ACRR

Objective

- Develop easy to use program that quickly aids operators and experimenters to estimate activation in the ACRR
  - Require no programming or code knowledge to execute program
  - Display dose rate results without need for opening additional files
  - Provide easy access to generated files

Motivation for Thesis

- There is currently no program that can quickly and accurately predict dose rates for ACRR.
- Staffing Concerns
  - Many new operators and experimenters who are not experienced with experiment activation
  - Many older staff retiring who posses the knowledge to determine wait times
- ALARA Considerations
  - Help prevent unexpected large dose rates
  - Prevent experimenters from exceeding administrative dose limits which can impede work later in the year

Annular Core Research Reactor

- Pulsing Mode that relies on Doppler broadening to add the negative reactivity which turns power (max ~50,000 MW)
- Steady State Mode licensed to 4 MW, currently 2.4 MW
- UO2-BeO fuel elements
- UZrH FREC-II fuel elements
- Neutron Radiography Facility

- PICTURE OF MOCK FUEL ELEMENT

- PICTURE OF NEUTRON RADIOGRAPHY FUEL IMAGE

Maximum Size Pulse

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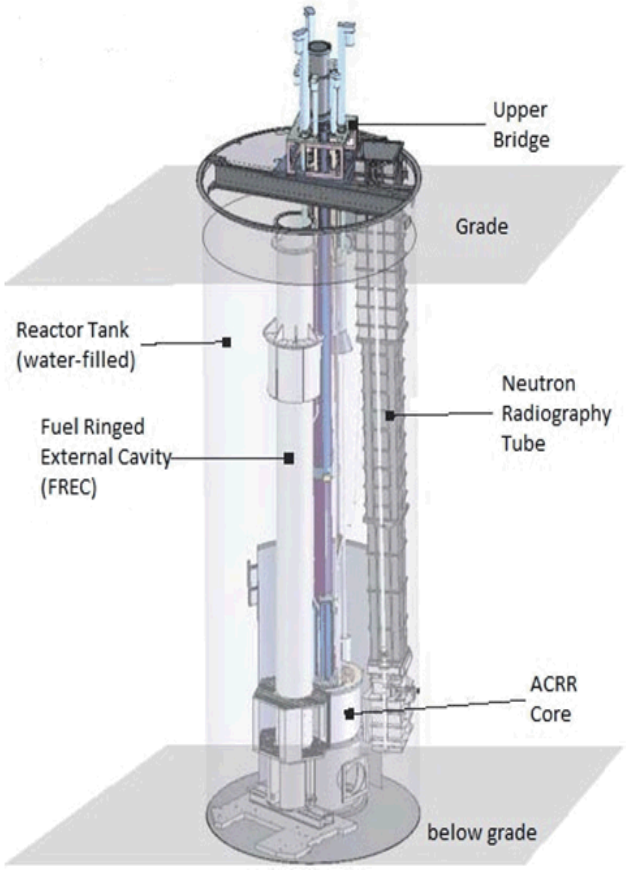
Experiment Handling

- Loaded into Central Cavity via overhead crane
- Irradiated and removed
- Handled by workers to guide to work area
- Parts removed or swapped out or taken to shielded holding cell
- Typically loaded into spectrum modifying bucket or on aluminum stand

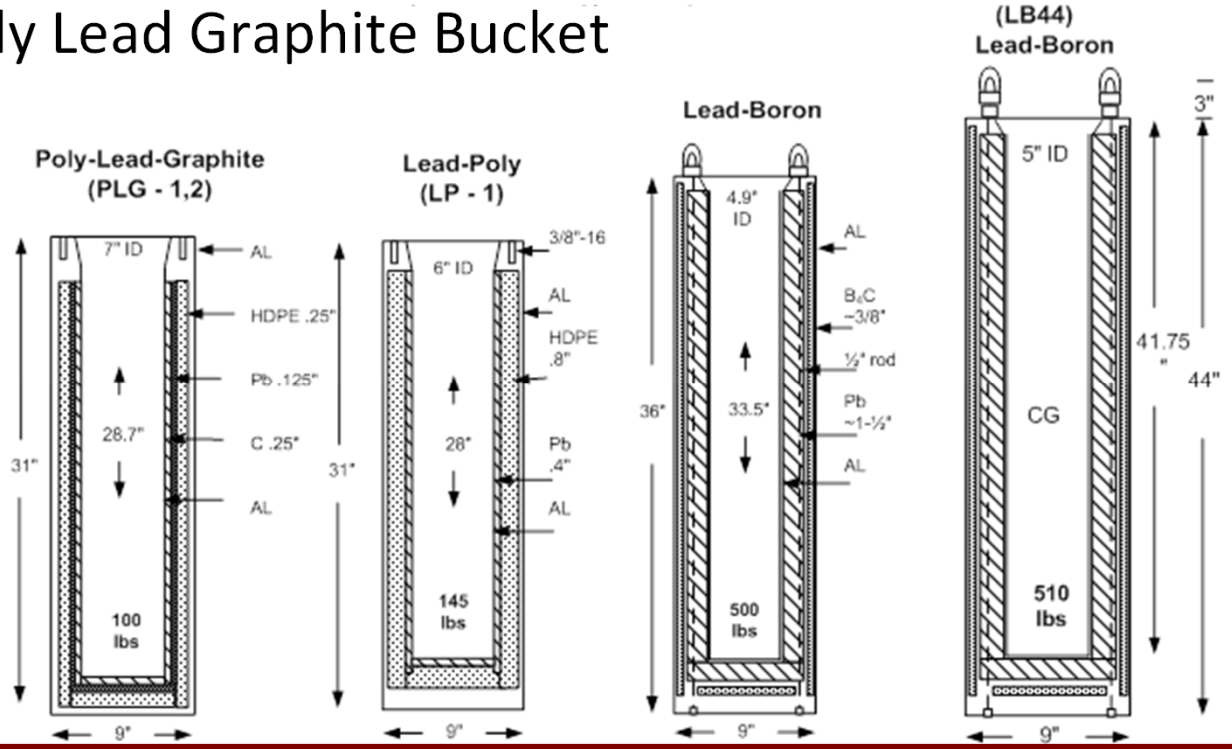


Types of Experiments

- Dosimetry Characterization
- Complex Electronics Assemblies
- Power Reactor Fuels
- UNM Physics Department Parts
- UNM Medical Isotope Production

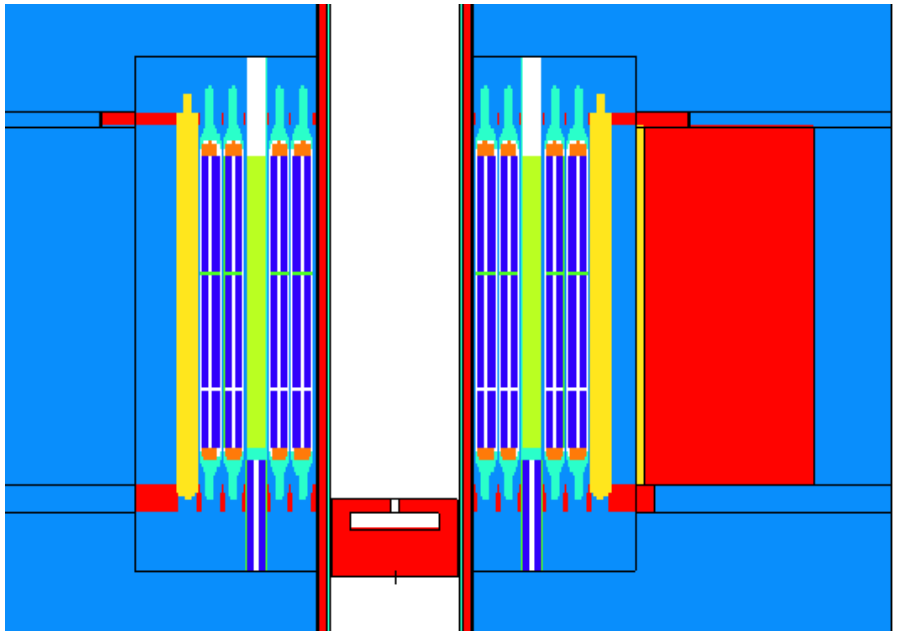
Spectrum Modifiers

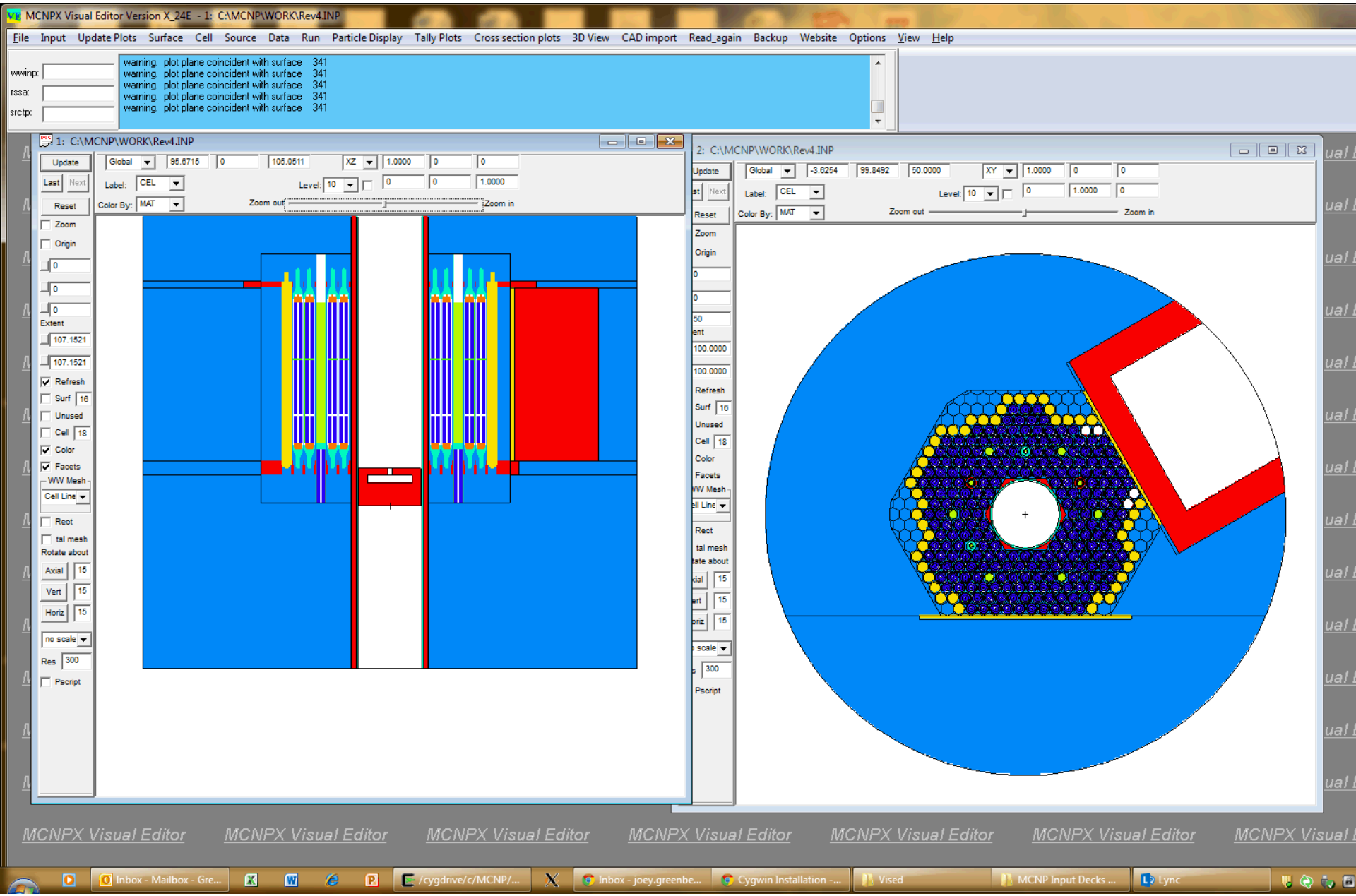
- Free field – aluminum stands or buckets
- Lead Boron Bucket
- Lead Poly Bucket
- Poly Lead Graphite Bucket



Free Field MCNP Model

- Run on the Sandia Labs super computing network
- 10,000,000 particle k-code runs




MCNPX Visual Editor Version X_24E - 1: C:\MCNP\WORK\Rev4.INP
File Input Update Plots Surface Cell Source Data Run Particle Display Tally Plots Cross section plots 3D View CAD import Read_again Backup Website Options View Help
warning. plot plane coincident with surface 341
warning. plot plane coincident with surface 341
warning. plot plane coincident with surface 341
warning. plot plane coincident with surface 341
1: C:\MCNP\WORK\Rev4.INP
2: C:\MCNP\WORK\Rev4.INP
Update
Reset
Zoom
Origin
Refresh
Color
Facets
Rect
Zoom out
Zoom in
MCNPX Visual Editor

Source Neutron to Flux Conversion

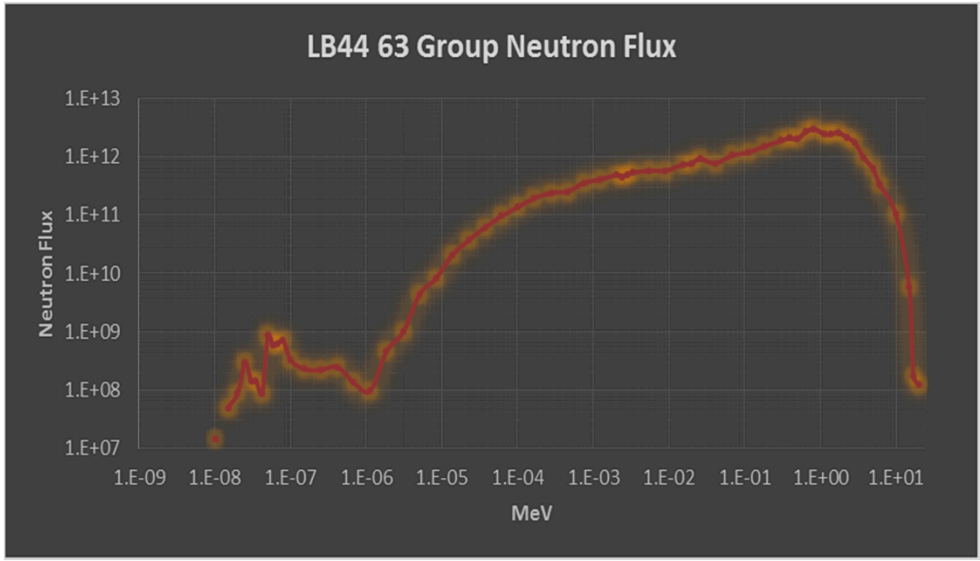
- Keff is utilized from MCNP code
- Energy Flux for graphs was determined by averaging the energy band and multiplying by the group flux divided by the energy

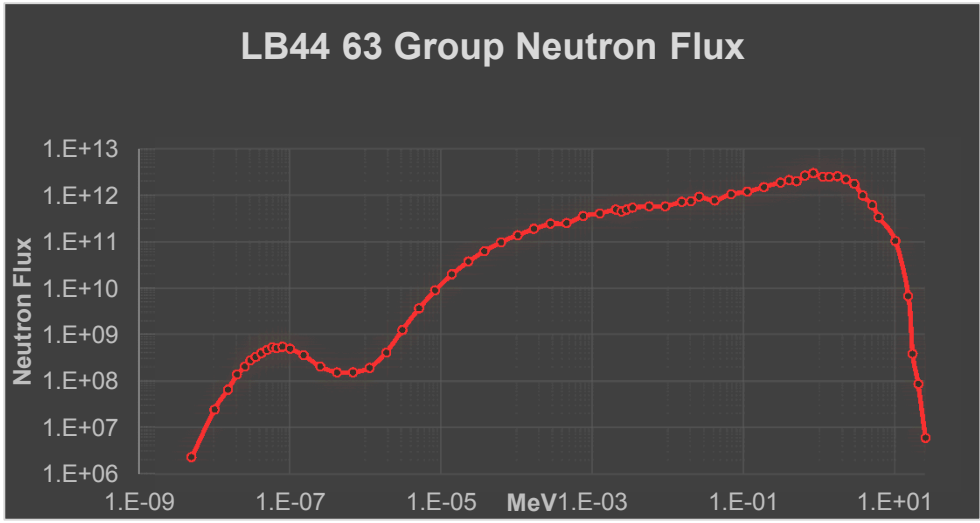
$$\Phi\left[\frac{\text{neutron}}{\text{cm}^2\text{s}}\right] = \frac{P[\text{W}]\bar{\nu}\left[\frac{\text{neutron}}{\text{fission}}\right]}{\left(1.6022\cdot10^{-13}\frac{\text{J}}{\text{MeV}}\right)w_f\left[\frac{\text{MeV}}{\text{fission}}\right]}\frac{1}{k_{eff}}\Phi_{F4}\left[\frac{1}{\text{cm}^2}\right]$$

- P – Power of the reactor in watts
- v – Average neutrons per fission 2.44
- w_f – energy released per fission 192.4 MeV
- ϕ – neutron flux in energy band
- ϕ_{f4} – f4 tally result from MCNP
- k_{eff} – MCNP effective multiplication factor

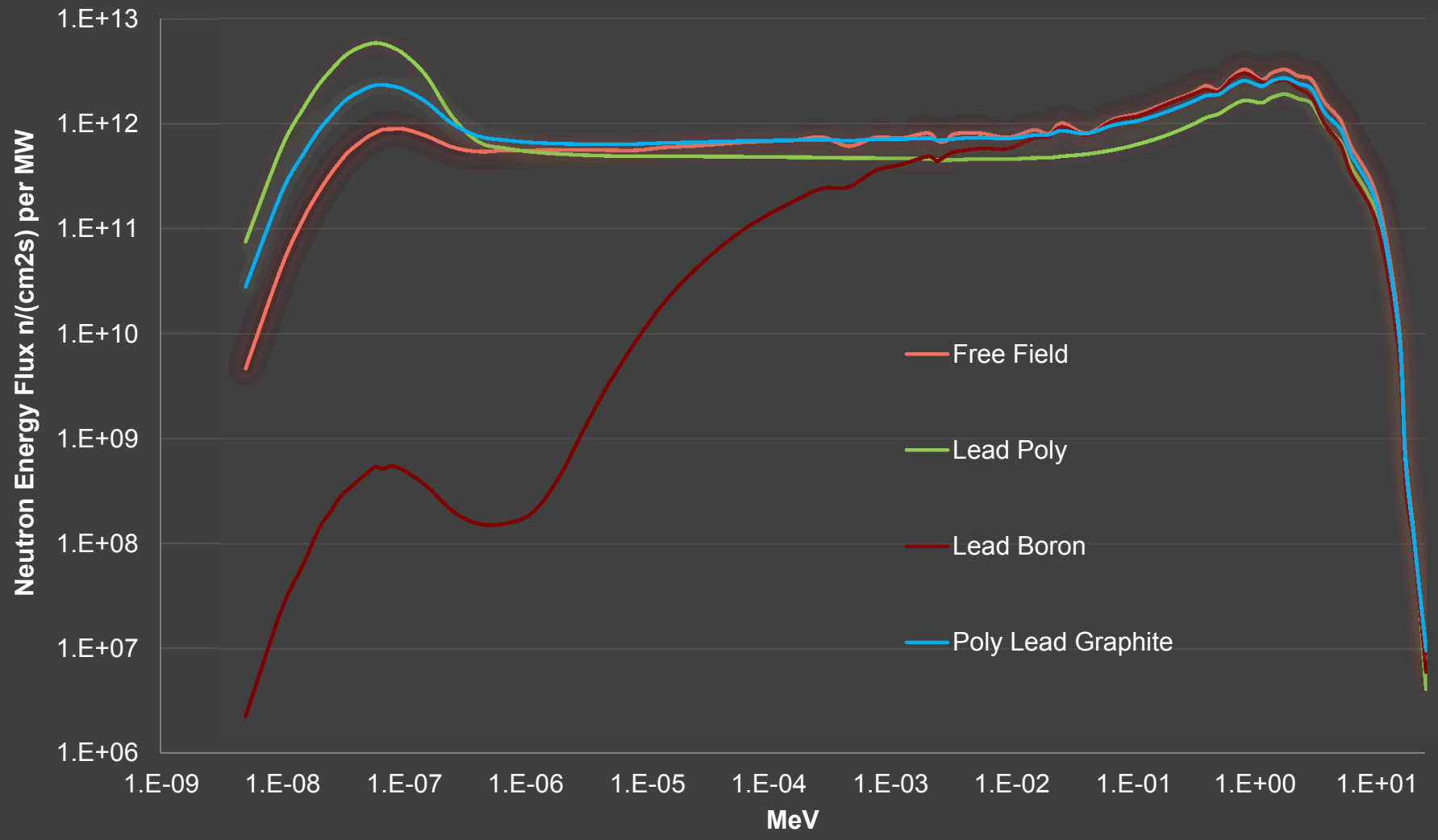
Other MCNP Models

- Same base MCNP file input deck with adjusted rod heights and removed comments for bucket under examination
- 100,000 starting particles resulted in inadequate data
- 10,000,000 particles provided realistic results



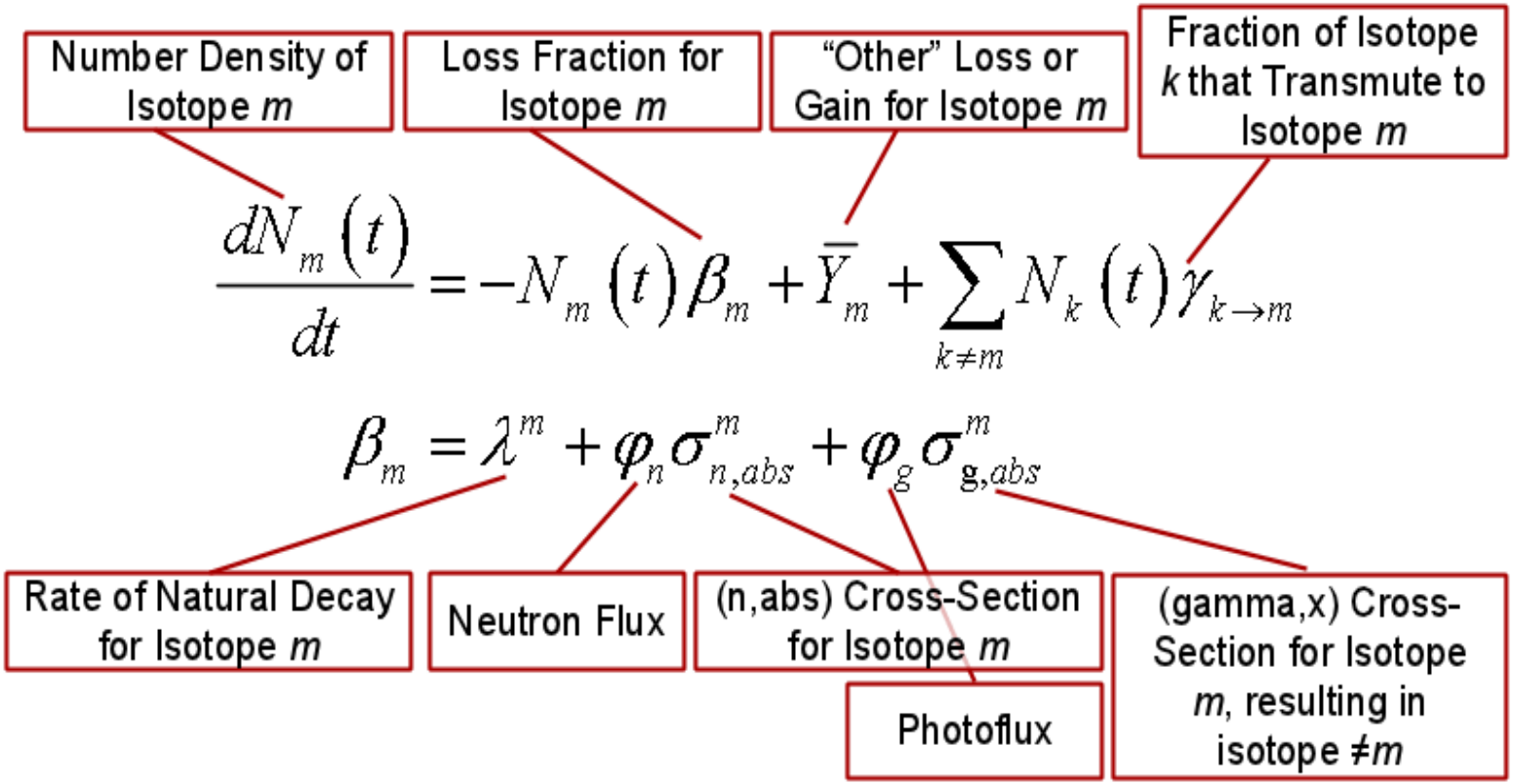


Bucket Energy Flux



CINDER2008 Burnup Code

- Bateman Equation

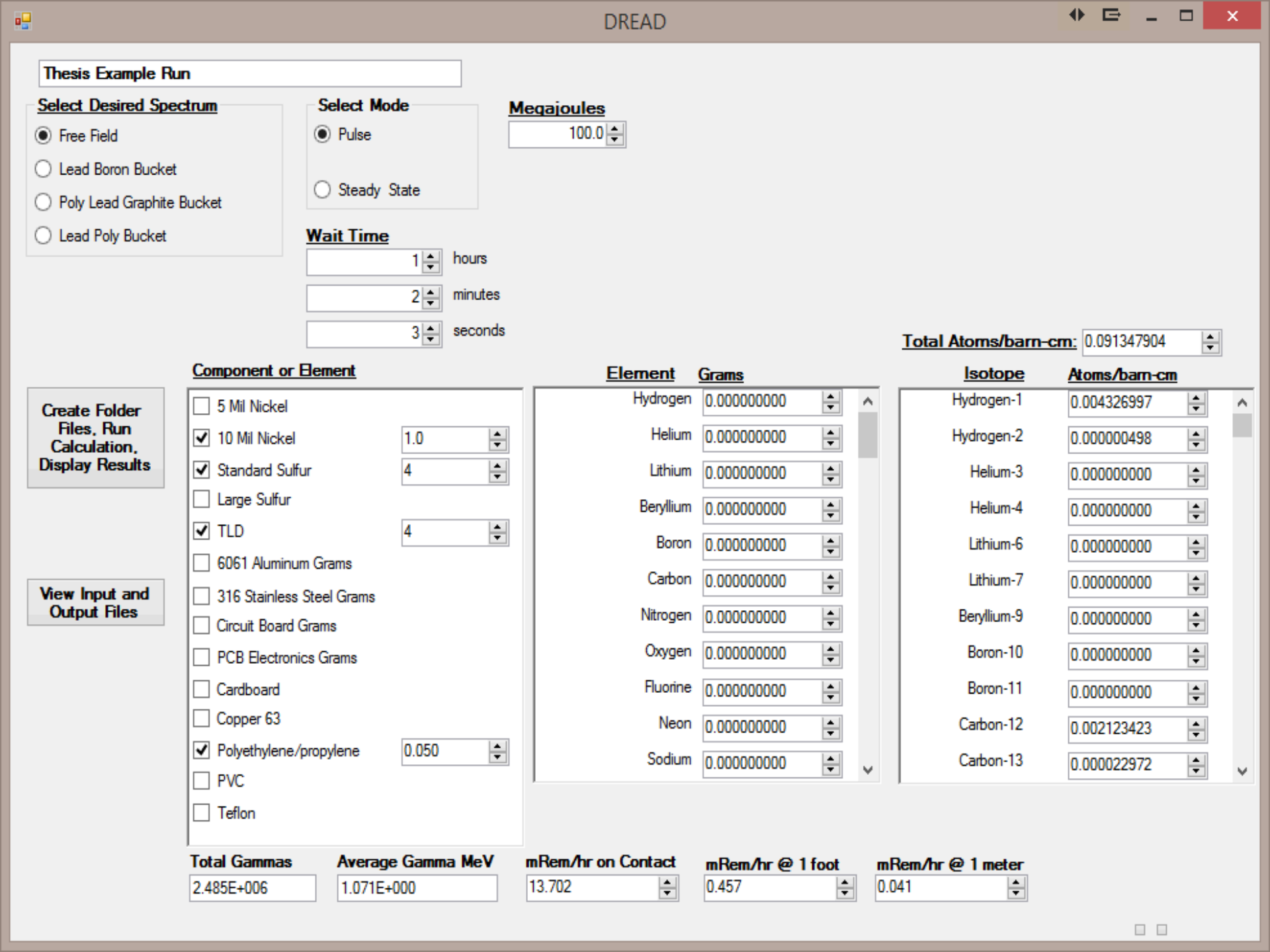


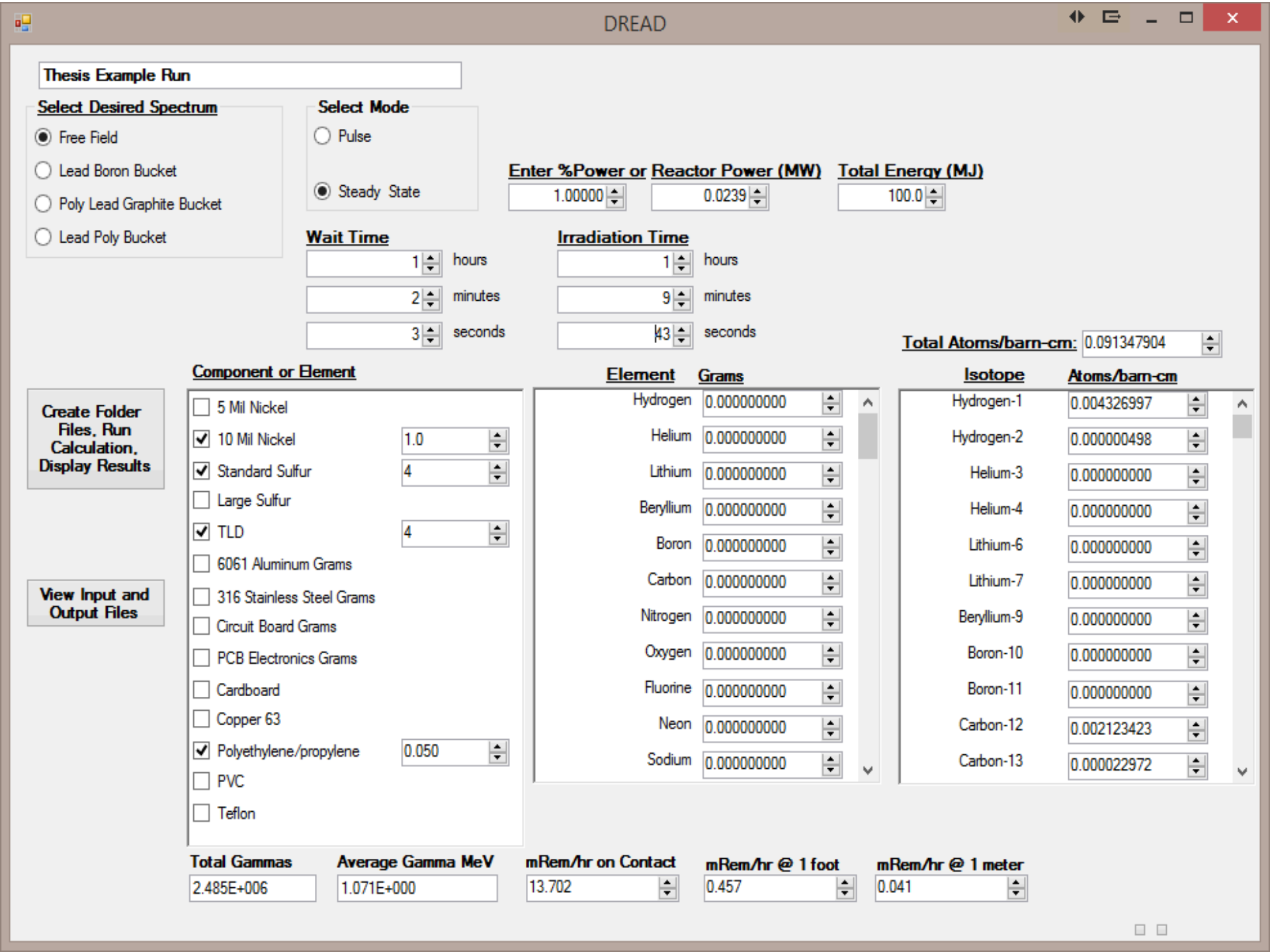
DREAD – Dose Rate Estimator for Activation and Decay

- Uses 63 group flux from MCNP runs
- Automatically generates input files (4) for CINDER to execute
- Automatically reads output files from CINDER and converts gamma rays into dose rates on contact, 1 foot, and 1 meter using equation from Shleien, 1984

Gamma Ray Flux-to-Dose Rate Conversion Factors
Polynomial Coefficients in Analytic Form
$\ln D(E) = A + Bx + Cx^2 + Fx^3$
$D(E)$ = (rem/h)/(cm^2-s), E = Photon Energy in MeV and x = ln E
(After Unger and Trubey ORNL/RSIC-45 1981)

Photon Energy (Mev)	A	B	C	F
0.01 to 0.03	-20.477	-1.7454		
0.03 to 0.5	-13.626	-0.57117	-1.0954	-0.24897
0.5 to 5.0	-13.133	0.72008	-0.033603	
5.0 to 15.0	-12.791	0.28309	0.10873	


DREAD
Thesis Example Run
Select Desired Spectrum
Free Field
Lead Boron Bucket
Poly Lead Graphite Bucket
Lead Poly Bucket
Select Mode
Pulse
Steady State
Megajoules
100.0
Wait Time
1
hours
2
minutes
3
seconds
Total Atoms/barn-cm:
0.091347904
Create Folder Files, Run Calculation, Display Results
View Input and Output Files
Component or Element
5 Mil Nickel
10 Mil Nickel
1.0
Standard Sulfur
4
Large Sulfur
TLD
4
6061 Aluminum Grams
316 Stainless Steel Grams
Circuit Board Grams
PCB Electronics Grams
Cardboard
Copper 63
Polyethylene/propylene
0.050
PVC
Teflon
Element
Grams
Hydrogen 0.000000000
Helium 0.000000000
Lithium 0.000000000
Beryllium 0.000000000
Boron 0.000000000
Carbon 0.000000000
Nitrogen 0.000000000
Oxygen 0.000000000
Fluorine 0.000000000
Neon 0.000000000
Sodium 0.000000000
Isotope
Atoms/barn-cm
Hydrogen-1 0.004326997
Hydrogen-2 0.000000498
Helium-3 0.000000000
Helium-4 0.000000000
Lithium-6 0.000000000
Lithium-7 0.000000000
Beryllium-9 0.000000000
Boron-10 0.000000000
Boron-11 0.000000000
Carbon-12 0.002123423
Carbon-13 0.000022972
Total Gammas
2.485E+006
Average Gamma MeV
1.071E+000
mRem/hr on Contact
13.702
mRem/hr @ 1 foot
0.457
mRem/hr @ 1 meter
0.041


DREAD
Thesis Example Run
Select Desired Spectrum
Free Field
Lead Boron Bucket
Poly Lead Graphite Bucket
Lead Poly Bucket
Select Mode
Pulse
Steady State
Enter %Power or
1.00000
Reactor Power (MW)
0.0239
Total Energy (MJ)
100.0
Wait Time
1 hours
2 minutes
3 seconds
Irradiation Time
1 hours
9 minutes
43 seconds
Total Atoms/barn-cm:
0.091347904
Create Folder Files, Run Calculation, Display Results
View Input and Output Files
Component or Element
5 Mil Nickel
10 Mil Nickel 1.0
Standard Sulfur 4
Large Sulfur
TLD 4
6061 Aluminum Grams
316 Stainless Steel Grams
Circuit Board Grams
PCB Electronics Grams
Cardboard
Copper 63
Polyethylene/propylene 0.050
PVC
Teflon
Element
Grams
Hydrogen 0.000000000
Helium 0.000000000
Lithium 0.000000000
Beryllium 0.000000000
Boron 0.000000000
Carbon 0.000000000
Nitrogen 0.000000000
Oxygen 0.000000000
Fluorine 0.000000000
Neon 0.000000000
Sodium 0.000000000
Isotope
Atoms/barn-cm
Hydrogen-1 0.004326997
Hydrogen-2 0.000000498
Helium-3 0.000000000
Helium-4 0.000000000
Lithium-6 0.000000000
Lithium-7 0.000000000
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Boron-10 0.000000000
Boron-11 0.000000000
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Total Gammas
2.485E+006
Average Gamma MeV
1.071E+000
mRem/hr on Contact
13.702
mRem/hr @ 1 foot
0.457
mRem/hr @ 1 meter
0.041

Validation

- Experiments were weighed and material composition was determined
- Dose Rate measurements were conducted on contact and at 1 foot for multiple experiments irradiated at ACRR

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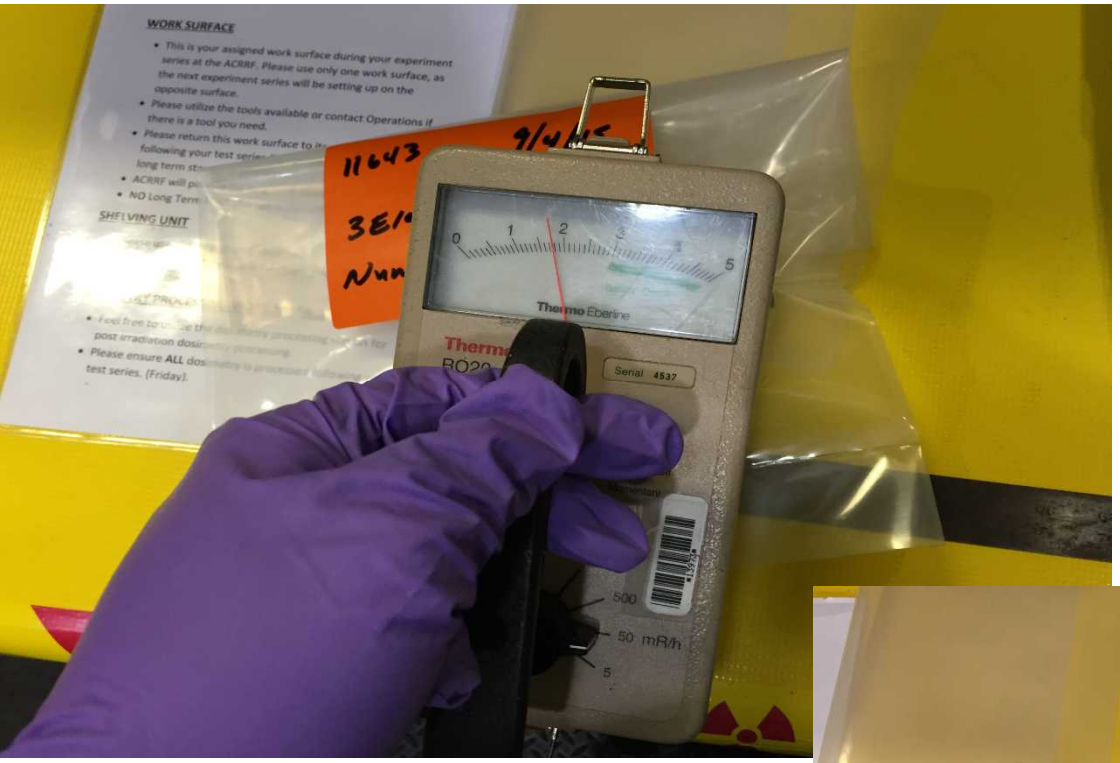


Free Field Results

#	Bucket	Pulse/Run Time	Wait Time	On Contact mrem/hr	1 foot mrem/hr	DREAD on contact	DREAD 1 ft
1	Free Field	Pulse	31 min	1300	60	2000	67
2	Free Field	Pulse	48 min	1500	65	2100	70
3	Free Field	Pulse	104 min	1300	48	1600	53
4	Free Field	Pulse	19 hr	130	5	180	6
5	Free Field	Pulse	35 min	2100	90	3056	101
6	Free Field	Pulse	90 min	1500	70	2376	79
7	Free Field	Pulse	18 hr	800	50	1536	52
8	Free Field	Pulse	40 min	600	25	951	31
9	Free Field	Pulse	45 min	500	22	837	27
10	Free Field	Pulse	20 min	2000	100	4048	135

Lead Boron Bucket Results

#	Bucket	Pulse/Run Time	Wait Time	On Contact mrem/hr	1 foot mrem/hr	DREAD on contact	DREAD 1 ft
1	LB 44"	~7 min	30 s	14	-	3.2	-
2	LB 44"	~14 min	60 s	2.75	-	3.4	-
3	LB 44"	~6 min	60 s	9	0.5	16.2	0.523
4	LB 44"	~6 min	30 s	14	1.1	34	1.197
5	LB 44"	~6 min	5 min	700	20	805	27.9
6	LB 44"	~6 min	5 min	1100	50	1784	59.4
7	LB 44"	~6 min	20 min	250	9	440	14
8	LB 44"	~6 min	2 hr	60	5.1	203	6.7
9	LB 44"	Pulse	45 min	160	8	273	9.1
10	LB 44"	Pulse	1 hr	800	28	1011	33
11	LB 44"	Pulse	2 hr	170	7	225	7.5

Poly Lead Graphite Bucket Results

#	Bucket	Pulse/Run Time	Wait Time	On Contact mrem/hr	1 foot mrem/hr	DREAD on contact	DREAD 1 ft
1	PLG	Pulse	3 hr	6500	250	8424	280
2	PLG	Pulse	3.5 hr	6800	250	9154	305
3	PLG	Pulse	3 hr	4000	140	5148	171
4	PLG	12 min	2 hr	5800	225	7930	264
5	PLG	18 min	2 hr	10000	415	14243	474

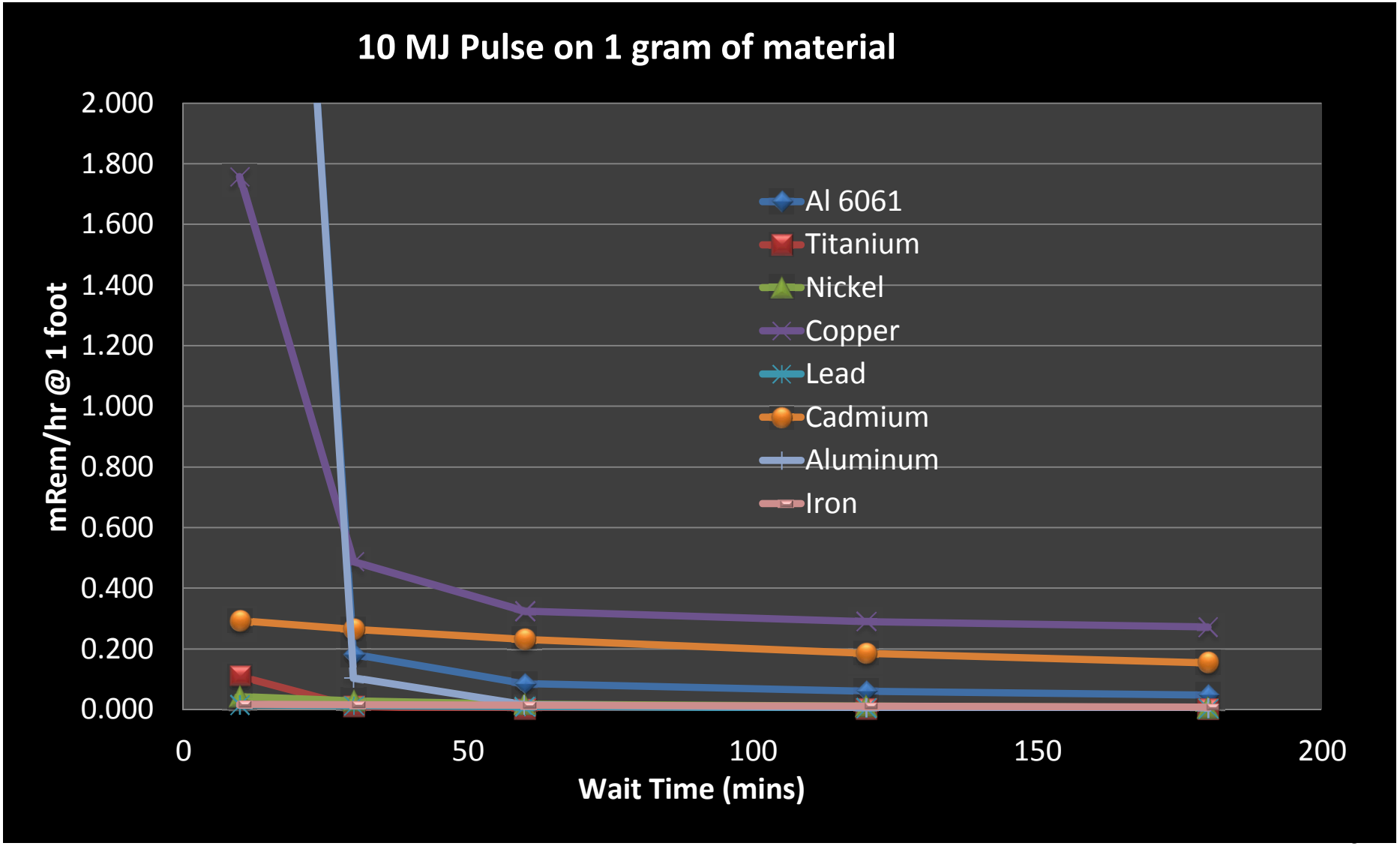
Lead Poly Bucket Results

#	Bucket	Pulse/Run Time	Wait Time	On Contact mrem/hr	1 foot mrem/hr	DREAD on contact	DREAD 1 ft
1	LP	Pulse	2 hr	5500	278	7100	237
2	LP	Pulse	3 hr	9000	500	12698	423
3	LP	Pulse	1.5 hr	5000	260	7260	242
4	LP	Pulse	5	14000	720	19426	647
5	LP	30 min	20 hr	5500	220	7321	244

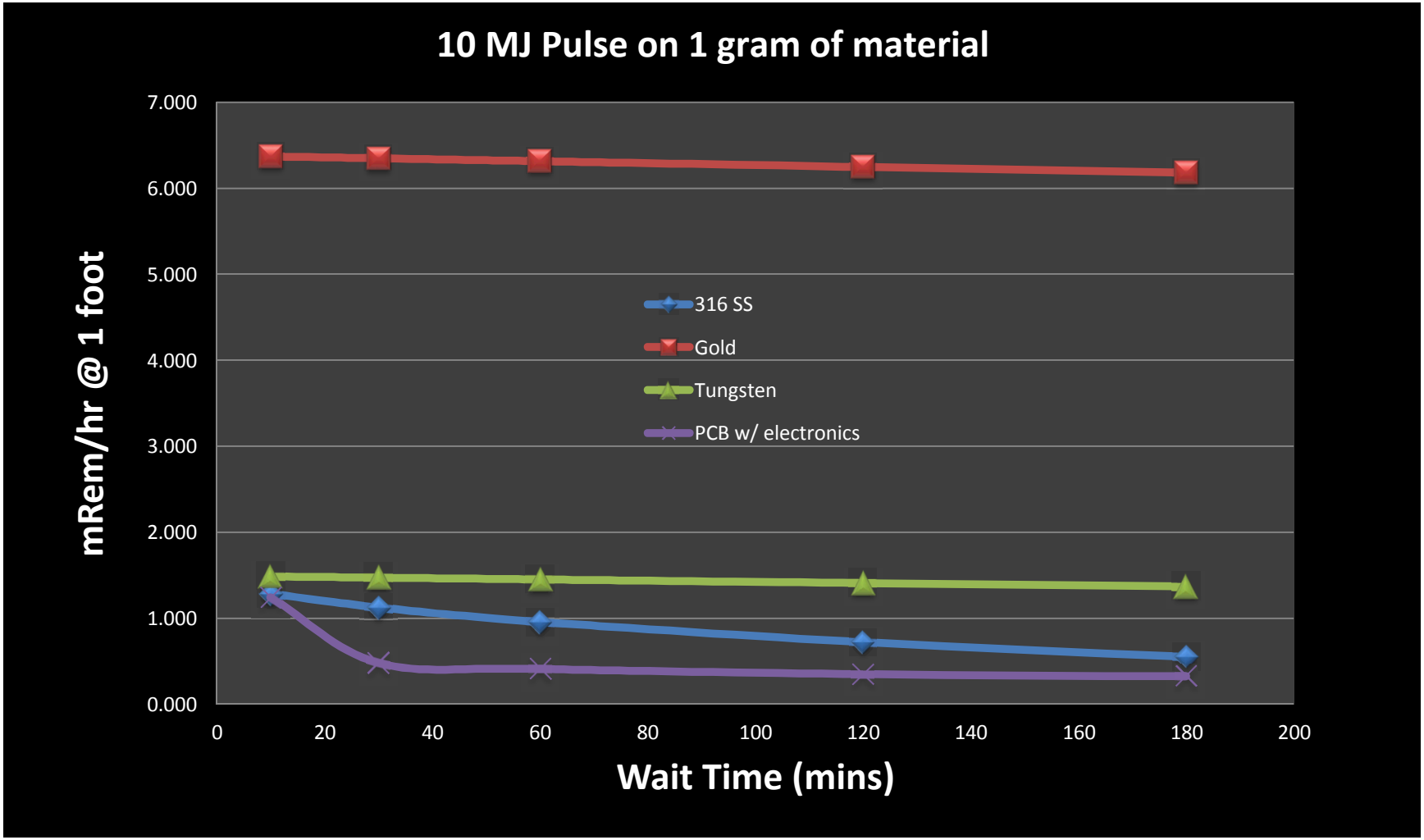
Result Data Averages

Spectrum	Average % DREAD vs. Actual	Average Factor between 1 foot and on contact
Free Field	16% higher	23
Lead Boron	22% higher	22
Poly Lead Graphite	18% higher	26
Lead Poly	12% higher	20
Average	17%	22.75

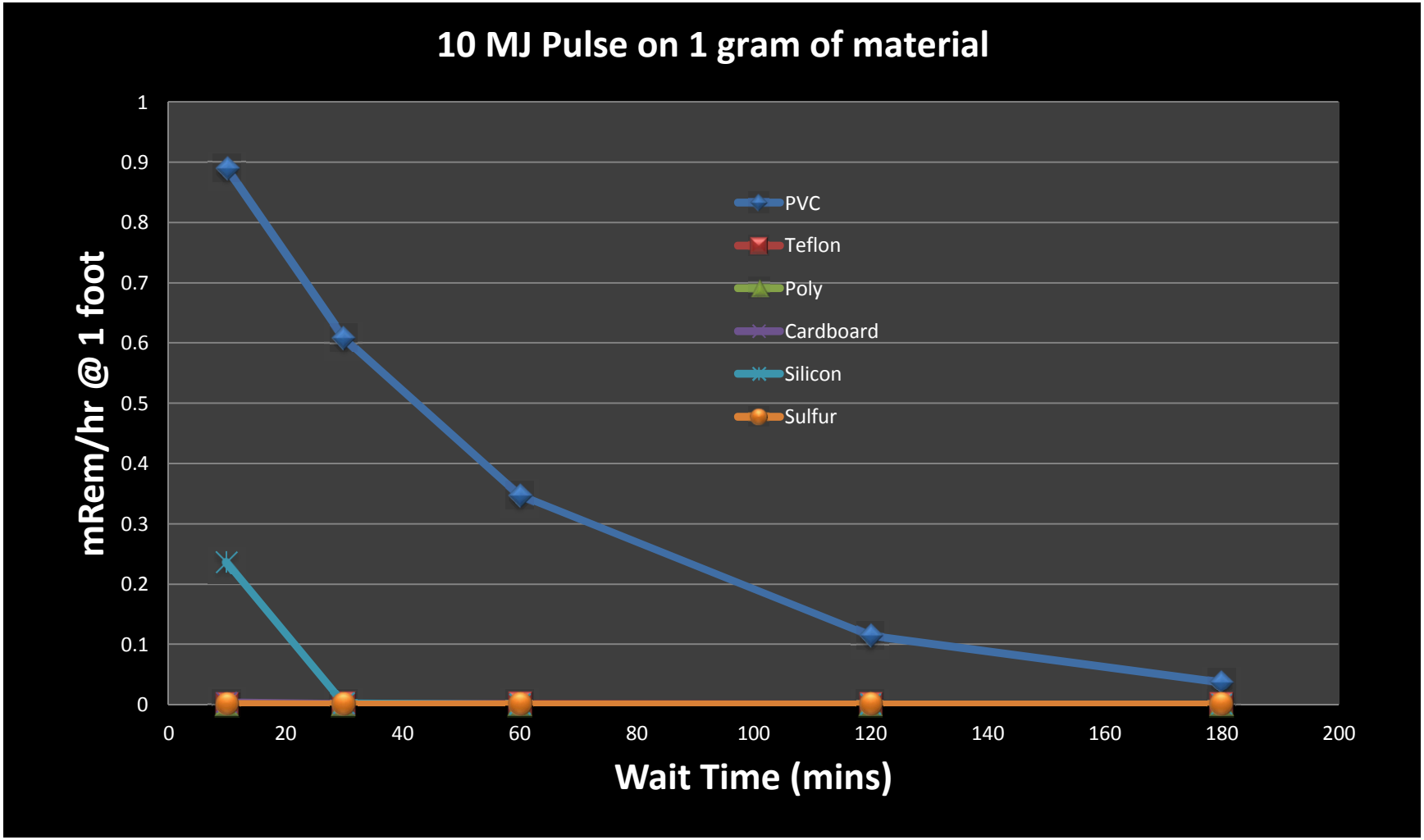
Other Uses


10 MJ Pulse on 1 gram of material
mRem/hr @ 1 foot
2.000
1.800
1.600
1.400
1.200
1.000
0.800
0.600
0.400
0.200
0.000
0
50
100
150
200
Wait Time (mins)
Al 6061
Titanium
Nickel
Copper
Lead
Cadmium
Aluminum
Iron

Other Uses


10 MJ Pulse on 1 gram of material
mRem/hr @ 1 foot
7.000
6.000
5.000
4.000
3.000
2.000
1.000
0.000
0
20
40
60
80
100
120
140
160
180
200
Wait Time (mins)
316 SS
Gold
Tungsten
PCB w/ electronics

Other Uses


10 MJ Pulse on 1 gram of material
mRem/hr @ 1 foot
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
120
140
160
180
200
Wait Time (mins)
PVC
Teflon
Poly
Cardboard
Silicon
Sulfur

Version 2.0

- Add entire bucket spectrum in addition to the 6cm sphere
- Add water, cadmium, and future buckets
- Add more materials that are commonly used
- Add other experiment cavities (FREC-II and NRT)