Preliminary Flattop-25 Reevaluation Results

Jeffrey A. Favorite
Monte Carlo Codes, Methods, and Applications Group (XCP-3)
Los Alamos National Laboratory
Los Alamos, New Mexico

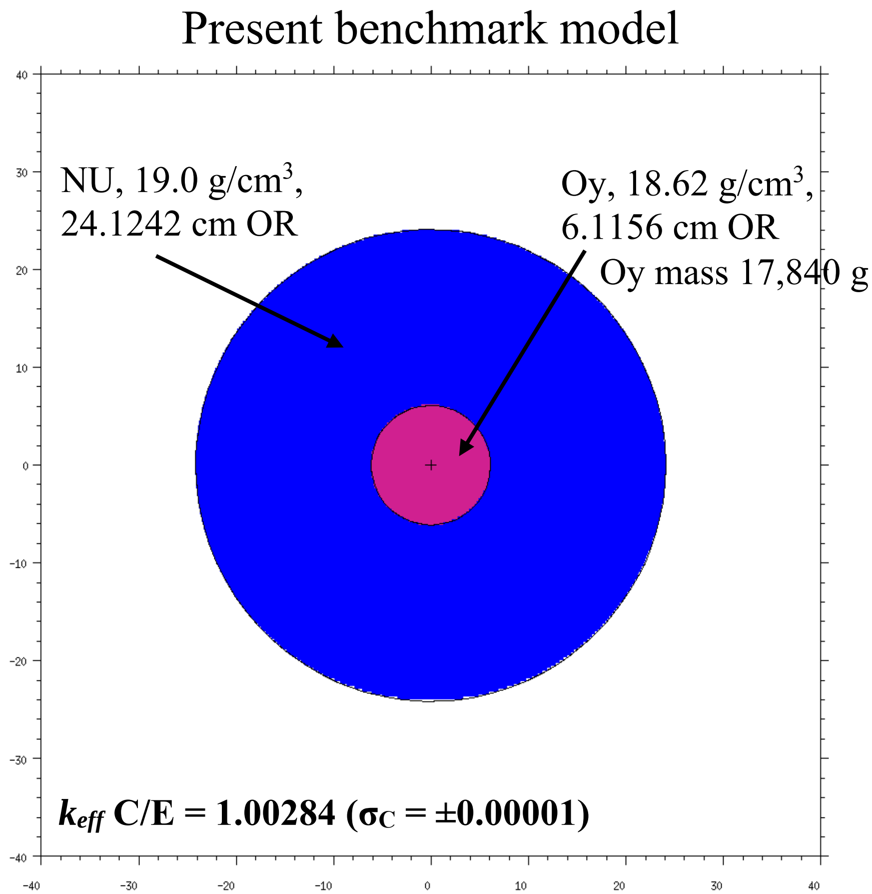
Nuclear Criticality Safety Program Technical Program Review
Albuquerque, NM
March 15-16, 2016

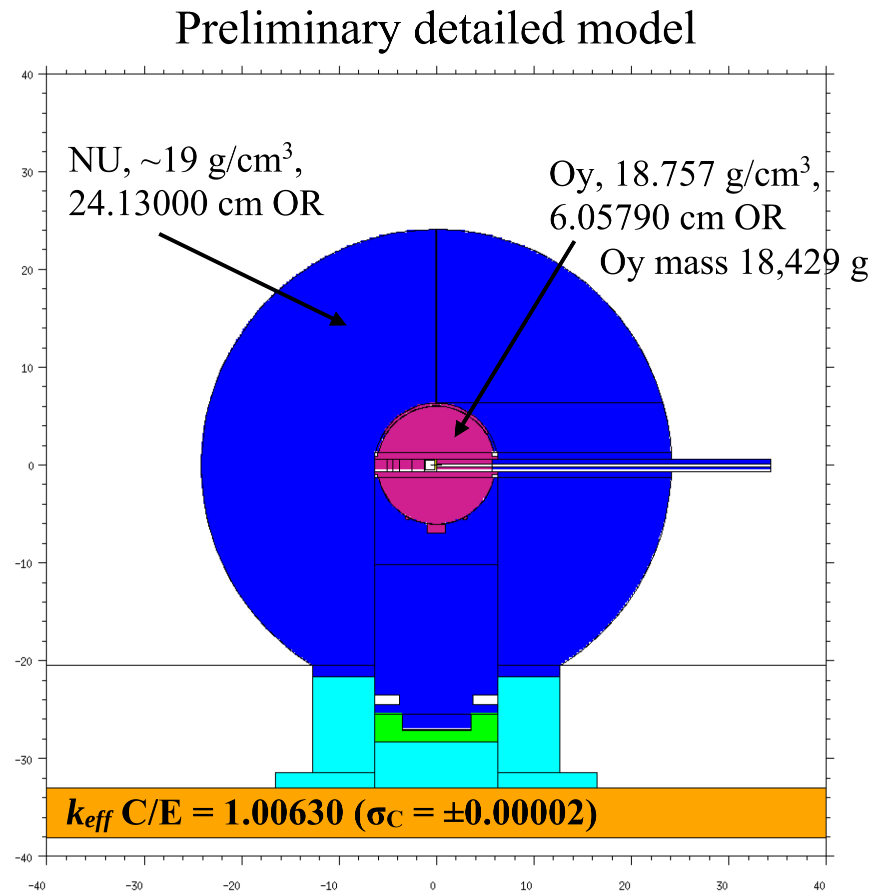
Acknowledgments

- Dave Hayes
- Bill Myers
- Rene Sanchez
- Joetta Goda
- Eric Sorensen
- Dave Poston and Morgan White each developed an MCNP model

- This work was supported by the DOE Nuclear Criticality Safety Program, funded and managed by the National Nuclear Security Administration for the Department of Energy.

HEU-MET-FAST-028





- My goal is to do for Flattop-25 what I did for Jezebel (PU-MET-FAST-001).
  - + Like Jezebel, the Flattop benchmarks all date from LA-4208, 1969.
  - + Unlike with Jezebel, Hansen and Paxton did not specify the corrections made to obtain the one-dimensional model.

Oralloy Parts

Lot ID	Description	Mass (g) from 1960	Volume (cm^3) calc. from drawings	Density (g/cm^3) (mass/volume)
8159	Cylinder ¼" × ½"	14.39	0.804398	17.889
8464A2[a]	Split cyl. 0.140" × ½" × 2¼"[a]	61.58	3.393555	18.146
8464B2[b]	Split cyl. 0.140" × ½" × 2¼"[b]	61.53	3.393555	18.131
8278	GH Plug Filler ½" × ½"	30.06	1.608796	18.685
8282	GH Plug Filler ½" × ½"	30.07	1.608796	18.691
8283A[c]	GH Plug Filler ¼" × ½"[c]	14.93	0.804398	18.560
8283B[d]	GH Plug Filler ½" × ½"[d]	26[d]	1.608796	16.161
Multiple	Mass Plug 0.748" × 0.330" disc	46.34[e]	2.482267	18.666[e]
8655[d]	Bolt[d]	37[d]	868.6998[f]	18.757[f]
8656[d]	Bolt[d]	37[d]	Incl. in core	Incl. in core
10636	Hemisphere 2.385 sph. R.	8676.11	Incl. in core	Incl. in core
10637	Hemisphere 2.385 sph. R.	7544.17	Incl. in core	Incl. in core
10914	Part 26A Core Half Cap	580.14	31.90469	18.184
10934	Part 37A GH Sleeve	852.29	45.82897	18.597

Core mass: 16,294 g

(a) Listed in 1960 ref. as 8464-A.
(b) Listed in 1960 ref. as 8464-B.
(c) Listed in 1960 ref. as 8283.
(d) Not listed in 1960 ref.; masses from by Dave Hayes (NEN-2).
(e) Average of 10 parts.
(f) Volume and density are for the core comprising the masses of parts 8655, 8656, 10636, and 10637 in a sphere of radius 2.385 inches.

- Densities have not been measured. LA-4208 (1969) assumed 18.806 g/cm^3.

Oralloy Enrichment

- Two sources for core isotopics.

Lot ID	Description	1960 Mass Accountability	1958 Memo
10636	Female part	93.27	93.22
10637	Male part	93.22	93.18

- All Oralloy parts use the mass average enrichment from the 1958 memo.

- Oralloy isotopics used in the benchmark:

Isotope	Wgt.%
^{233}U	0.015
^{234}U	1.125
^{235}U	93.201
^{236}U	0.228
^{238}U	5.431

References for Tuballoy Parts

Flat-top Weight Checks

I. Predicted Block Weights

a) Wt. of 19" Diameter Sphere (9.5" = 24.13 cm)

$M = 4.1889 \times 18.9 \times 24.13 \times 24.13 \times 24.13 \times 10^{-3} = 1112.3$ kg.

b) Wt. of 5" Diameter Hemisphere (2.5" = 6.35 cm)

$M = 2.0944 \times 18.9 \times 6.35 \times 6.35 \times 6.35 \times 10^{-3} = 10.14$ kg.

c) Wt. of 5" Diameter Cyl. ~~8.5"~~ 10.0" High (~~8.5" = 21.59 cm~~ 10.0" = 25.40 cm)

$M = 3.1416 \times 18.9 \times 6.35 \times 6.35 \times 21.59 \times 10^{-3} = 51.69$ kg (25.4; 60.81)

Total Block Wts = a) - b) - c) = ~~1050.5~~ 1041.4

∴ Hemisphere Block = ~~525.2~~ 520.7 kg.

Each Split-Hemisphere Block = ~~262.6~~ 260.3

II. Observed Block Weights

a) Hemisphere Block

	Solid Piece
494.00	
3.95	control rod E
3.97	" " G
16.22	" " F
1.25	Glory hole 1"→½" adaptor
~.42	" ½"→0" plug
519.81	

b) Split-Hemispheres

259 reweighed	
179.70	Solid
1.50	washers etc.
181.20	
260 check	

-2-

Flat-top Weight Checks

III Predicted Plug + "Filled Cavity" Wts.

b)+c) = ~~61.83~~ 70.95 kg.

IV Actual Plug Assembly Wts.

	a) Oy	b) Pu	c) 23	d) Comp.
	36.75	36.75	36.75	36.75
	13.50	18.60	18.75	16.75
	0.65	6.20	6.30	5.00
	0.56	0.60	.48	.80
Tu =	51.46	62.15	62.28	59.30
Deficit for Active Matl. =	19.49	8.80	8.67	11.65

J.O. 06656

Date Recd 6-3-54

FLATTOP Characterization Data
Charlene Cappiello 9/1/2006

Item	NM (g)	Scale Number
FT-SPLITROD	648.5	B168
FT-ROD-F	16049	B190
B Plug	149.5	B168
A Block Plug	119	B168
Safety Block (reflector)	490000	020540 (dynamometer)
A Block	231000	020540 (dynamometer)
B Block	233000	020540 (dynamometer)
FT-ROD-E	3885	B168
FT-ROD-G	3935	B168
FT-BASE-PED	36704	B190
	1015490	

Tuballoy Parts

Description	Mass (kg) from 1954	Volume (cm^3) calc. from drawings	Density (g/cm^3) (mass/volume)	Mass (kg) from 2006	Diff w.r.t. 1954 mass
Hemisphere (control rod block)	494.00	26003.4	18.998	490.000	–0.81%
Quarter-sphere A	260.5[a]	13677.4	18.936	231.119[b]	–10.81%
Quarter-sphere B	260.5[a]	13676.4	18.938	233.1495[b]	–10.04%
Control Rod E	3.95	211.7088	18.658	3.885	–1.65%
Control Rod F	16.22	855.7582	18.954	16.049	–1.05%
Control Rod G	3.97	211.7088	18.752	3.935	–0.88%
Glory hole adapter	1.25	67.0646	18.647	Not given	N/A
Split rod (glory hole fill)	Not given	No drawing	N/A	0.6485	N/A
Pedestal base[c]	36.75	1962.733	18.724	36.704	–0.13%
Pedestal body[c]	13.50	788.98	17.111	Not given	N/A
Total for plug (base, body, and two small parts)	51.46[d]	2701.59[d]	19.048[e]	Not given	N/A
Adapter ring	Not given	367.864[f]	N/A	Not given	N/A
Half-cap (part SS-1-R)	0.650[g]	34.8173	18.669	Not given	N/A
Mass adjustment plug	Not given	2.48227	N/A	Not given	N/A

(a) Includes mass of "washers etc."
(b) Includes mass of plug.
(c) The base and the body are modeled more simply than the actual parts.
(d) Includes four pieces.
(e) Average of four pieces.
(f) Includes all three pieces.
(g) Mass from a drawing; it is not known whether this is a design mass or a measured mass.

- Densities have not been measured. LA-4208 (1969) assumed 19.0 g/cm^3.

Tuballoy Isotopics

- All Tuballoy parts use natural uranium isotopics.
- Tuballoy isotopics used in the benchmark:

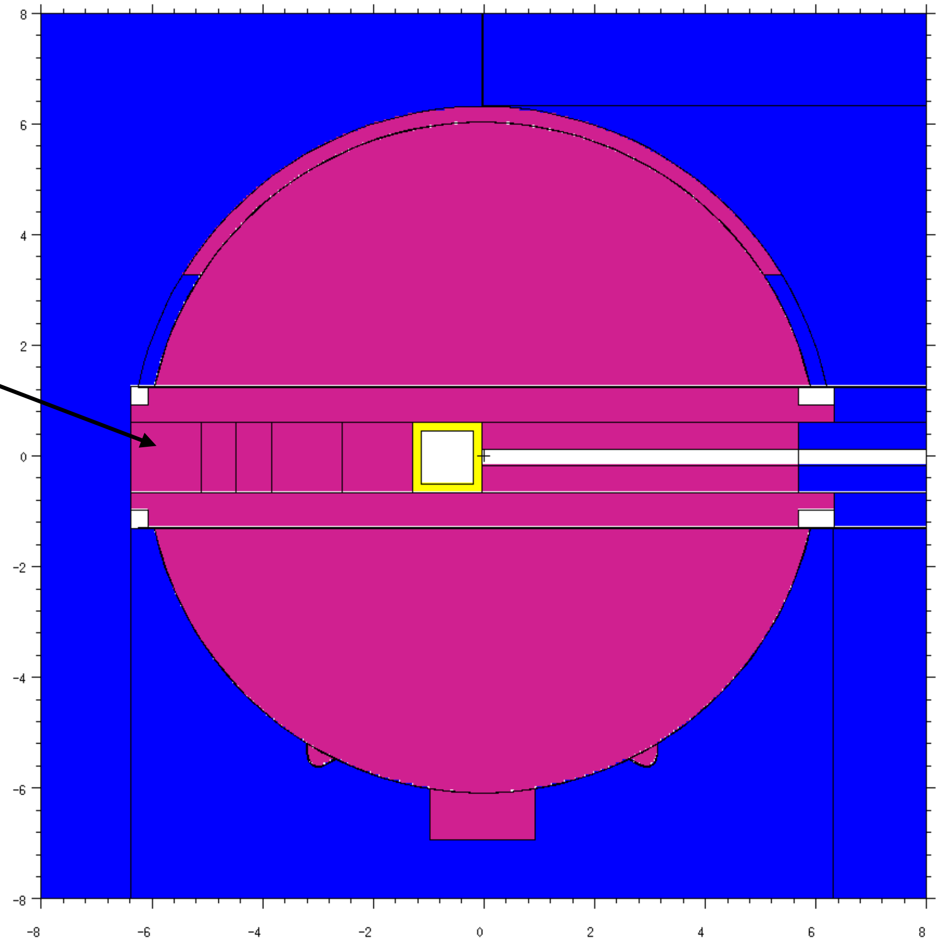
Isotope	At.%	Wgt.%
^{234}U	0.0055	0.0054079
^{235}U	0.72	0.7109708
^{238}U	99.2745	99.283621

Structural Components

- The support structure includes steel and brass.
- The table is made of bridge steel.
- There is a small aluminum can in the glory hole.

Experimental Configuration

- Dave Hayes (Los Alamos National Laboratory), the Flattop Project Leader, has suggested modeling a run from Nov. 28, 2011, that replicated a run from July 6, 2004.
  - + Oy and Tu half-caps
  - + Ten Oy mass adjustment buttons and one Tu mass adjustment button
  - + Control rods fully inserted
  - + Specific glory hole fill

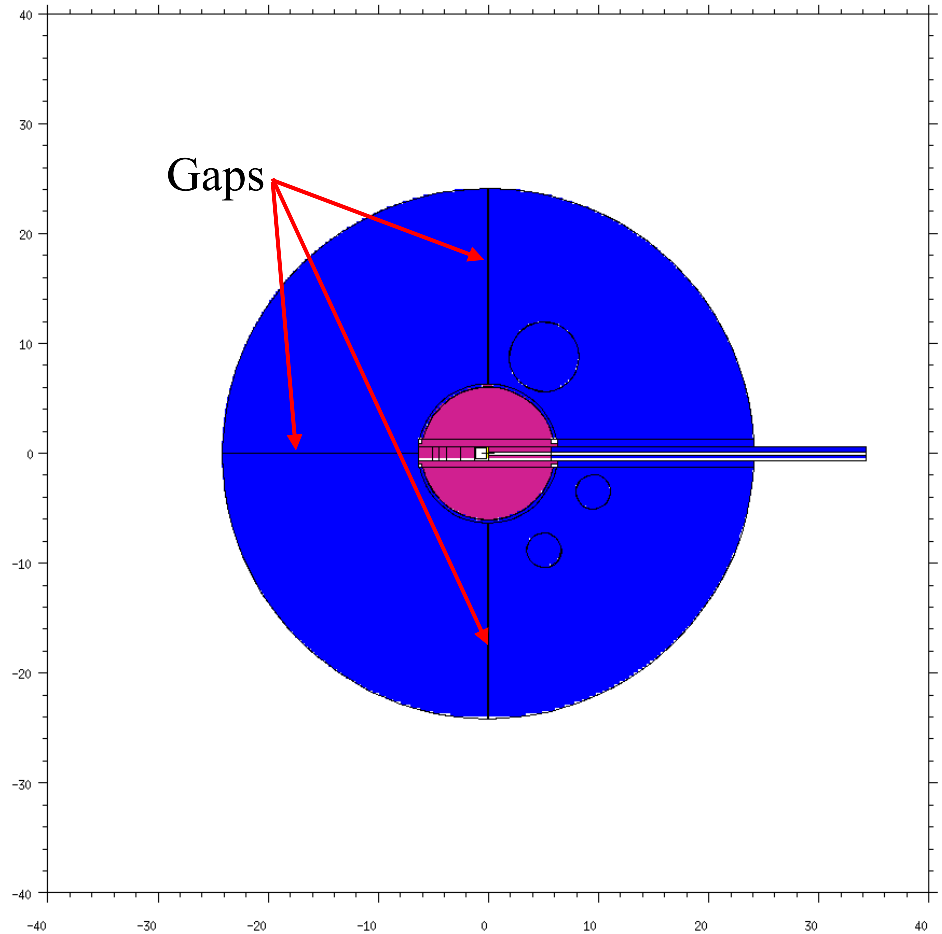


- The excess reactivity was $0.50, which has been a reproducible value for this configuration.
  - + Using a delayed neutron fraction β_{eff} = 0.00685 (from MCNP6), the experimental k_{eff} is 1.00344.

Gaps

- The model includes a parallel gap of 0.02 cm between each of the pairs of flat mating planes of the three major reflector parts.

- The gap is modeled by removing material from the Tu reflector parts.
  + 803 g Tu are lost due to the gaps.
  + 0.08% Tu mass is lost due to the gaps



UNCLASSIFIED

Uncertainty

- Oy mass: ±(1 g)/(7544.17 g) = ±0.01%
- Oy core radius: ±0.003 inch → Oy density: ±0.4%
- k_{eff} uncertainty due to Oy masses, dimensions, and densities: ±0.00071

- Tu mass: ±1% (1954 vs. 2006)
- Tu volume: ±1%
  - Corresponds to uncertainties of ±0.032 and ±0.0303 inch in the quarter-sphere and hemisphere radii, respectively.
- k_{eff} uncertainty due to Tu masses, dimensions, and densities: ±0.00137

- Gaps: ±0.02 cm → k_{eff} uncertainty ±0.00025

- Oy ^{235}U and ^{238}U weight fractions: ±0.05% → k_{eff} uncertainty ±0.00018

- Structural material density uncertainty has no effect on k_{eff} uncertainty.

- Total (preliminary) k_{eff} uncertainty is ±0.00157.

- Doubling the assumed Oy density uncertainty results in a k_{eff} uncertainty of ±0.00141 (due to Oy).
- Doubling the assumed Tu density uncertainty results in a k_{eff} uncertainty of ±0.00207 (due to Tu).
- Doubling both simultaneously, the resulting total k_{eff} uncertainty is ±0.00252.

- Preliminary estimated uncertainty of k_{eff} uncertainty is +100%/–0%.

Summary/Status as of Feb. 1, 2016

- Measured k_{eff}: 1.00344
- Calculated k_{eff}: 1.00976 ± 0.00002
- Uncertainty: ±0.00160 to ±0.00320

- Calculated k_{eff} is just within 2σ of measured k_{eff}

- Present benchmark k_{eff} is 1.00000 ± 0.00300 (I added a sig. fig.)
  - Uncertainty is from "engineering judgment"

New Measurements

- On Feb. 1, 2016, Dave Hayes measured (not to benchmark precision) the mass and dimensions of some glory hole filler pieces and the reflector sleeve.
  + Masses and densities compared with 1960 (Oy) or 1954 (NU):

Lot ID	Description	Old mass (g)	Mass (g) from 2016	Mass diff.	Old density (g/cm³)	"New" density (g/cm³)	Density diff.
8159	Cylinder ¼" × ½"	14.39	14.2	–1.32%	17.889	18.669	4.36%
8278	GH Plug Filler ½" × ½"	30.06	29.5	–1.86%	18.685	18.607	–0.42%
8282	GH Plug Filler ½" × ½"	30.07	29.6	–1.56%	18.691	18.634	–0.30%
8283A	GH Plug Filler ¼" × ½"	14.93	14.7	–1.54%	18.560	18.633	0.39%
8283B	GH Plug Filler ½" × ½"	~~26[a]~~	29.7	~~14.23%~~	~~16.161~~	18.616	~~15.19%~~
–	NU reflector sleeve	1250	1224.4	–2.05%	18.647	18.700	0.28%

(a) Estimated.

- Beware! Densities computed from measured dimensions are notoriously inaccurate.
  + But are they less accurate than densities computed from drawing dimensions?

- Conclusions:
  + Oy density uncertainty of ±0.4% may be appropriate.
  + Considering the 2016 vs. 1960 mass differences and the 2006 vs. 1954 mass differences for Tu, it appears that uranium is disappearing.

Uranium Oxidation

- How much mass is lost due to oxidation and spall in 56 years?
  + Bruce A. Hilton, "Review of Oxidation Rates of DOE Spent Nuclear Fuel, Part I: Metallic Fuel," Argonne National Laboratory report ANL-00/24 (Nov. 2000).
  + Assume the oxidation rate y is linear with time t, exponential with temperature T:

$$y = 1.09\times10^{8}\exp\left(\frac{-71.3\pm2.1\,\text{kJ/mol}}{RT}\right)t + C\ (\text{mg U})/\text{cm}^2/\text{hr},\ 38°\text{C} < T < 300°\text{C}$$

  + Assume $C = 0$, $T = 40 \pm 10$ °C.
  + Assume that all oxidation leads to spall.

- Sample losses:

Part	Loss rate (g U)/yr	Loss in 56 years (g U)	Loss in 56 years (%)
½" × ½" plug (30 g)	0.0092 ± 0.0109	0.5 to 1.1	1.7% to 3.7%
Oy core	0.68 ± 0.81	38 to 84	0.2% to 0.5%
Quarter-sphere reflector	4.15 ± 4.94	232 to 508	0.09% to 0.2%

- We seem to have found the culprit responsible for mass differences.

- The volume should be changing but the bulk density should be constant.

Status and Options as of March 2016

- We do not know the mass, density, or dimensions of any of the parts to benchmark precision.

- For Oy: We could use the 1960 masses, but the Oy mass uncertainties would be much larger than we assumed – and they are biases with uncertainties.
  + If the Oy mass uncertainty is 0.2% (rather than 0.01%), the total k_{eff} uncertainty becomes ±0.00189 (rather than ±0.00157).
  + A better approach: Weigh the parts (don't disassemble the core).

- For Tu: We could use the 2006 masses.
  + The assumed mass uncertainty is already 1%.
  + But there is a 10%-11% difference in the quarter-sphere masses.

- For both: What to do about densities?
  + Calculate from old masses and design dimensions?
  + Calculate from new masses and measured dimensions?
  + Calculate from new masses and design dimensions?
  + Use densities assumed in LA-4208?
  + Measure directly?
  + Measure directly the density of parts of similar age and provenance?

- Dimensions: Given mass and density, I will find consistent dimensions.

Summary and Conclusions

- I have constructed a detailed MCNP model of a recent Flattop-25 configuration.
  + The Oy masses are wrong (too high, 0.2%-1%?).
  + The Tu masses are wrong (too high, 0.1%-10%?).
  + The Oy and Tu densities are wrong (too low? 0.4%?).
  + k_{eff} is wrong (too high, 0.63%).

- Path forward:
  + Weigh all the Oy parts and as many Tu parts as we can to benchmark precision.
  + Explore options for measuring the density of some of the parts (or similar parts).
  + Explore options for obtaining high-precision dimensions.
    - This may be the only way to characterize the the ½-ton and ¼-ton reflector parts.

Comments?

- favorite@lanl.gov
- (505) 667-7941