MCNP4C Photon Dose Calculations Compared to Measurements

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OVERALL GOAL

Re−calculate neutron and photon dose rates for PWR fuel in dry storage.

CONFIGURATIONS

- canisters
- transfer casks
- bunkers *(photons reported here)*

ISFSI

Independent Spent Fuel Storage Installation

Two PWRs
NUHOMS 24P Design
Focused on two recent canisters
Had radiation surveys

CANISTER

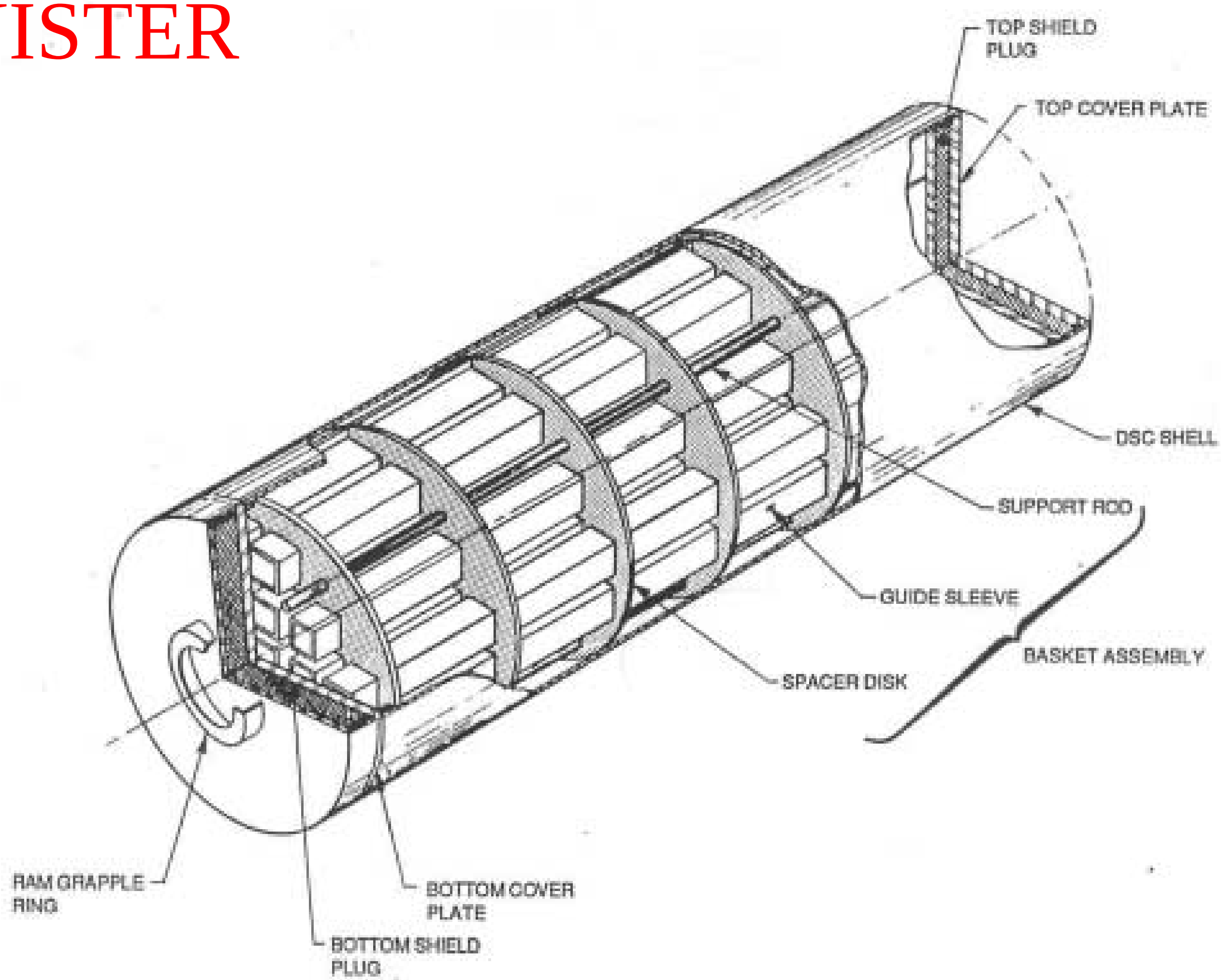


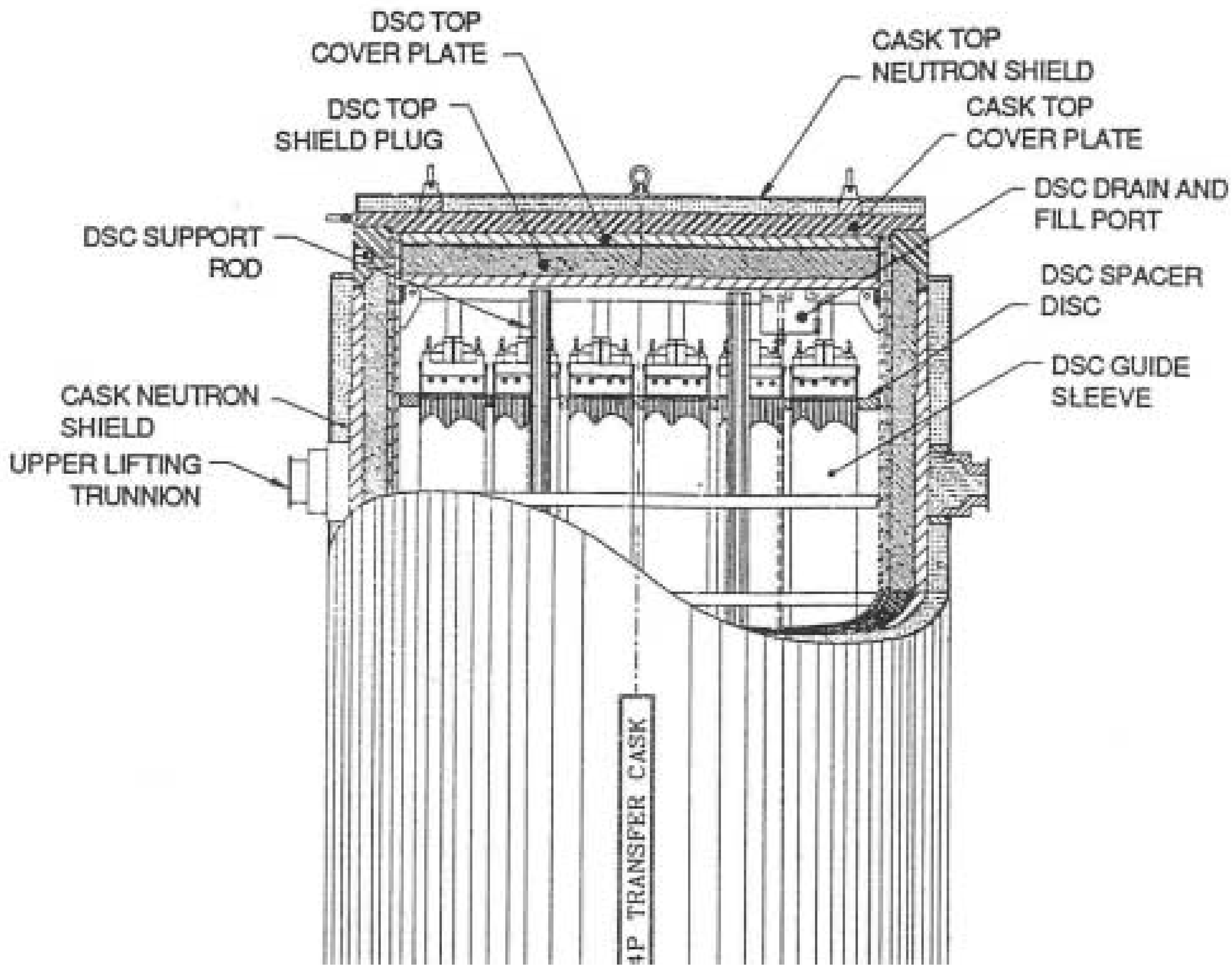
Figure 1.3-1

NUHOMS®-24P Dry Shielded Canister Assembly Components

SIMILAR (NAC) CANISTER
no shell

CASK

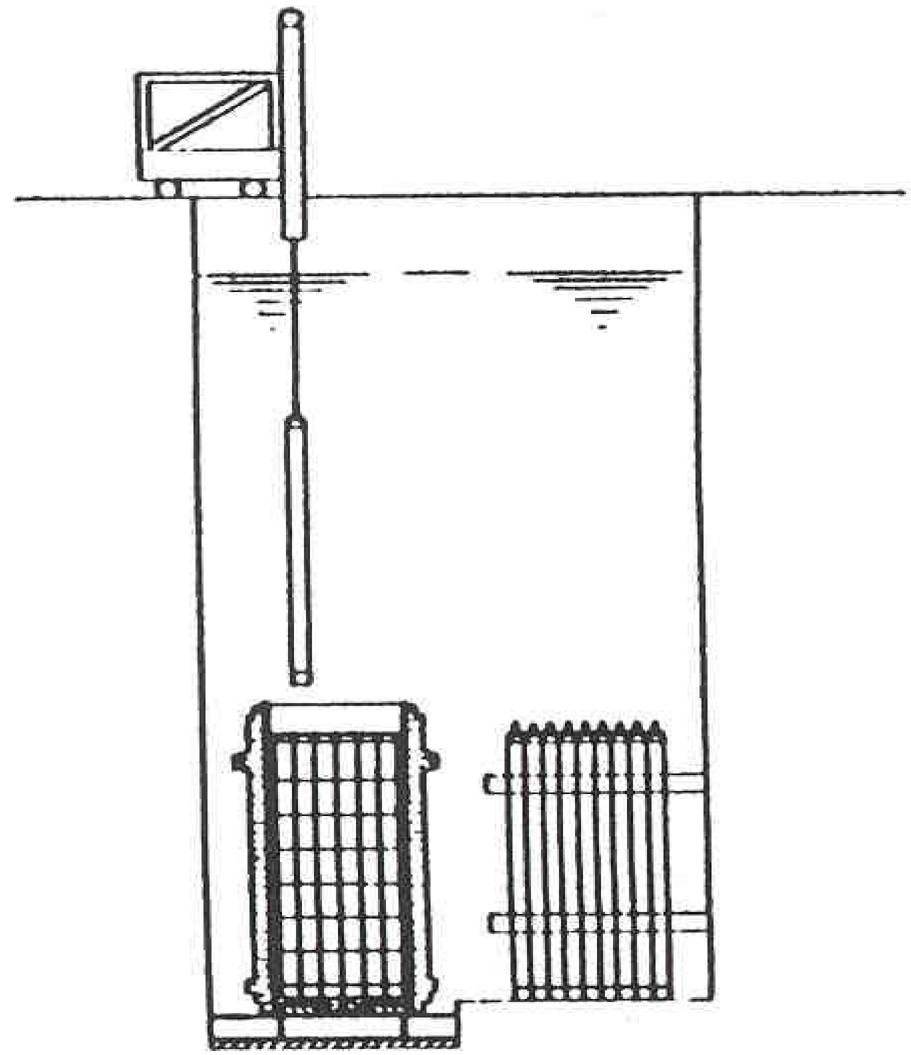
CASK TOP SECTION



BUNKERS

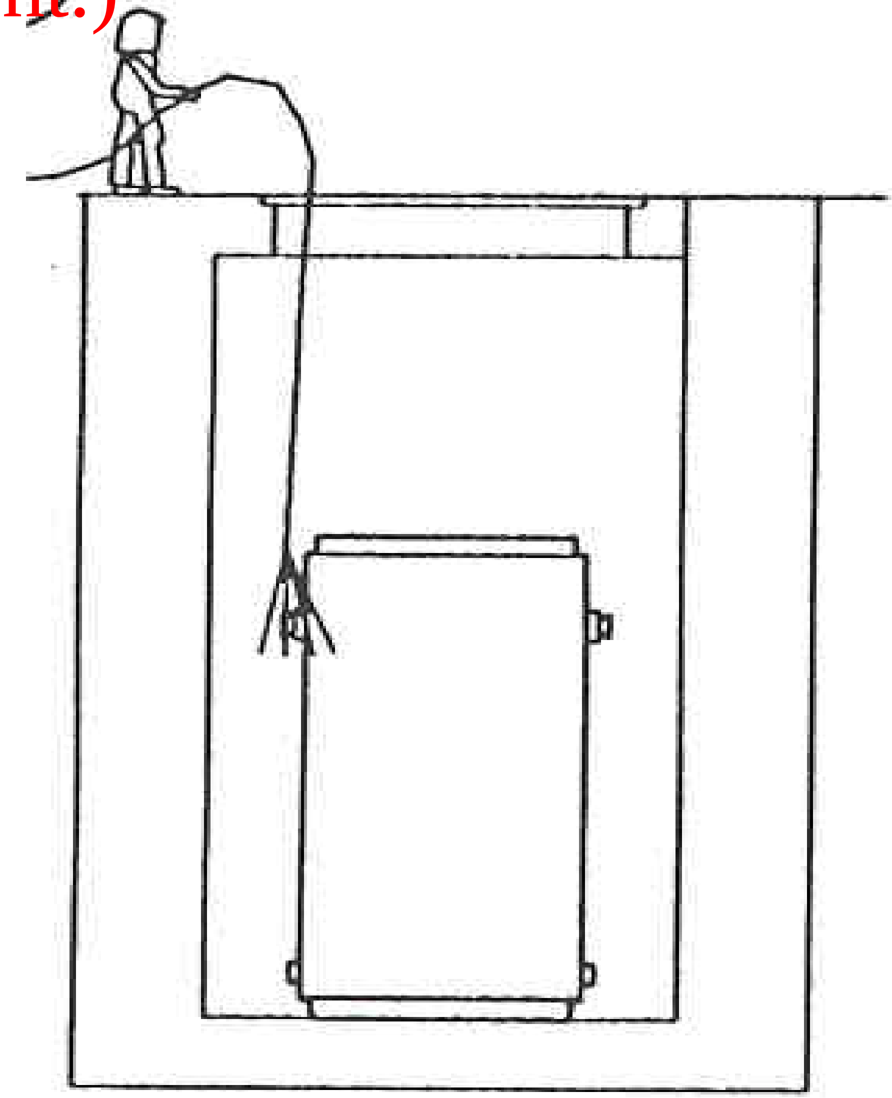
LOAD SEQUENCE

1. Canister Into Cask
2. Cask Into Spent Fuel Pool
3. 24 Assemblies Loaded Into the Canister



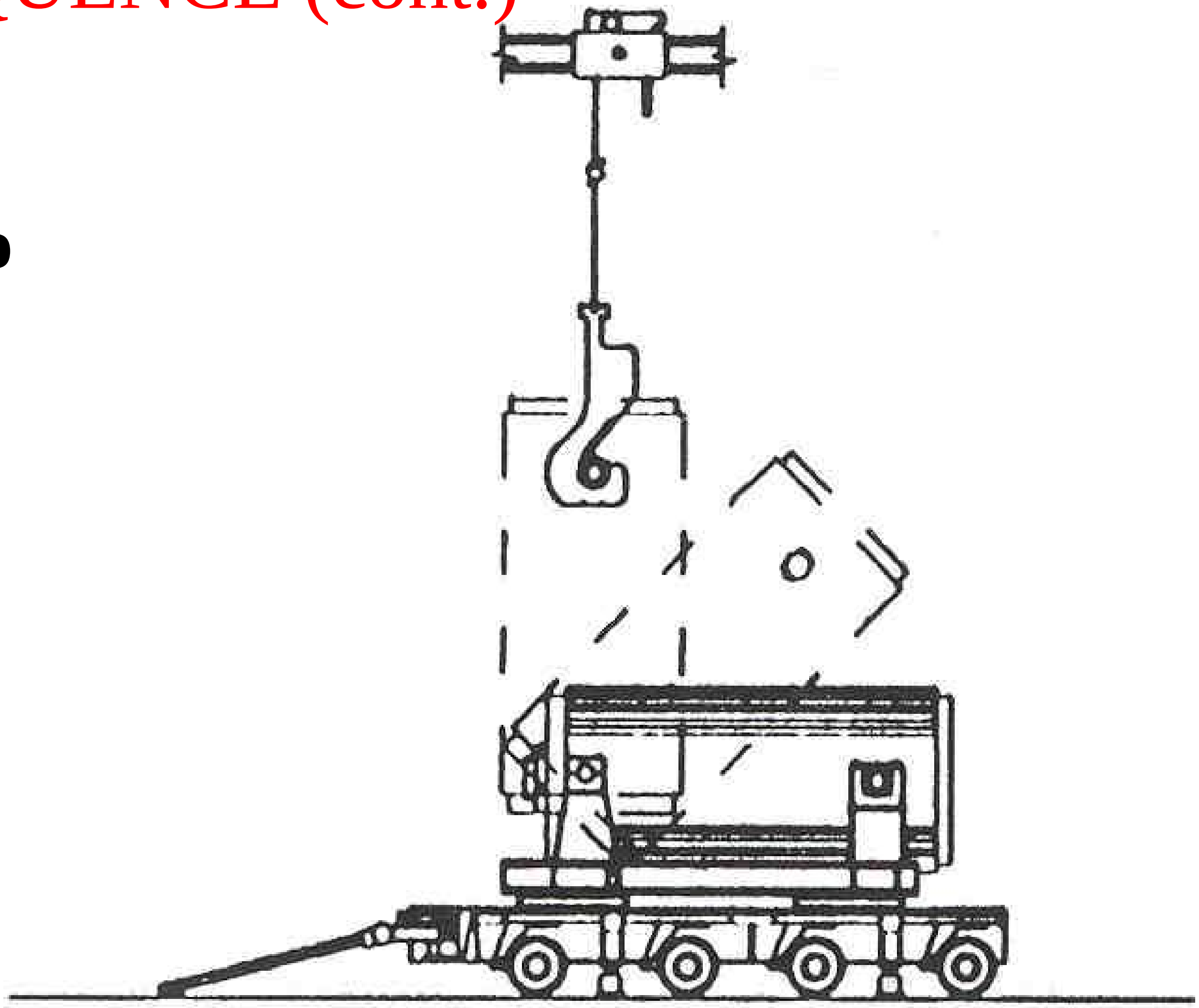
LOAD SEQUENCE (cont.)

4. Cask Hoisted to Cask Pit and washed
5. Canister Dried, Welded, Surveyed
6. Cask Closed and Surveyed



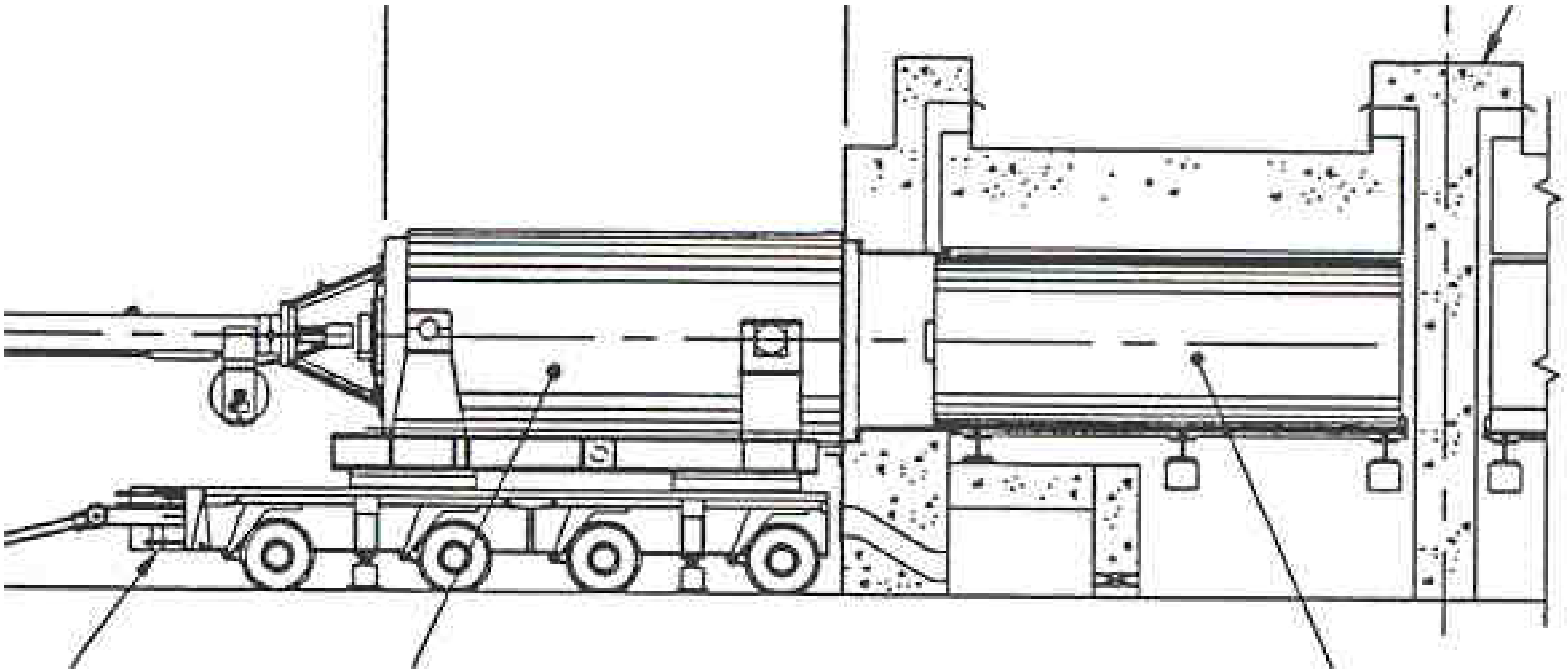
LOAD SEQUENCE (cont.)

7. **Cask hoisted to truck**
8. **Truck driven to Bunker**



LOAD SEQUENCE (cont.)

9. **Canister Pushed into Bunker**
10. **Bunker Door Shut**



SOURCE POWER METHOD

ORIGEN2.1 *(historical reasons)*

- Various axial burnups
- Luksic flux factors for end−fittings+ Empirical adjustments

CANISTER LOAD

10	metric tons fuel
21	assemblies
	@40 GWD/MTU
3	weaker
12	years decay
16	kW heat
4.2E16	photons/s
3.8E9	neutrons/s

CANISTER LOAD (cont.)

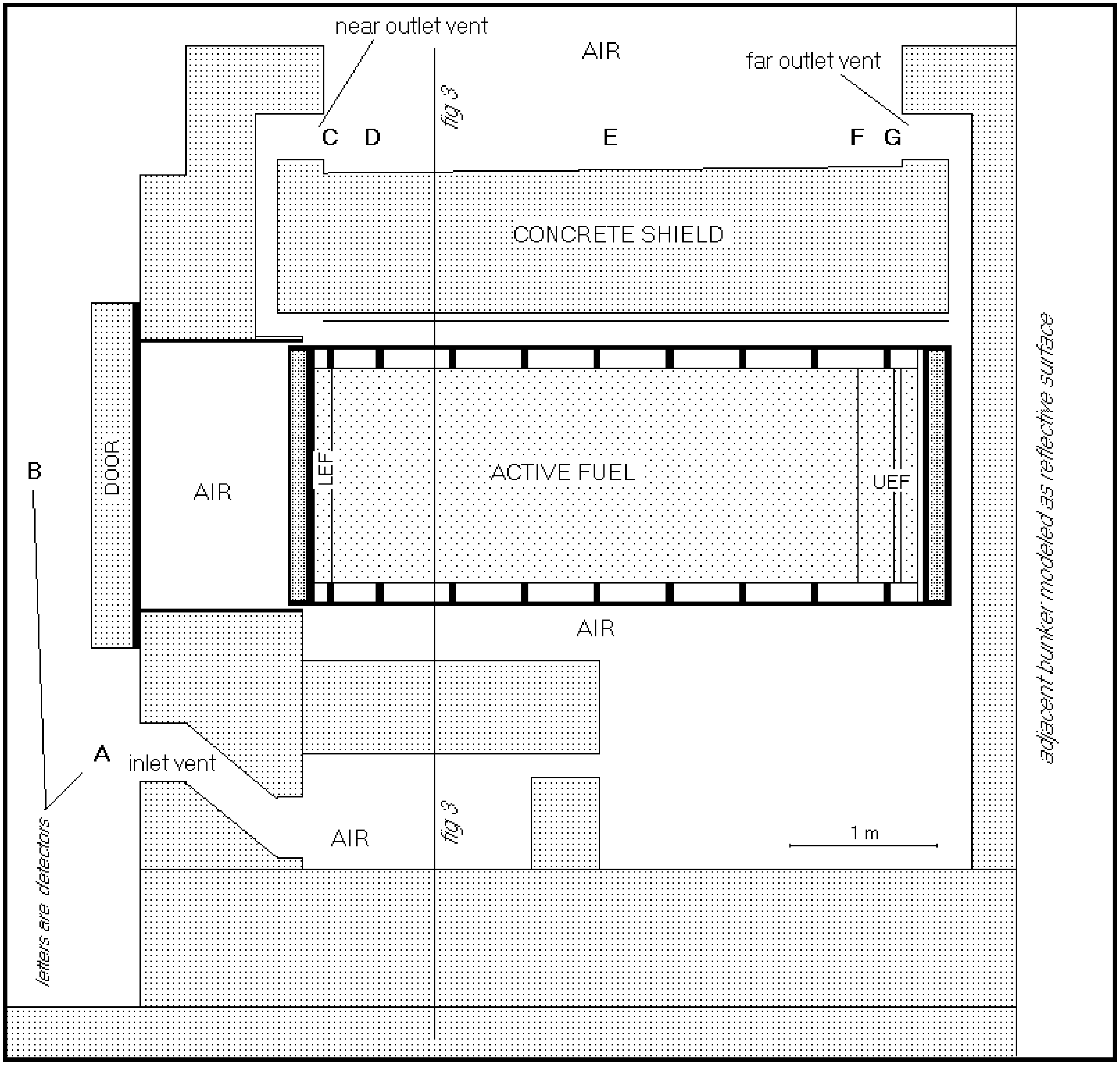
Assembly	Burnup GWD/MTU	Decay years	Enrichment % U235
1	44.6	11.7	3.40
2	43.5	11.7	4.05
3	43.4	11.7	4.05
4	43.4	11.7	4.05
5	42.7	11.7	4.05
6	40.0	12.7	4.05
7	39.9	12.7	4.05
8	39.9	12.7	4.05
9	39.9	12.7	4.05
10	39.8	12.7	4.05
11	39.4	12.7	3.40
12	39.3	12.7	4.05
13	39.1	12.7	4.05
14	38.3	12.7	4.05
15	38.2	12.7	4.05
16	38.1	12.7	3.40
17	37.6	11.7	4.05
18	36.5	12.7	4.05
19	36.4	12.7	4.05
20	36.4	12.7	4.05
21	36.4	11.7	4.05
22	31.9	16.6	3.65
23	30.5	19.9	2.99
24	27.5	21.2	2.45
ave	**38.4**	**13.2**	**3.84**
std err %	**10**	**18**	**11**

DOSE CALCULATION SUMMARY

MCNP4C − four models
Homogenized fuel
Eleven axial source regions
Basket detail
Concrete re−bar/aggregate
R0−2 energy response

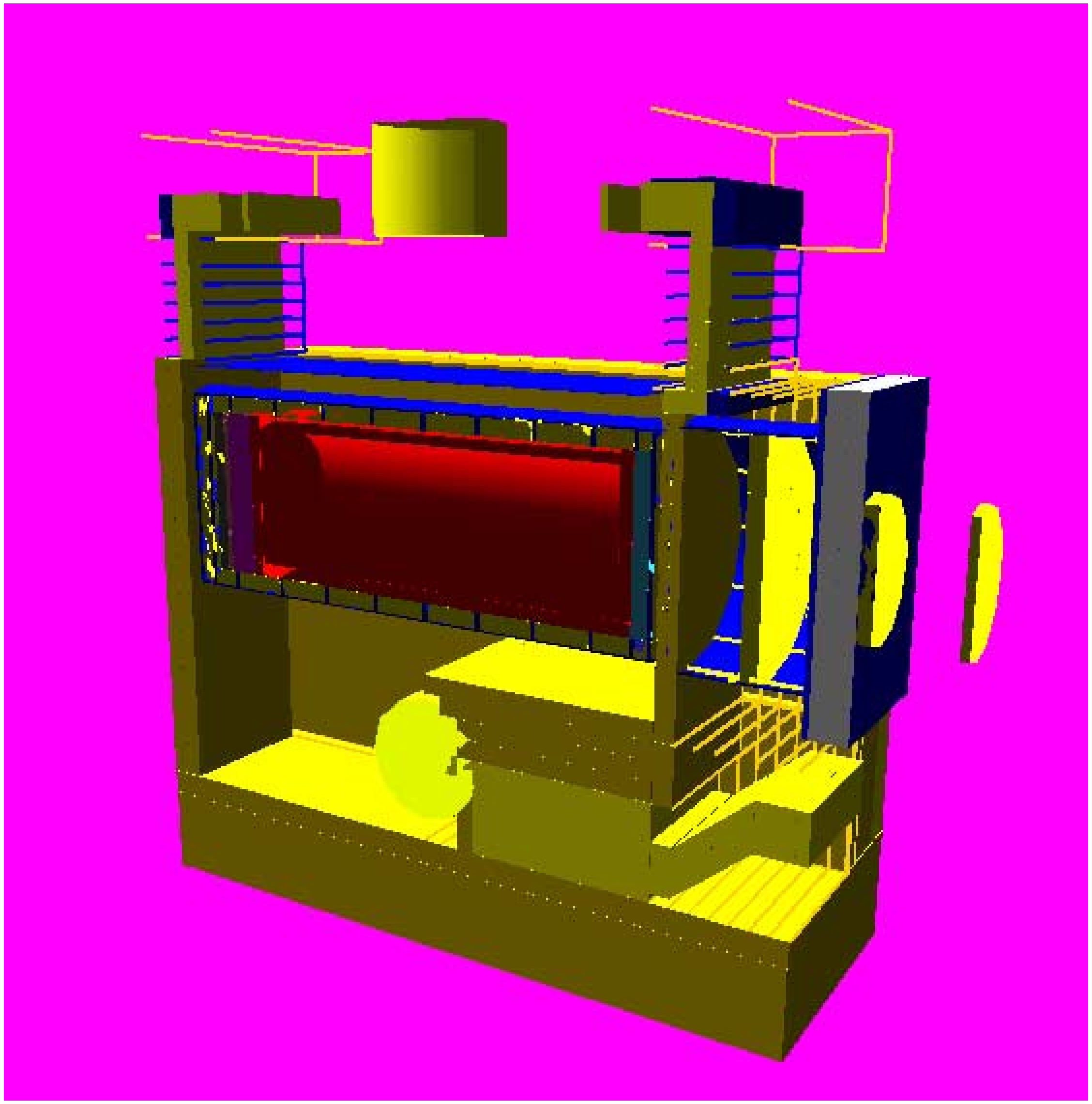
BUNKER MODEL

Note Detectors A through G



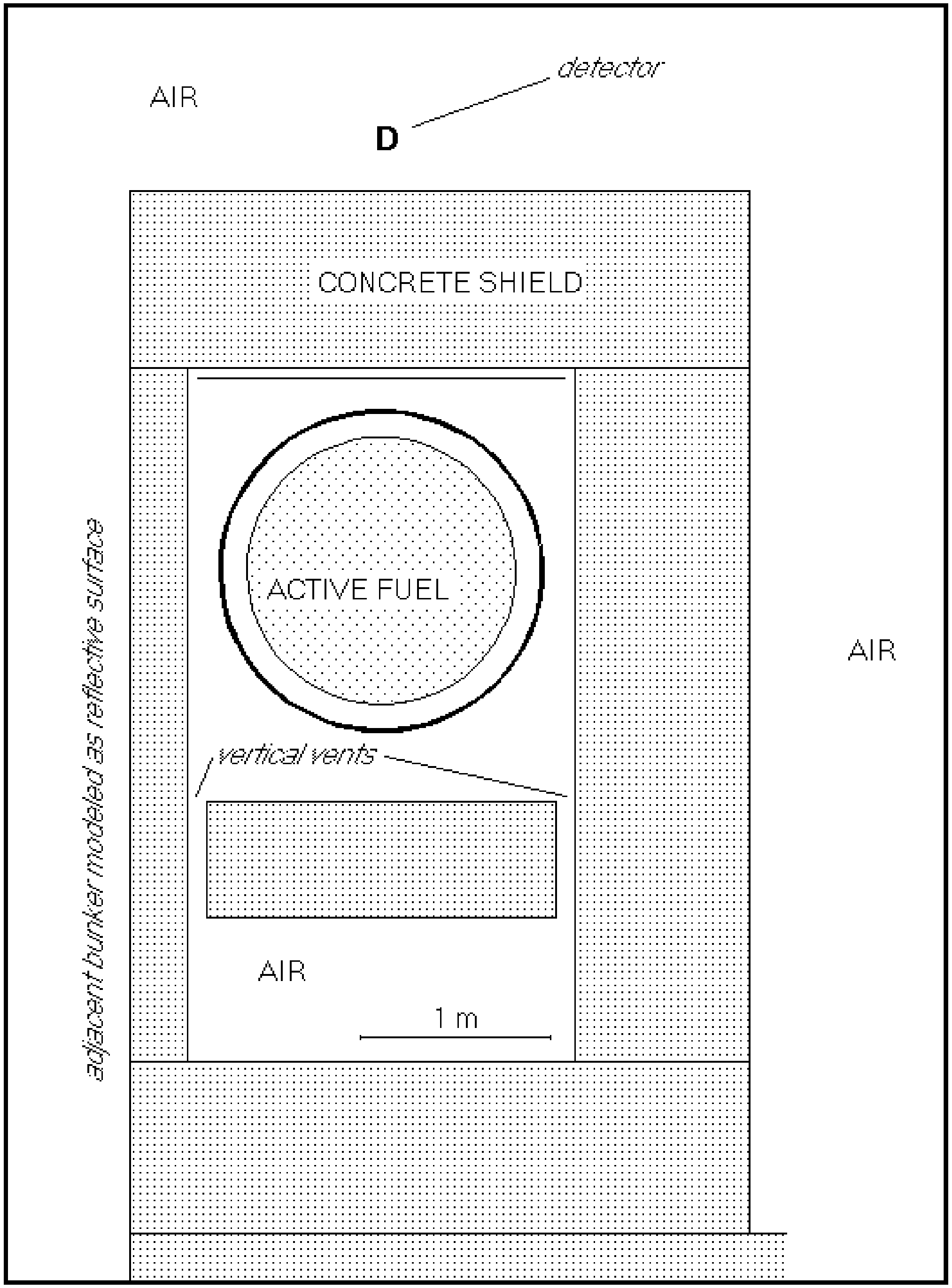
BUNKER MODEL VIEW by MORITZ

(Ken Van Riper)



BUNKER MODEL

cross section



RESULTS SUMMARY

Model	Description	Range C/M
1	Base Model	1.8 − 17.5
2	+basket and rebar	1.8 − 9.5
3	+axial burn-up	1.6 − 3.3
4	+Eberline RO-2 response	0.96 − 2.2

CONCLUSION

ORIGEN2.1 and MCNP4C
can achieve
C/M of 0.96 to 2.2.

CALCULATIONAL CHALLENGES

- Source Nuclides
  - Cs137 Axial Dist.
  - Co60 End Fittings
  - Cm244 Fuel
- Source Depth
  - 70 cm (18 mfp = infinite)
- Shield Depth
  - 90 cm concrete (18 mfp)
  - 11 cm lead (11 mfp)
- Vent Streaming
  - 3−dimensional
  - energy shift from 1 to 0.1 MeV

CALCULATIONAL OPTIONS

1. Parametrics (QAD and GGG)
   - Not made for neutrons
   - Not made for penetrations

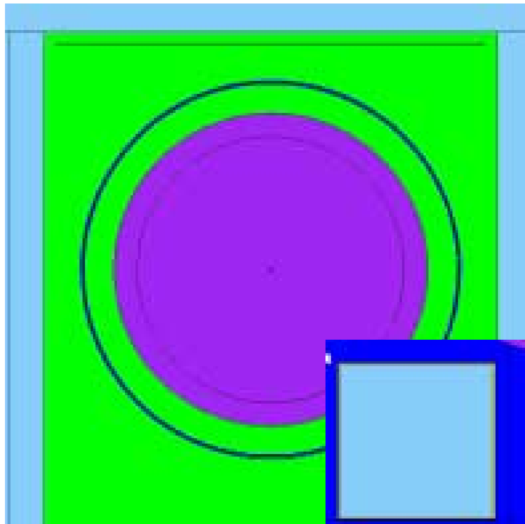
2. Discrete Ordinates (DORT)
   - Quadrature sets require user attention
   - Not made for 3D

CALCULATIONAL OPTIONS

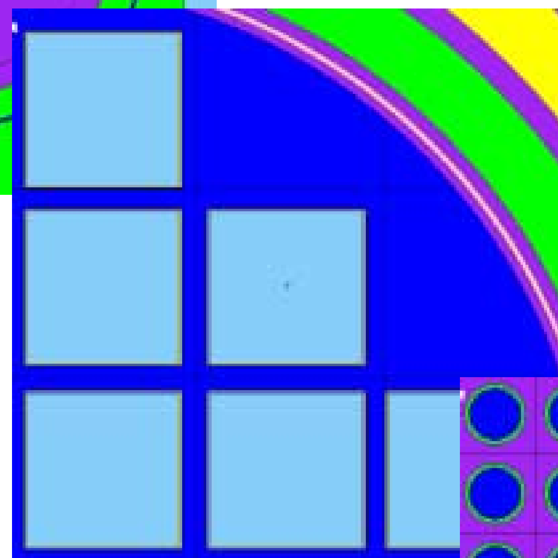
3. Monte Carlo − Detailed Geometry
    - Pin or Assembly detail
    - Not required − 1 mfp = 4 cm

4. Monte Carlo − Homogenized Geometry
    - Measurements
    - Increase Detail Until Desired C/M
    - C/M = Calculated/Measured Ratios

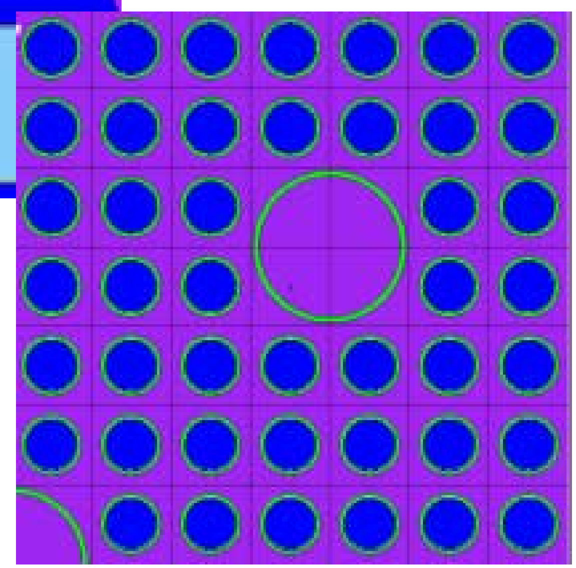
fuel



assemblies



pins



MODELING
DETAIL

MCNP4C Models − Increasing Detail

Model 1 − Base Model

Model 2 − added re−bar and basket

Model 3 − added axial detail

Model 4 − added detector energy response

MCNP MODEL 1

Three axial source regions:
- Lower end fitting
- Active fuel
- Upper end fitting

Concrete density 2.4 g/cc

Dose rates in mrem/h *(ANSI 6.1.1.−77)*

RESULTS

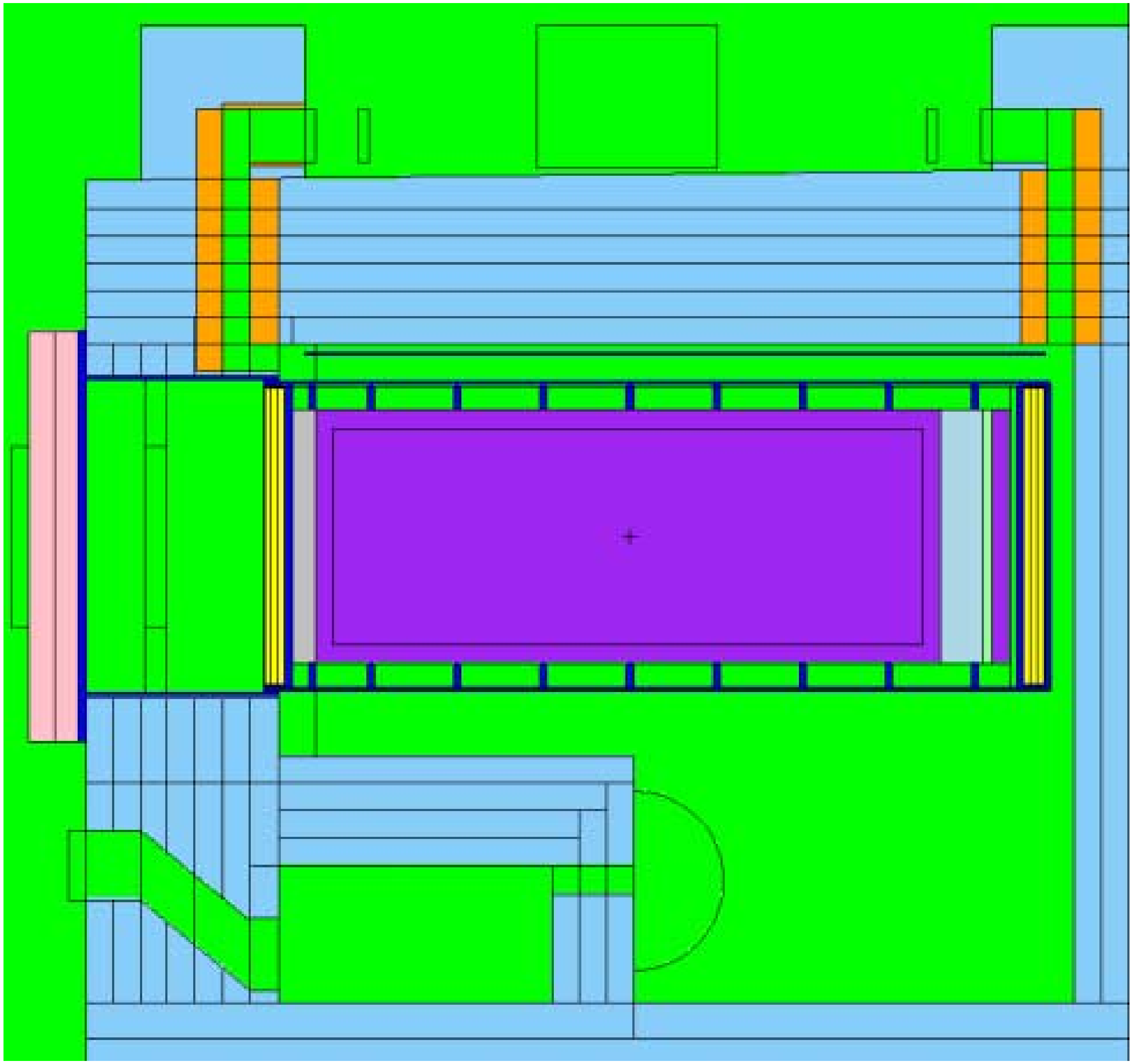
- $2 < C/M < 18$

MCNP MODEL 2

Added canister basket
Added multiple concrete regions
- re−bar
- empirical aggregate
- $2.44 < \text{density} < 2.52$ g/cc

RESULTS
- $2 < C/M < 10$

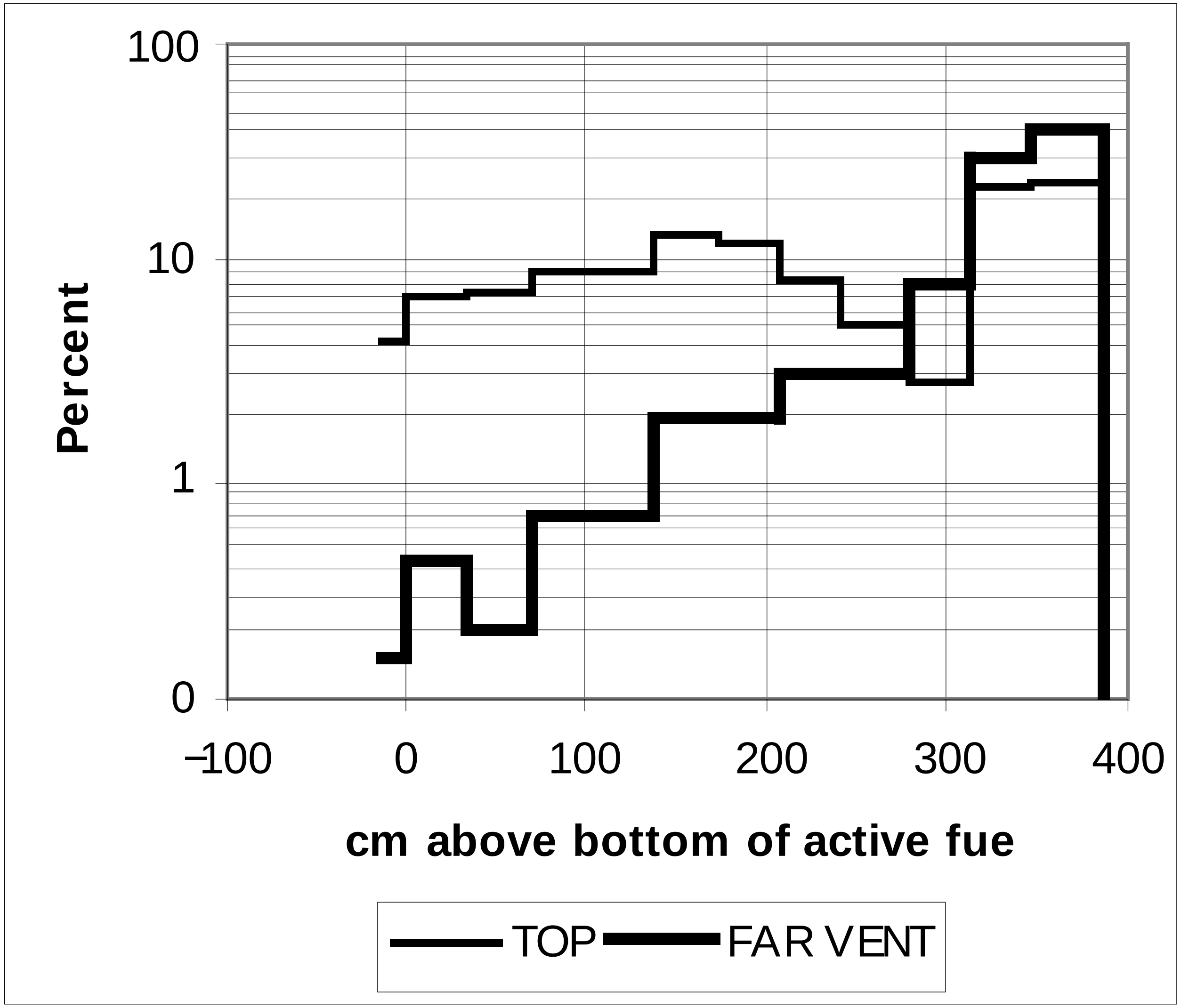
MODEL 2
(showing
re−bar)



MODEL 2
(Effect of Re−bar)

Concrete thickness (cm)	mR/h measured	C/M no rebar	C/M with rebar
61	425	3.5	1.6
91	25	3.5	1.0

MODEL 2
(Axial Sensitivity of Detectors E and G)



MODEL 3

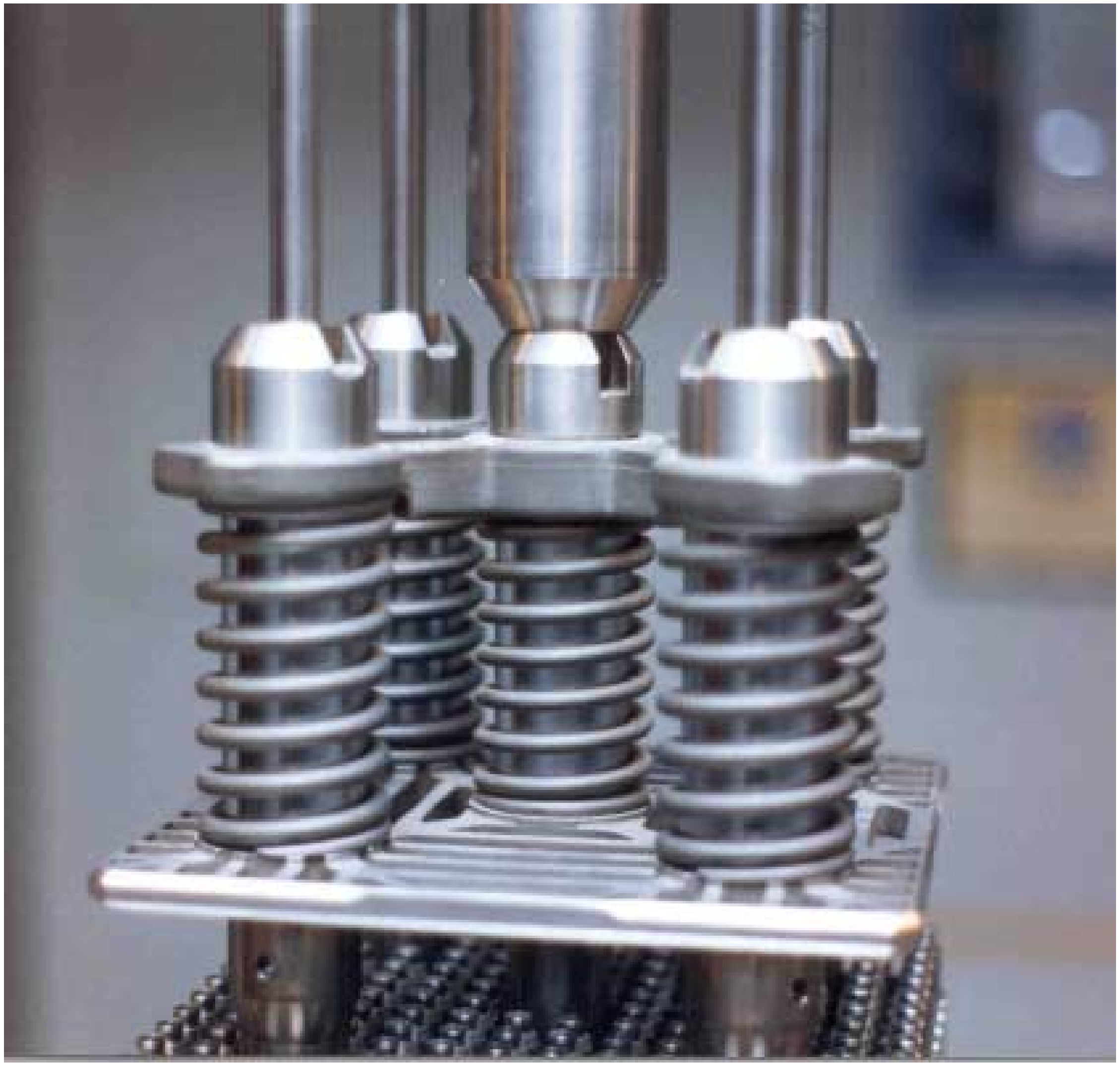
Added Axial Source Refinement

- Active Fuel – 7 Zones
- Upper End Fitting
  - 3 Zones
  - Luksic (PNL–6906) Flux Factors
  - Springs reduced 3x (empirical data)

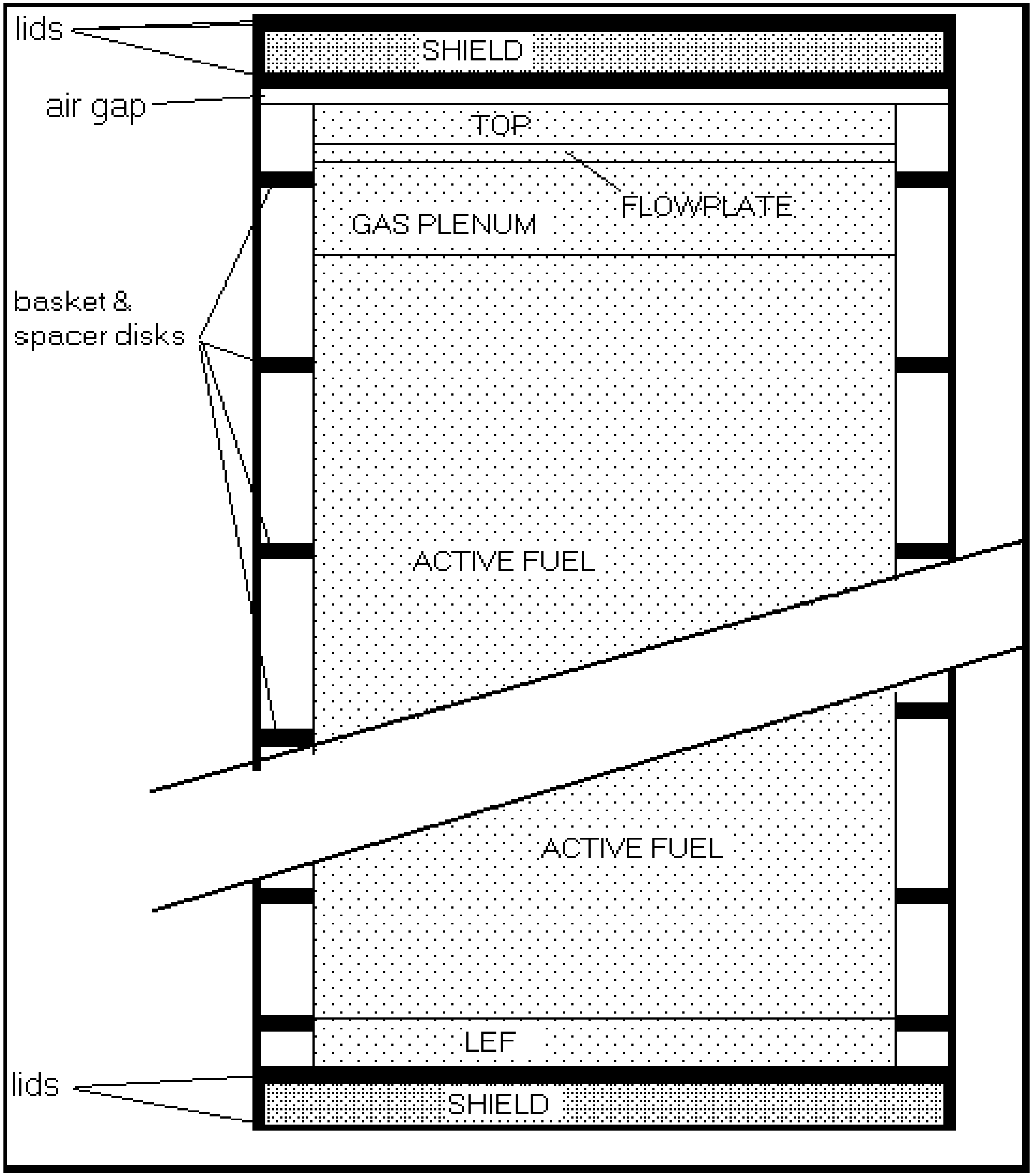
RESULTS

$1.6 < C/M < 3.3$

MODEL 3
Upper End Fitting Springs

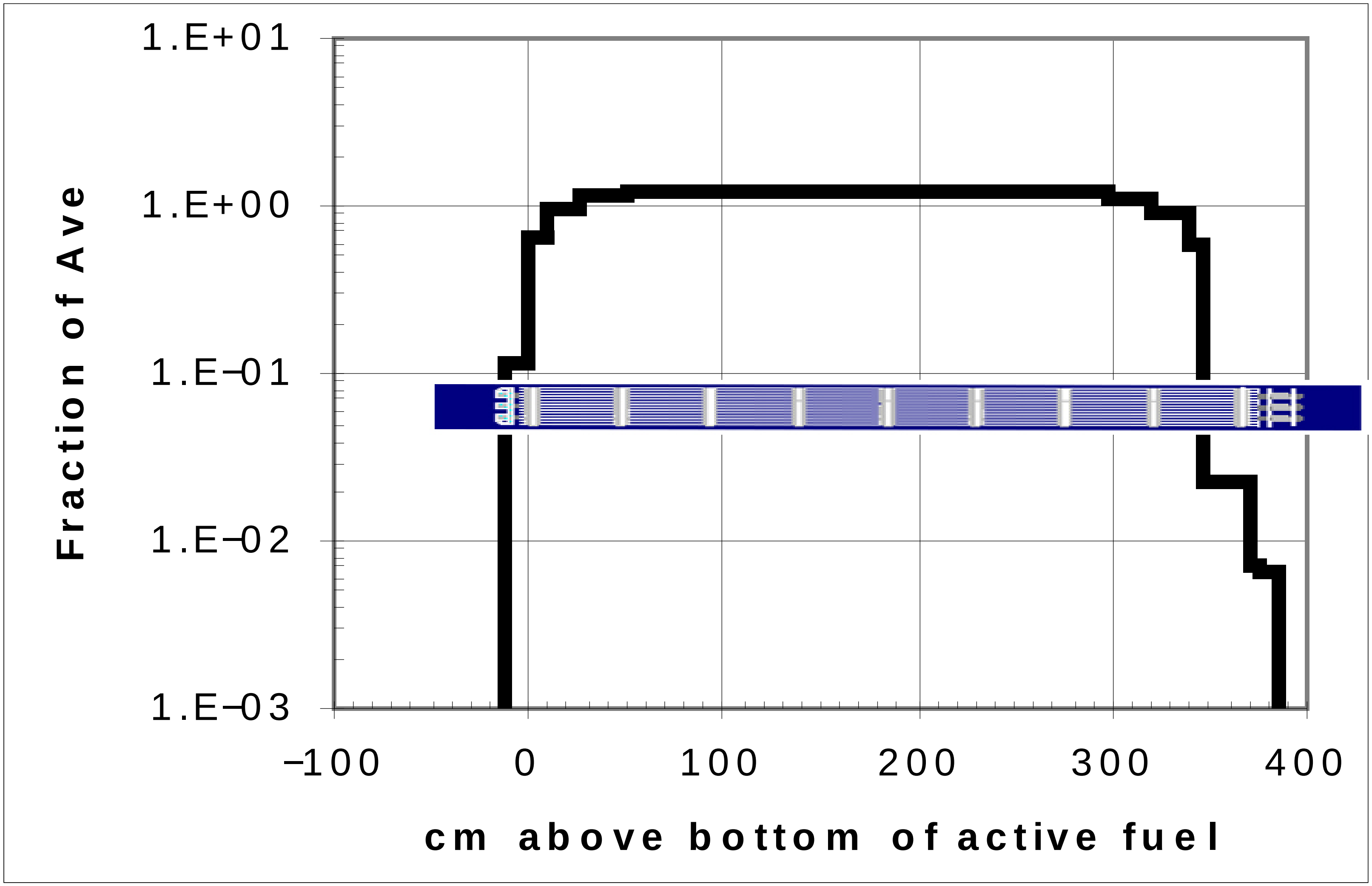


MODEL 3
Canister

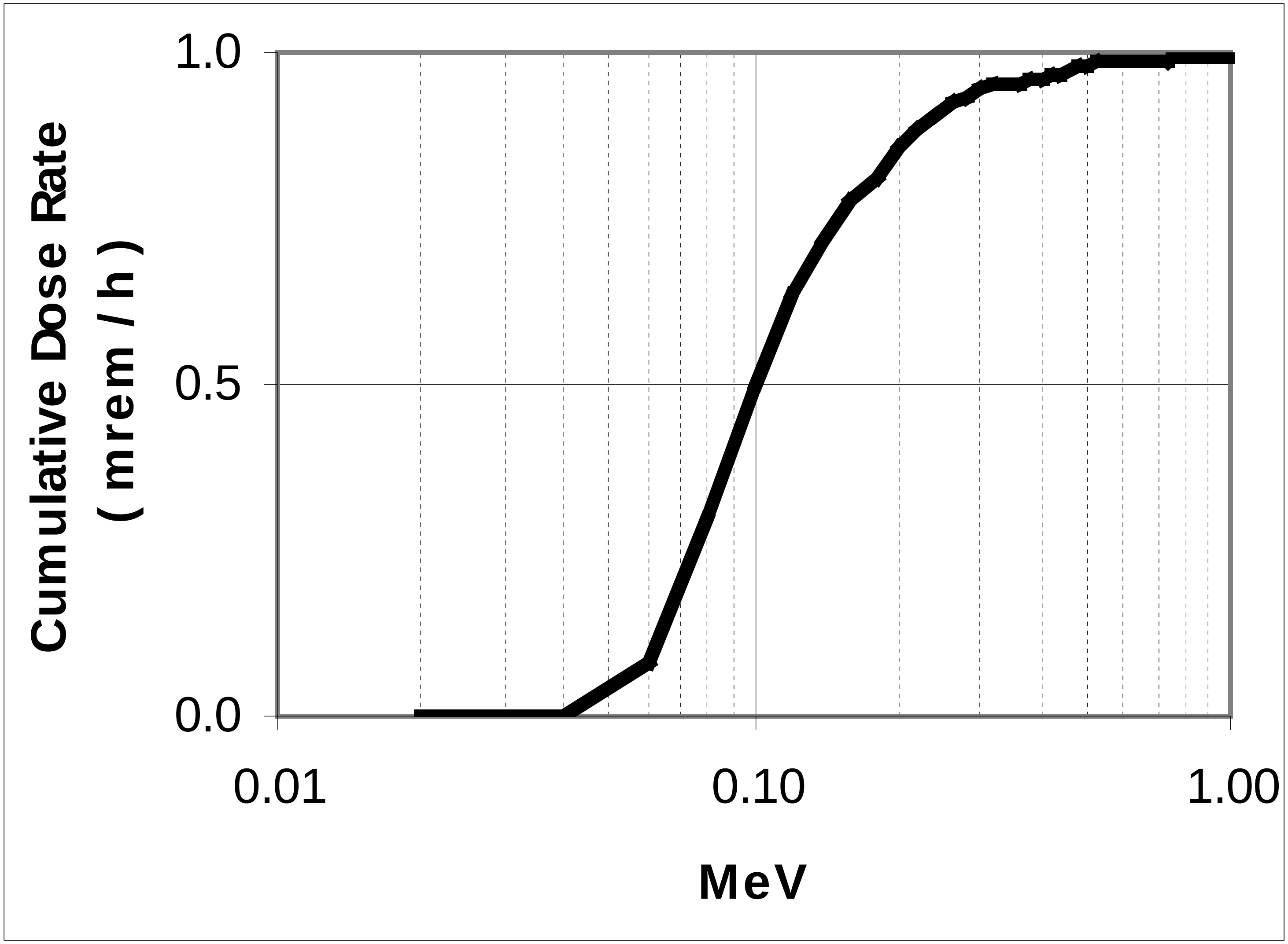


MODEL 3

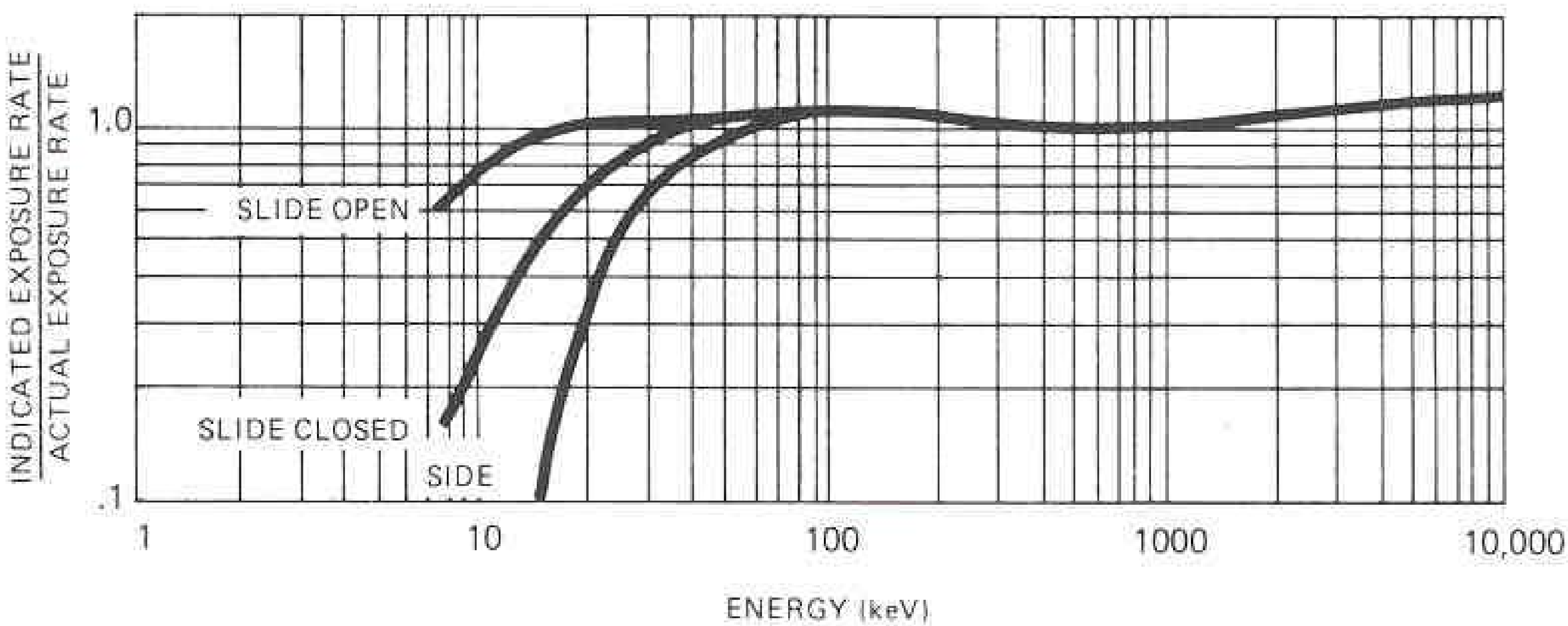
Axial Photon Distribution



MODEL 3
100 KeV Average at Vent



MODEL 4
Eberline RO−2 Energy Response



MODEL 4

Added Eberline RO−2 Energy Response

Rem vs Roentgen

(Calibrated within 10%)

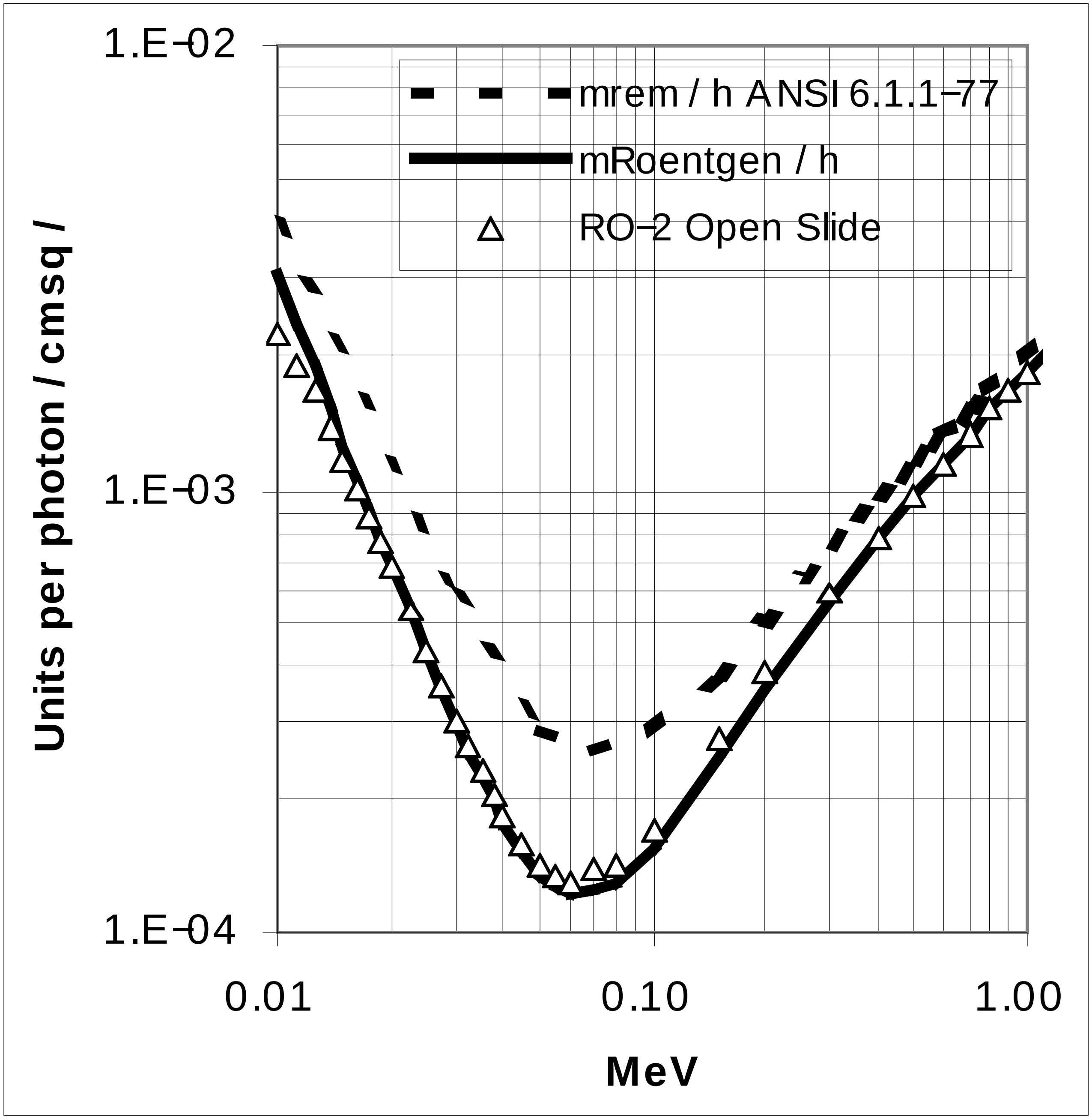
Calculated Roentgen

Corrected from 40 to 70 Degrees F

RESULTS

$.96 < C/M < 2.2$

Rem =
2 x
Roentgen
at 80 KeV



PHOTON RESULTS BY MODEL

Model	Description	Range C/M
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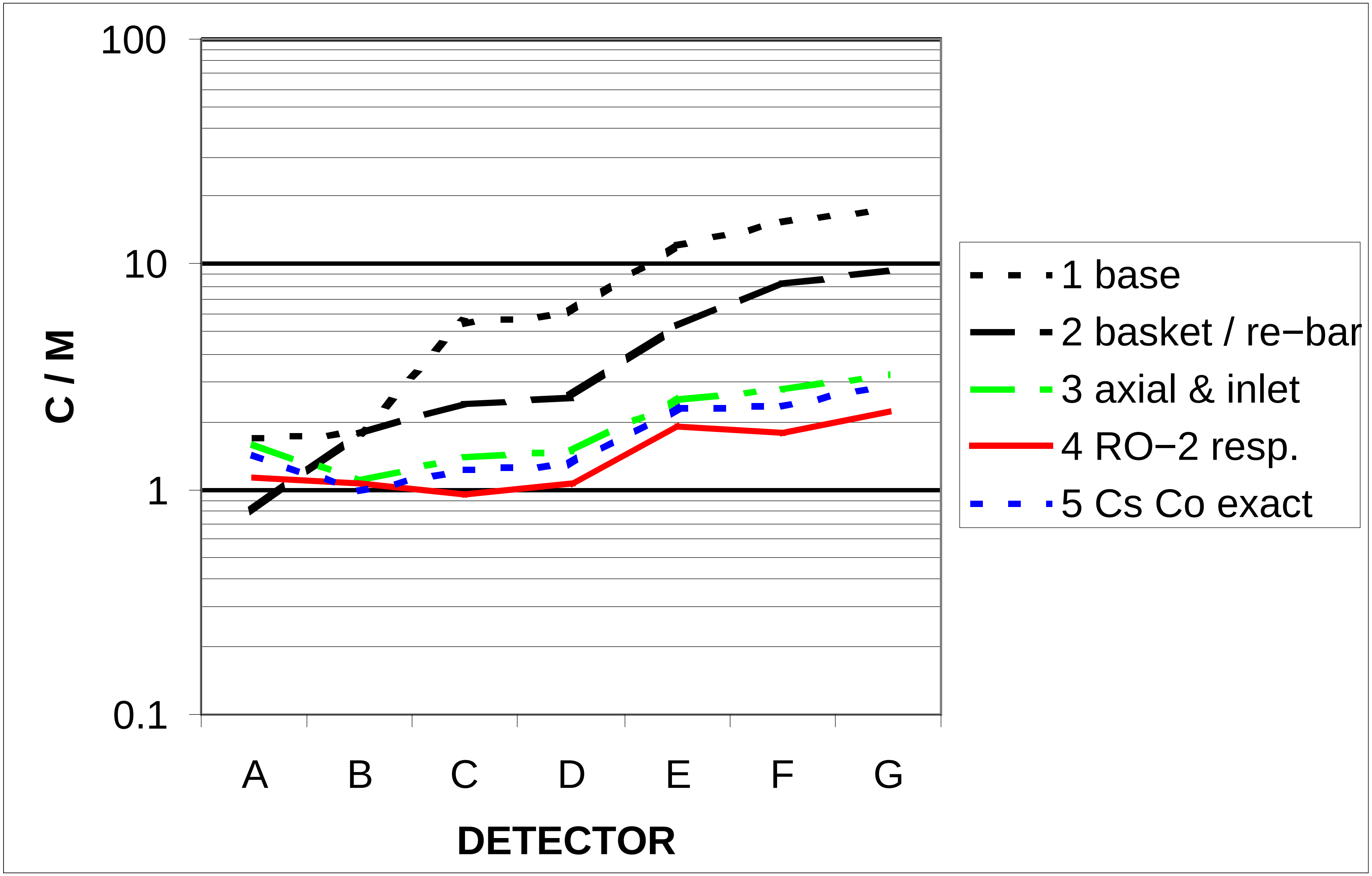
Photon C/M by Detector and Model



% CONTRIBUTION
BY PHOTON SOURCE

Detector	Lower EF	Fuel	Upper EF
A	2	96	2
B	83	16	1
C	17	82	1
D	14	84	2
E	5	83	12
F	0	69	30
G	0	67	33

Neutron C/M

Location	C/M
Top Vents	0.2 to 0.3
Contact Bottom DSC	0.7 to 0.8
Through 2 Ft Concrete	1.6

CONCLUSIONS

ORIGEN2.1 and MCNP4C can model photons from bunkered fuel within factor of two. We achieved this with:

- iteration against measurements
- homogenized assemblies
- eleven axial source zones
- end−fitting data beyond Luksic
- basket and discs
- multiple re−bar zones
- aggregate detail for concrete
- exposure energy response for detectors

NEXT TIME

Accelerate − Some runs took 3000 minutes

- Partition at Canister Surface
- Run Sources Separately

Balance Model

- Better Cell Splitting
- More regions in fuel
- Weight Windows

ORIGEN−S (more accurate energies and transuranics)

Characterize Co−60 by Measurement in Fuel Pool

Fuel Placement

MCNP4C Photon Dose Calculations Compared to Measurements

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