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KSU Co-60 Silo Skyshine Shielding Benchmarks

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Kansas State University Co-60 Silo Skyshine Experiment

Auspices

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Acknowledgement

Many thanks to Dr. Daniel Siefman for contributions to the polynomial fits used to determine the uncertainty in measured exposure rates due to the uncertainty in detector positions.

Kansas State University Co-60 Silo Skyshine Experiment

Introduction:

Roseberry and Nason provide the details of the concrete pads, concrete silo and steel cask plate, collimator wedges (for unshielded measurements) and the cover plate shields (for shielded measurements). The geometric details used in the COG simulation model are provided in the **Dimensions** sections.

Roseberry and Nason provide no information on material compositions other than some reported densities. In lieu of measured data, compositions are assumed based on data published in the PNNL compendium and by ORNL as reported in the **Materials** section.

Note that experimental results are given in units of exposure (R = Roentgens). Contemporary fluence-to-exposure data published by Rogers are used for COG simulations.

This document also cites model details published by T. Jackson (CNS).

References:

1. Murray Lee Roseberry, "Benchmark Skyshine Exposure Rates," Master's Thesis, Kansas State University, 1980.

2. Randall Robert Nason, "Analysis of Skyshine Spectral Measurements," Master's Thesis, Kansas State University, 1979.

3. Nuclear Science and Engineering: **79**, 404-416(1981), A Benchmark Gamma-Ray Skyshine Experiment," R. R. Nason, J. K. Shultis, R. E. Faw, and C. E. Clifford.

4. PNNL-15870, Rev. 2, "Compendium of Material Composition Data for Radiation Transport Modeling," April 2021.

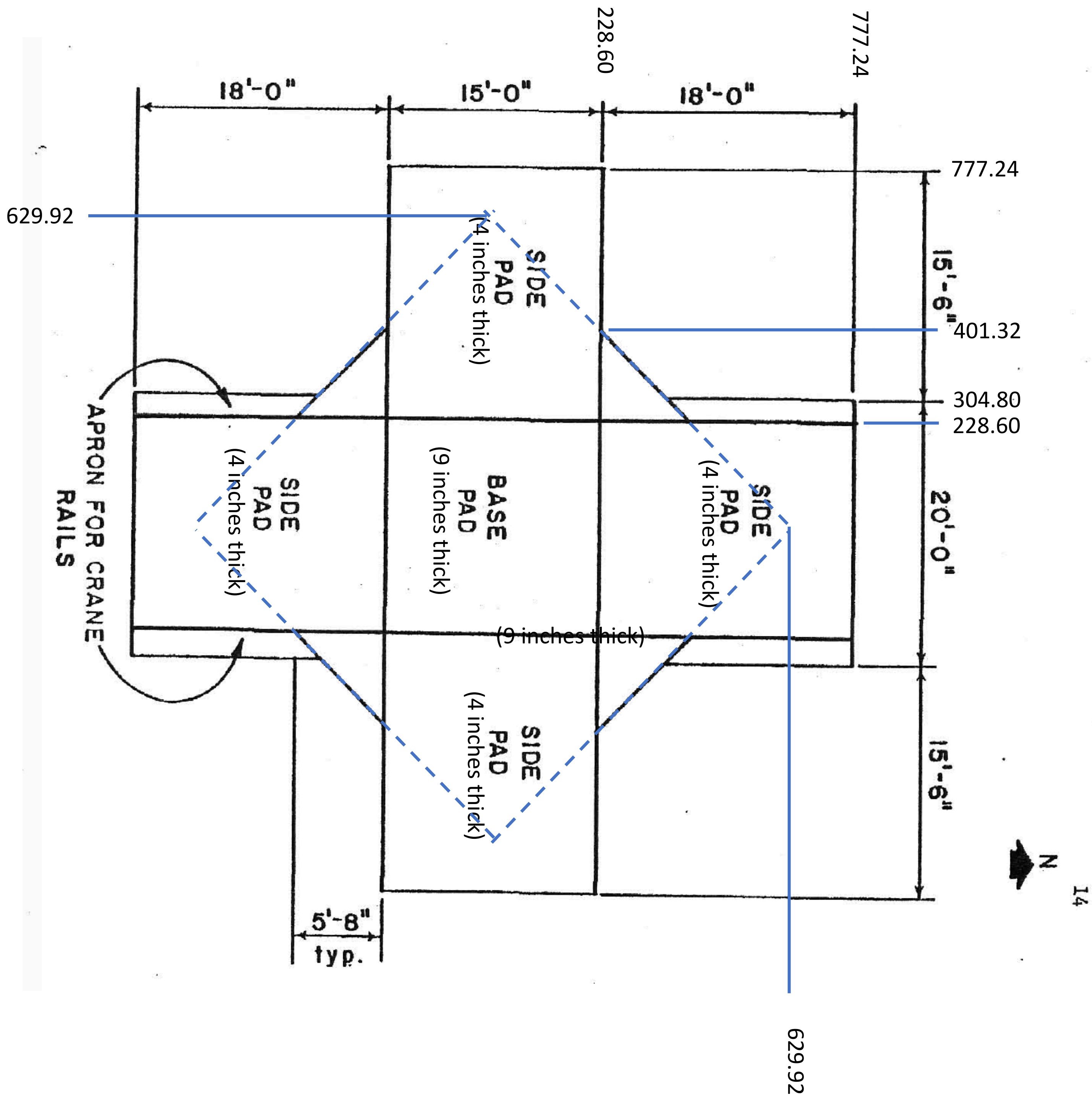
5. ORNL-4289, Vol. II, "Time-Dependent Neutron and Secondary Gamma-Ray Transport in an Air-Over-Ground Geometry, Volume II. Tabulated Data," E. A. Straker, September 30, 1968.

6. D. W. O. Rogers, "Fluence to Dose Equivalent Conversion Factors Calculated with EGS3 for Electrons from 100 keV to 20 GeV and Photons from 11 keV to 20 GeV," Health Physics: **46** (4) 891-914, 1984.

7. RP YAREA-F-0818 000 00, "Validation of MCNP6.1 for Shielding Analysis using the Workstations ENGHPC, CENGHPC, and ENGHPC02," Timothy D. Jackson, Consolidated Nuclear Security, LLC, March 2, 2017.

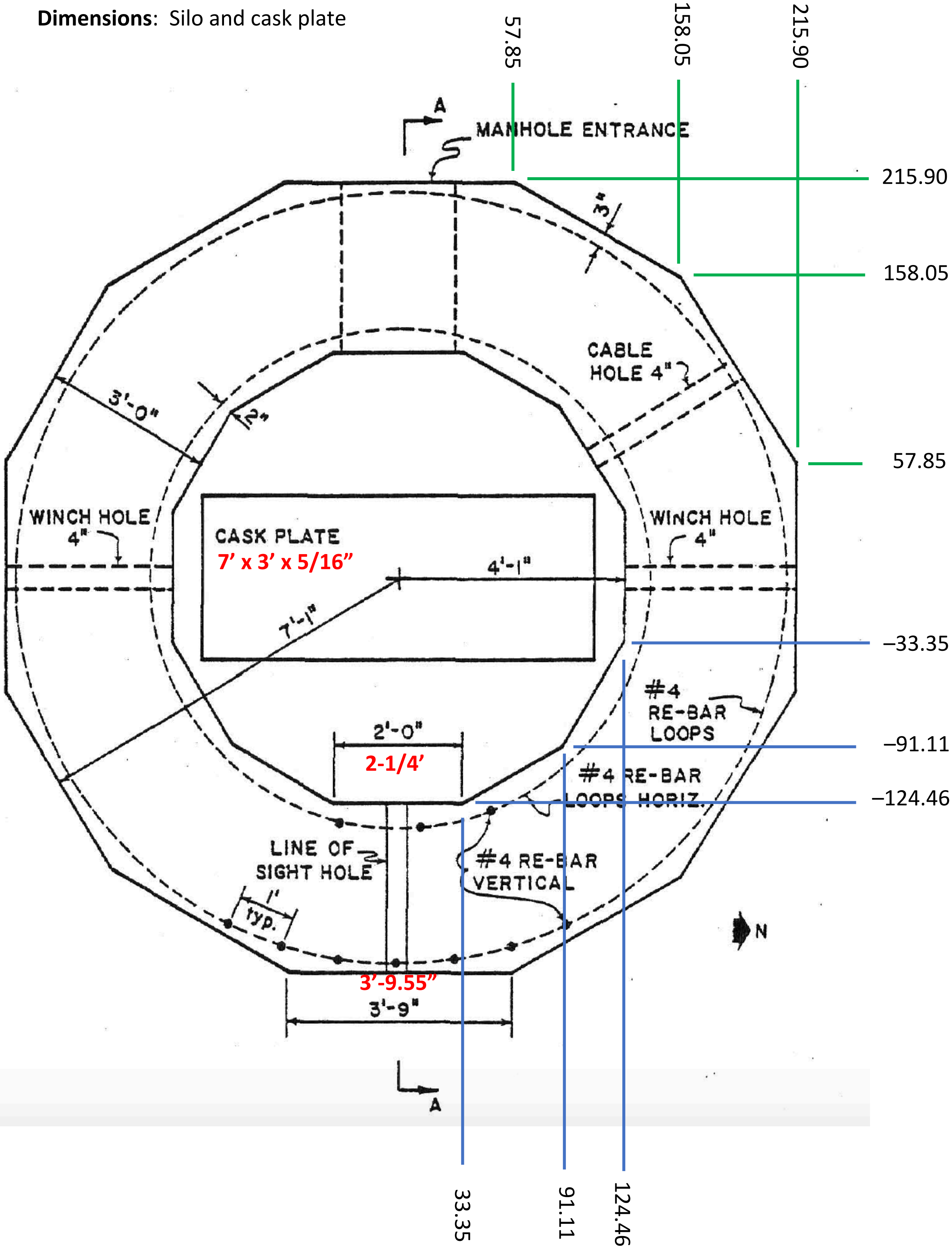
Kansas State University Co-60 Silo Skyshine Experiment

Dimensions: Concrete Pads



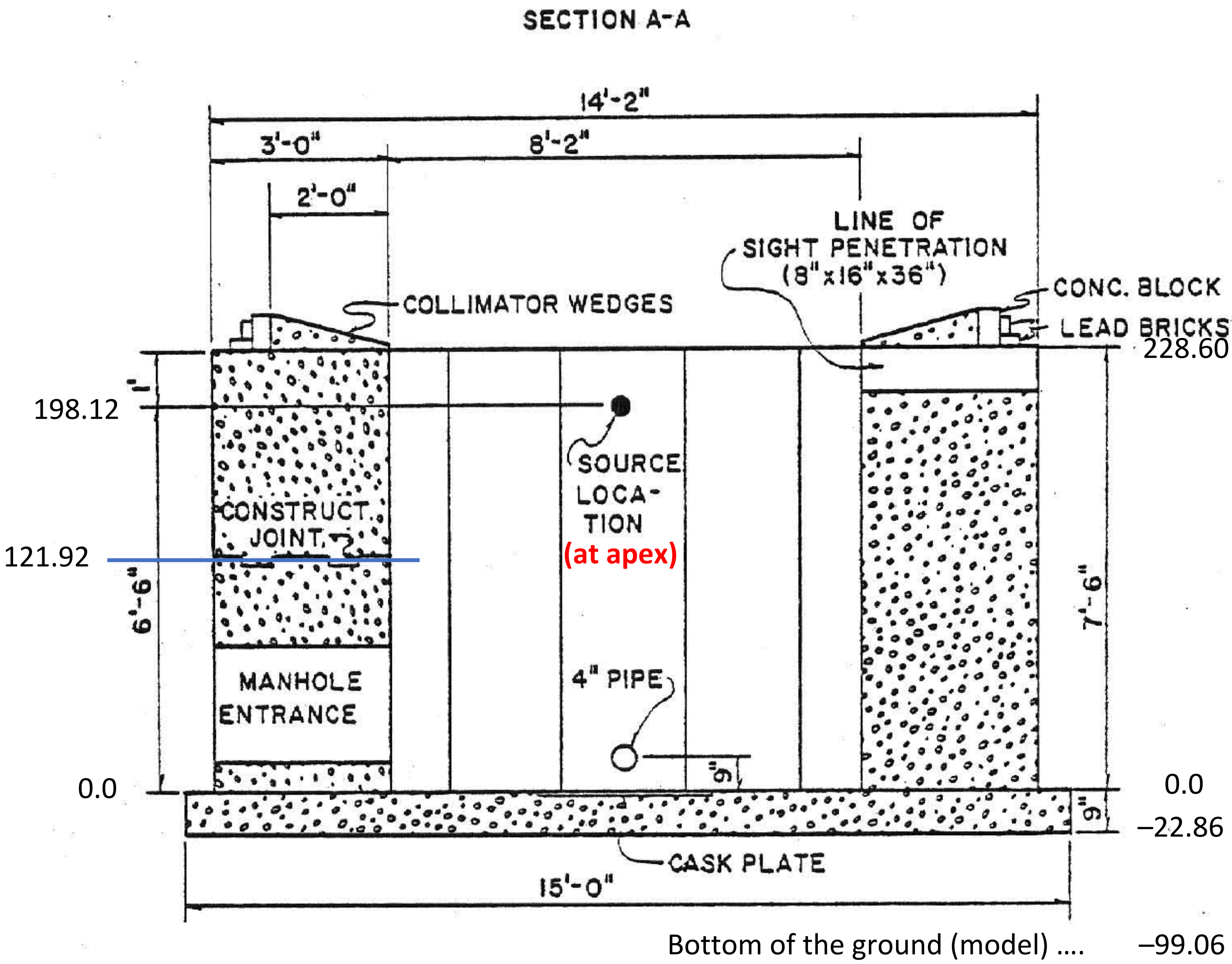
Kansas State University Co-60 Silo Skyshine Experiment

Dimensions: Silo and cask plate



Kansas State University Co-60 Silo Skyshine Experiment

Dimensions: Elevation view



Notes:

1. CNS models the ground extending to a depth of 30 inches beneath the concrete pads.
2. Air extends 1000 meters or 100,000 cm above and horizontally from the source.
3. The ground also extends 100,000 cm horizontally from the source.
4. The concrete collimator wedges are modelled but the backing concrete blocks and lead bricks are omitted from the model.
5. The detectors are 1-foot radius tori at 198.12 cm elevation and various radial distances.
6. The details of the source casks and cask cart are unknown and not included in the model.

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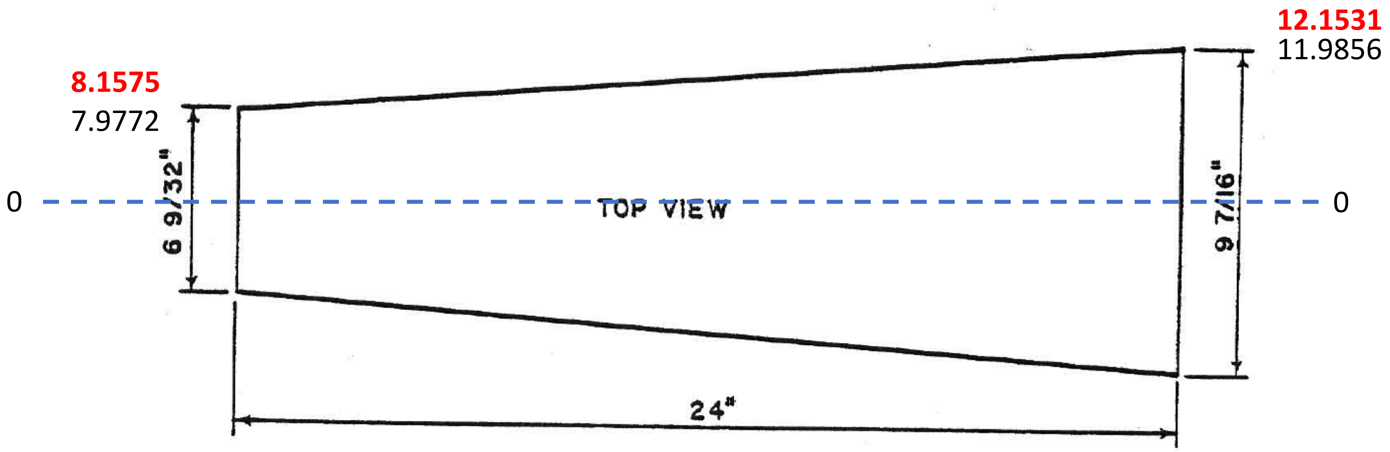
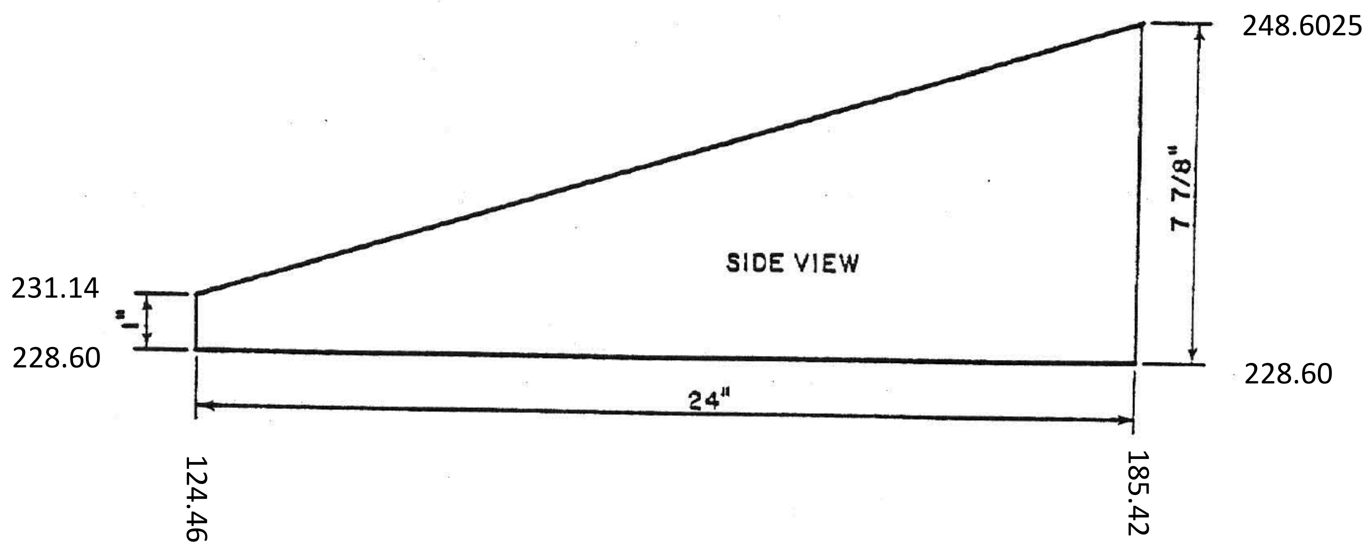
Dimensions: Collimator Wedges for unshielded Skyshine measurements

Note: 48 wedges formed an annulus with an inside diameter of 249 cm. Values in **RED** correspond to 48 wedges (3.75 degree half-angle) with no gaps. The gaps are included in the model.

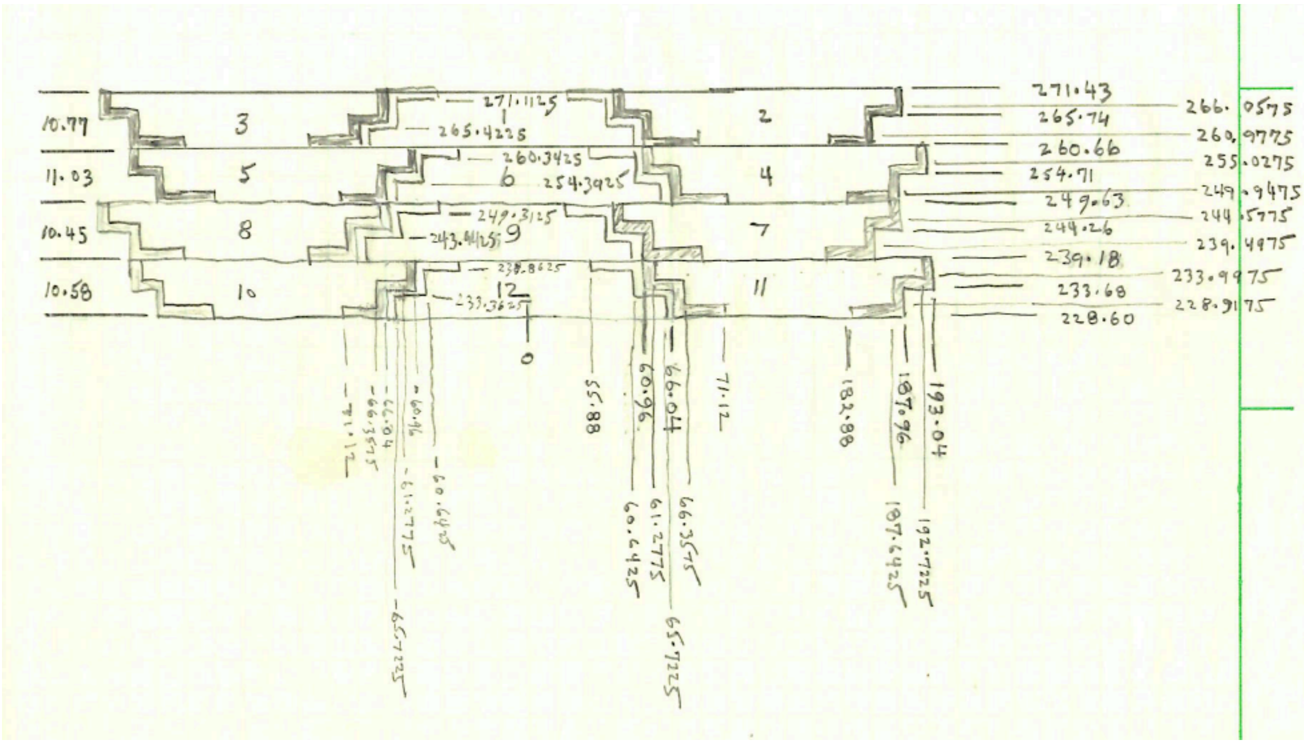




Kansas State University Co-60 Silo Skyshine Experiment

Dimensions: Concrete Silo Roof Shields (see Roseberry, Figs. 2-6 & 2-7 (below)).

Notes: No rebar is present in the model. The width of 3 shields is 3 x 4’4” = 156 in. = 396.24 cm.



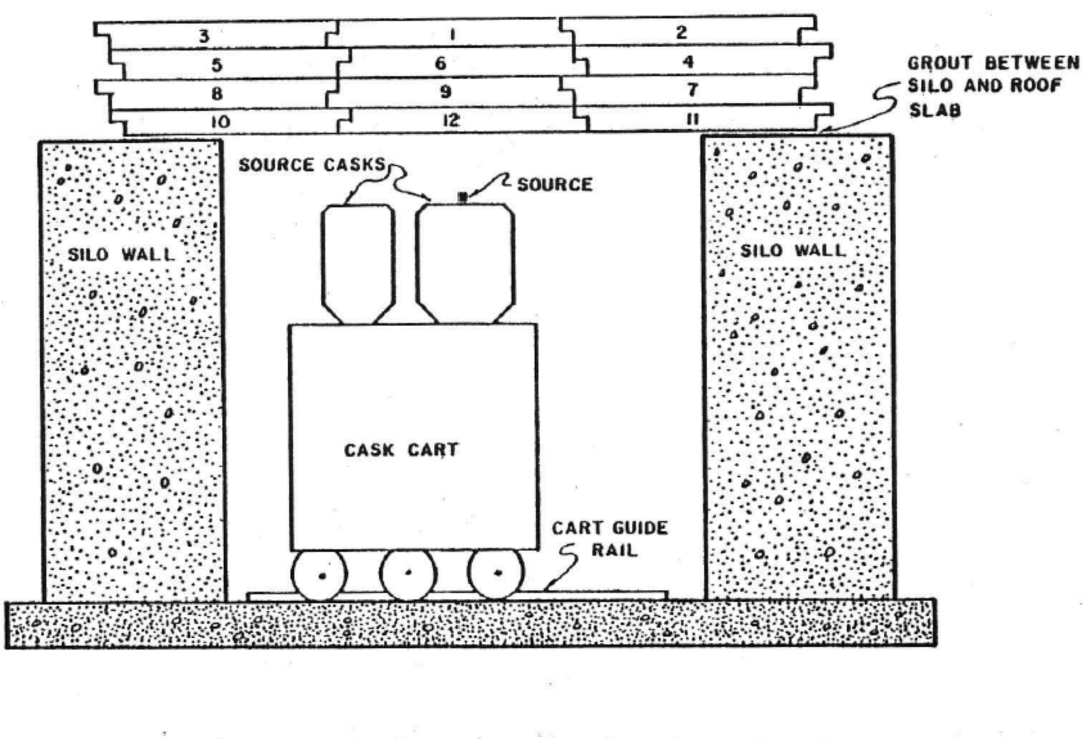


Fig. 2-7. View of the source silo showing the roof slabs in position for the shielded source configuration.

Kansas State University Co-60 Silo Skyshine Experiment

Materials: Concrete, Air, Ground, and Steel

The concrete composition was not specified. Ordinary concrete assumed per PNNL-15870, Rev. 2, Entry 102, as shown in Table 1. Densities of 2.17 $\pm$ 0.02, 2.13 $\pm$ 0.02 and 1.93 $\pm$ 0.02 g/cc were reported by Roseberry, Table 2-2, for the silo, roof shields and collimator wedges, respectively.

The composition of the air was not specified. Dry air near sea level assumed per PNNL-15870, Rev. 2, Entry No. 4, as shown in Table 2. Note that this composition corresponds to 0.03% CO_2, 78.09% N_2, 20.95% O_2, and 0.93% Ar. The composition for humid air adjusts these parameters assuming 4% H_2O as provided in Table 3. All results in this report consider only dry air as the mean Z is not sufficiently reduced to make a significant difference in shielding results.

Table 1. Concrete

Element	wt.-%
H	30.5322
C	0.2880
O	50.0410
Na	0.9212
Mg	0.0725
Al	1.0298
Si	15.1046
K	0.3578
Ca	1.4924
Fe	0.1605

Table 2. Dry Air

Element	at.-%
C	0.0150
N	78.4429
O	21.0750
Ar	0.4671

Table 3. Humid Air

Element	at.-%
C	0.014
N	73.621
O	21.999
Ar	0.438
H	3.928

The composition of the ground was not specified. Ground assumed with ρ = 1.7 g/cc per ORNL-4289, Volume II, Table 1, as repeated in Table 3 below, which is consistent with the Baikal (ICSBEP/SINBAD) benchmark.

Table 4. Ground

Element	at.-%
H	16
O	57
Si	19
Al	8

The steel alloy was not specified. Inexpensive carbon steel assumed with ρ = 7.85 g/cc and containing 0.2 wt.% C and 99.8 wt.% Fe.

Kansas State University Co-60 Silo Skyshine Experiment

Calculations:

All calculations were performed using COG11.3 with ENDF/B-VIII.0 cross sections and fluence-to-exposure conversion factors by Rogers, Table 3. A summary of the basic model details is provided in Table 5. Input files ksu1 and ksua are provided in Appendices D and E, respectively.

Table 5. COG calculational model details

File	Source Elevation*	Neutrons	Model	Range	Air (mg/cc)
ksu1	203.20 cm	1E+8	^{60}Co in silo with collimator wedges.	50 – 200 m	1.096
ksu2	198.12 cm	1E+9	^{60}Co in silo with collimator wedges.	300 – 700 m	1.096
ksu3	203.20 cm	1E+8	^{60}Co in silo with 21.0 cm concrete roof.	30 – 50 m	1.166
ksu4	198.12 cm	1E+8	^{60}Co in silo with 21.0 cm concrete roof.	70, 200 m	1.112
ksu5	198.12 cm	1E+8	^{60}Co in silo with 21.0 cm concrete roof.	100 m	1.162
ksu6	198.12 cm	1E+8	^{60}Co in silo with 21.0 cm concrete roof.	150 m	1.161
ksu7	198.12 cm	1E+9	^{60}Co in silo with 21.0 cm concrete roof.	300, 400, 600 m	1.152
ksu8	198.12 cm	1E+9	^{60}Co in silo with 21.0 cm concrete roof.	500 m	1.113
ksu9	198.12 cm	1E+9	^{60}Co in silo with 21.0 cm concrete roof.	700 m	1.116
ksua	198.12 cm	1E+9	^{60}Co in silo with 42.8 cm concrete roof.	30 – 50 m	1.114
ksub	198.12 cm	1E+8	^{60}Co in silo with 42.8 cm concrete roof.	70 – 300 m	1.110
ksuc	198.12 cm	1E+8	^{60}Co in silo with 42.8 cm concrete roof.	400 m	1.113

*The apex of the collimator cone is at 198.12 cm per Roseberry, page 26: : "The 10 Ci source was 2" from the apex of the collimator core when exposed. The mid-points of the larger sources were at the apex of the collimator core when these sources were properly positioned and raised."

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Results: Uncovered source collimated to a vertical 150.5° cone

Experiment						COG		
r (m)	ρ* (mg/cc)	ρr (g/cm^2)	Source** (Ci)	Exposure Rate (μR/hr)	Exposure Rate (μR/hr•Ci)	Exposure Rate (R/s•Ci)	Exposure Rate (μR/hr•Ci)	C/E***
50	1.096	5.48	10.33	284.0 ± 0.4	27.49 ± 0.04	7.019E-9 ± 0.4%	25.27 ± 0.4%	0.92 ± 5.0%
100	1.096	10.96	10.33	113.3 ± 0.7	10.97 ± 0.07	2.695E-9 ± 0.4%	9.70 ± 0.4%	0.88 ± 5.1%
200	1.096	21.92	10.33	28.1 ± 0.4	2.72 ± 0.04	7.326E-10 ± 0.6%	2.64 ± 0.6%	0.97 ± 5.2%
300	1.096	32.88	229.1	193.0 ± 0.9	0.842 ± 0.004	2.397E-10 ± 0.3%	0.863 ± 0.3%	1.02 ± 5.1%
400	1.096	43.84	229.1	78.0 ± 0.4	0.340 ± 0.002	9.520E-11 ± 0.4%	0.343 ± 0.4%	1.01 ± 5.1%
500	1.096	54.80	229.1	29.3 ± 0.6	0.128 ± 0.003	4.099E-11 ± 0.5%	0.148 ± 0.5%	1.15 ± 5.5%
600	1.096	65.76	3804	225.0 ± 0.4	0.0591 ± 0.0001	1.782E-11 ± 0.7%	0.0642 ± 0.7%	1.09 ± 5.2%
700	1.096	76.72	3804	101.0 ± 0.9	0.0266 ± 0.0002	8.148E-12 ± 0.9%	0.0293 ± 0.9%	1.10 ± 5.1%

* 2% uncertainty in air density (negligible).
** 5% uncertainty in source strength.
*** Also includes the uncertainty in the exposure rate due to the uncertainty in detector position (see App. A).

Results: Source covered by 21.0 cm of concrete at 2.13 g/cc

Experiment						COG		
r (m)	ρ* (mg/cc)	ρr (g/cm^2)	Source** (Ci)	Exposure Rate (μR/hr)	Exposure Rate (μR/hr•Ci)	Exposure Rate (R/s•Ci)	Exposure Rate (μR/hr•Ci)	C/E
30	1.166	3.499	10.22	51.9 ± 0.5	5.08 ± 0.05	1.472E-9 ± 0.8%	5.300 ± 0.8%	1.04 ± 5.5%
50	1.166	5.831	10.22	28.1 ± 0.5	2.75 ± 0.05	7.512E-10 ± 0.8%	2.704 ± 0.8%	0.98 ± 5.5%
70	1.112	7.786	227.1	328.2 ± 0.5	1.445 ± 0.002	4.337E-10 ± 0.9%	1.561 ± 0.9%	1.08 ± 5.2%
100	1.162	11.62	226.7	186.1 ± 0.7	0.821 ± 0.003	2.405E-10 ± 1.1%	0.866 ± 1.1%	1.05 ± 5.2%
150	1.161	17.42	226.7	79.0 ± 0.6	0.348 ± 0.003	1.016E-10 ± 1.3%	0.366 ± 1.3%	1.05 ± 5.3%
200	1.112	22.24	227.1	37.3 ± 0.5	0.164 ± 0.002	5.078E-11 ± 1.6%	0.183 ± 1.6%	1.11 ± 5.5%
300	1.152	34.57	3764	168.6 ± 0.5	0.0448 ± 0.0001	1.412E-11 ± 0.8%	0.0508 ± 0.8%	1.13 ± 5.2%
400	1.152	46.08	3764	51.9 ± 0.7	0.0138 ± 0.0002	4.432E-12 ± 1.3%	0.0160 ± 1.3%	1.16 ± 5.5%
500	1.113	55.63	3770	18.8 ± 0.4	0.00499 ± 0.00011	1.705E-12 ± 1.9%	0.00614 ± 1.9%	**1.23** ± 5.9%
600	1.152	69.15	3764	6.0 ± 0.6	0.00159 ± 0.00016	5.297E-13 ± 3.1%	0.00191 ± 3.1%	1.20 ± 11.7%
700	1.116	78.14	3770	2.5 ± 0.5	0.00066 ± 0.00013	2.421E-13 ± 4.4%	0.00087 ± 4.4%	1.32 ± 21.1%

* 2% uncertainty in air density (negligible).
** 5% uncertainty in source strength.
*** Also includes the uncertainty in the exposure rate due to the uncertainty in detector position (see App. B).
The result in **RED** has $|C/E - 1| > 3\sigma$.

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Results: Source covered by 42.8 cm of concrete at 2.13 g/cc

Experiment						COG		
r (m)	ρ* (mg/cc)	ρr (g/cm^2)	Source** (Ci)	Exposure Rate (μR/hr)	Exposure Rate (μR/hr•kCi)	Exposure Rate (R/s•kCi)	Exposure Rate (μR/hr•kCi)	C/E
30	1.114	3.343	226.6	93.4 ± 0.5	412.2 ± 2.2	1.666E-7 ± 0.9%	599.6 ± 0.9%	**1.45** ± 5.5%
50	1.114	5.572	226.6	50.6 ± 0.4	223.3 ± 1.8	7.652E-8 ± 1.0%	275.5 ± 1.0%	**1.23** ± 5.3%
70	1.110	7.772	226.6	26.4 ± 0.6	116.5 ± 2.6	4.461E-8 ± 1.1%	160.6 ± 1.1%	**1.38** ± 5.8%
100	1.110	11.10	226.6	15.4 ± 0.5	68.0 ± 2.2	2.363E-8 ± 1.2%	85.1 ± 1.2%	**1.25** ± 6.1%
150	1.110	16.65	3763	110.1 ± 0.6	29.3 ± 0.16	9.576E-9 ± 1.5%	34.5 ± 1.5%	**1.18** ± 5.3%
200	1.110	22.19	3763	50.2 ± 0.5	13.3 ± 0.13	4.580E-9 ± 1.8%	16.5 ± 1.8%	**1.24** ± 5.5%
300	1.110	33.29	3763	12.6 ± 0.4	3.35 ± 0.11	1.290E-9 ± 2.9%	4.64 ± 2.9%	**1.39** ± 6.7%
400	1.113	44.52	3763	4.1 ± 0.5	1.09 ± 0.13	4.319E-10 ± 4.6%	1.55 ± 4.6%	**1.43** ± 14.0%

* 2% uncertainty in air density (negligible).
** 5% uncertainty in source strength.
*** Also includes the uncertainty in the exposure rate due to the uncertainty in detector position (see App. C).
Results in **RED** have |C/E – 1| > 3σ.

Conclusions:

All results for the unshielded silo are in excellent agreement with the experimental values. Simulation results appear to increase slightly with increasing distance.

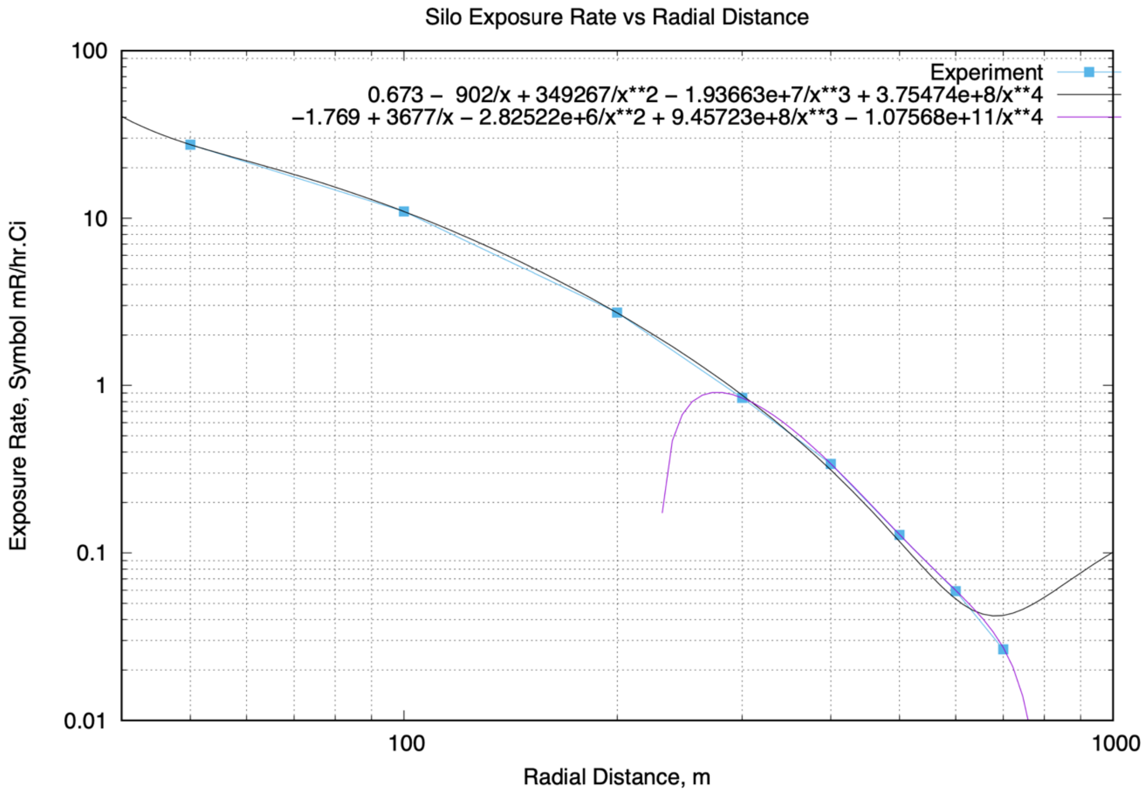
This trend of simulation results increasing with increasing distance is also noted for the silo shielded by 21.0 inches of concrete roof slab shields. These simulation results are also in agreement with experimental values for all cases except at 500 m distance, which corresponds to |C/E – 1| = 3.9σ. Note that C/E – 1 > 0 for all but one case indicating simulation results are overpredicted slightly.

Simulation results for the silo shielded by 42.8 inches of concrete roof slab shields are significantly overpredicted but not necessarily increasing with increasing range.

All results are 0.88 ≤ C/E ≤ 1.45 indicating good overall performance.

Appendix A

Exposure Rate Uncertainty due to Positioning Uncertainty – Uncovered KSU Silo



Distance, R (meters)	Exposure Rate, $\dot{X}$ (μR/hr•Ci)	$d\dot{X}/dR$ (μR/hr•Ci•m)	$\Delta\dot{X} = (dX/dR)\Delta R$ (μR/hr•Ci)	$\Delta\dot{X}/\dot{X}$ (%)
50 ± 0.5	27.49 ± 0.04	–0.739	± 0.370	± 1.3
100 ± 0.5	10.97 ± 0.07	–0.178	± 0.0888	± 0.8
200 ± 0.5	2.72 ± 0.04	–0.0332	± 0.0166	± 0.6
300 ± 1.0	0.842 ± 0.004	–0.00930	± 0.00930	± 1.1
400 ± 1.0	0.340 ± 0.002	–0.00333*	± 0.00333	± 1.0
500 ± 1.0	0.128 ± 0.003	–0.00113	± 0.00113	± 0.9
600 ± 1.0	0.0591 ± 0.0001	–0.00041	± 0.00041	± 0.7
700 ± 1.0	0.0266 ± 0.0002	–0.00029	± 0.00029	± 1.1

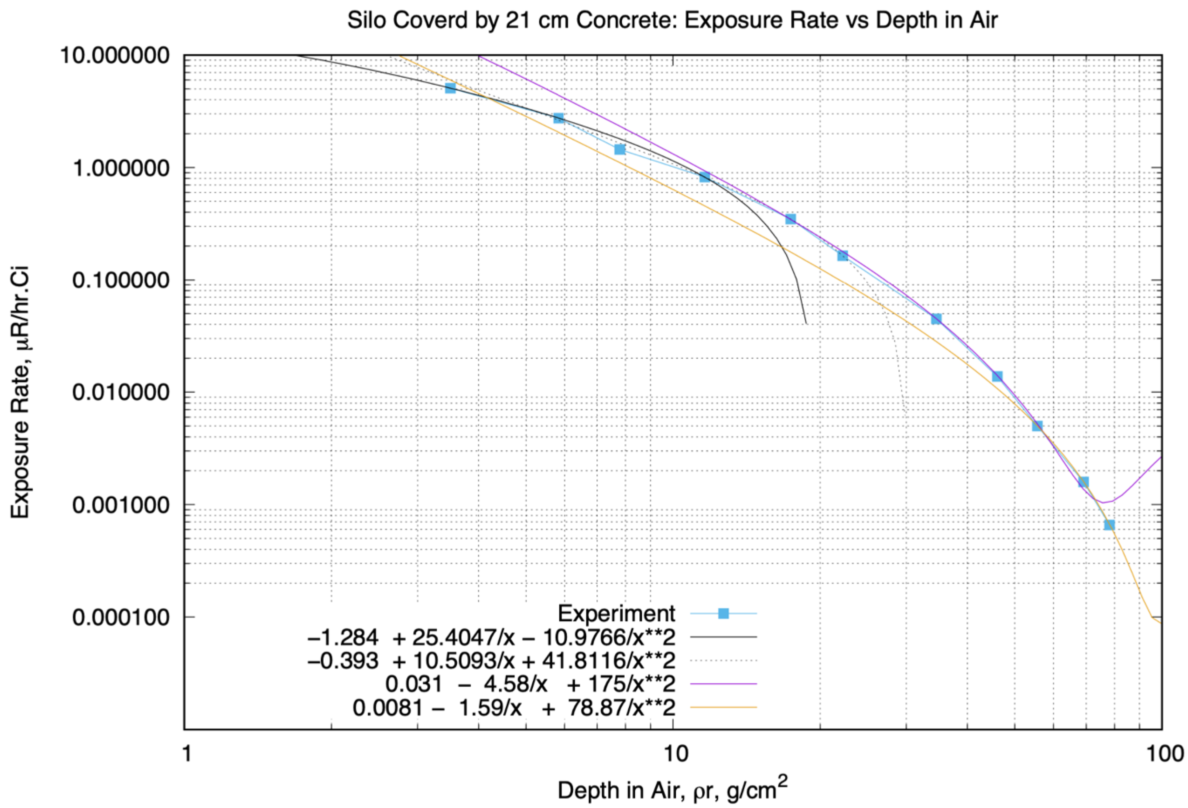
*Average value of both fits

Range, R	Fit
50 – 400	$\dot{X} = +0.673 - 902/R + 349{,}267/R^2 - 1.93663e7/R^3 + 3.75474e8/R^4$
400 – 800	$\dot{X} = -1.769 + 3677/R - 2.82522e6/R^2 + 9.45723e8/R^3 - 1.07568e11/R^4$

Range, R	Derivative
50 – 400	$d\dot{X}/dR = +902/R^2 - 698{,}534/R^3 + 5.80909e7/R^4 - 1.50190e9/R^5$
400 – 800	$d\dot{X}/dR = -3677/R^2 + 5.65044e6/R^3 - 2.83717e9/R^4 + 4.30272e11/R^5$

Appendix B

Exposure Rate Uncertainty due to Positioning Uncertainty – KSU Silo Covered with 21” Concrete

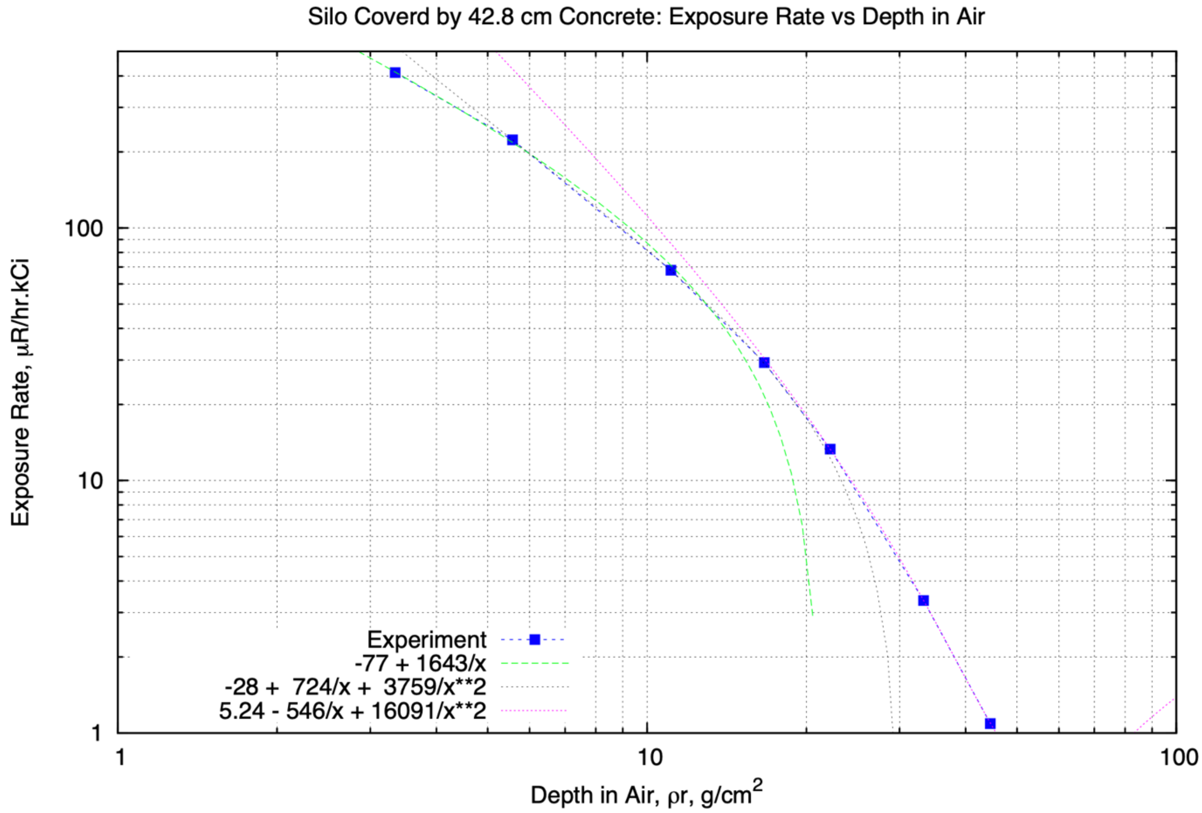


Distance, R (meters)	Air Density, ρ (mg/cm^3)	Depth, ρR (g/cm^2)	Exposure Rate, $\dot{X}$ (μR/hr•Ci)	$\rho d\dot{X}/d(\rho R)$ (μR/hr•Ci•cm)	$\Delta\dot{X} = (dX/dR)\Delta R$ (μR/hr•Ci)	$\Delta\dot{X}/\dot{X}$ (%)
30 ± 0.5	1.166	3.499	5.08 ± 0.05	–0.001821	–0.0911	±1.8%
50 ± 0.5	1.166	5.831	2.75 ± 0.05	–0.000742	–0.0371	±1.3%
70 ± 0.5	1.112	7.786	1.445 ± 0.002	–0.000390	–0.0195	±1.3%
100 ± 0.5	1.162	11.62	0.821 ± 0.003	–0.000152	–0.00761	±0.9%
150 ± 0.5	1.161	17.42	0.348 ± 0.003	–0.0000593	–0.00297	±0.9%
200 ± 0.5	1.112	22.24	0.164 ± 0.002	–0.0000251	–0.00125	±0.8%
300 ± 1.0	1.152	34.57	0.0448 ± 0.0001	–0.00000534	–0.000534	±1.2%
400 ± 1.0	1.152	46.08	0.0138 ± 0.0002	–0.00000164	–0.000164	±1.2%
500 ± 1.0	1.113	55.63	0.00499 ± 0.00011	–0.000000616	–0.0000616	±1.2%
600 ± 1.0	1.152	69.15	0.00159 ± 0.00016	–0.000000167	–0.0000167	±1.1%
700 ± 1.0	1.116	78.14	0.00066 ± 0.00013	–0.000000079	–0.0000079	±1.2%

Range, ρR	Fit	Derivative
3 - 6	$\dot{X} = -1.284 + 25.4/(\rho R) - 10.98/(\rho R^2)$	$d\dot{X}/d(\rho R) = -25.4/(\rho R)^2 + 21.96/(\rho R)^3$
6 - 15	$\dot{X} = -0.393 + 10.5/(\rho R) + 41.81/(\rho R^2)$	$d\dot{X}/d(\rho R) = -10.5/(\rho R)^2 - 83.62/(\rho R)^3$
15 - 60	$\dot{X} = +0.031 - 4.58/(\rho R) + 175.0/(\rho R^2)$	$d\dot{X}/d(\rho R) = +4.58/(\rho R)^2 - 350/(\rho R)^3$
60-80	$\dot{X} = +0.008 - 1.59/(\rho R) + 78.87/(\rho R^2)$	$d\dot{X}/d(\rho R) = +1.59/(\rho R)^2 - 158(\rho R)^3$

Appendix C

Exposure Rate Uncertainty due to Positioning Uncertainty – KSU Silo Covered with 42.8" Concrete



Experiment				Fitted Experimental Results		
Distance, R (meters)	Air Density, ρ (mg/cm³)	Depth, ρR (g/cm²)	Exposure Rate, $\dot{X}$ (μR/hr•kCi)	$\rho d\dot{X}/d(\rho R)$ (μR/hr•Ci•cm)	$\Delta\dot{X} = (dX/dR)\Delta R$ (μR/hr•Ci)	$\Delta\dot{X}/\dot{X}$ (%)
30 ± 0.5	1.114	3.343	412.2 ± 2.2	−0.1638	±8.189	±2.0
50 ± 0.5	1.114	5.572	223.3 ± 1.8	−0.05895	±2.948	±1.3
70 ± 0.5	1.110	7.772	116.5 ± 2.6	−0.03108	±1.554	±1.3
100 ± 0.5	1.110	11.10	68.0 ± 2.2	−0.01262	±0.6312	±0.9
150 ± 0.5	1.110	16.65	29.3 ± 0.16	−0.004707	±0.2353	±0.8
200 ± 0.5	1.110	22.19	13.3 ± 0.13	−0.002039	±0.1019	±0.8
300 ± 1.0	1.110	33.29	3.35 ± 0.11	−0.0004214	±0.04214	±1.3
400 ± 1.0	1.113	44.52	1.09 ± 0.13	−0.00009932	±0.009932	±0.9

Range, ρR	Fit	Derivative
3 - 6	$\dot{X} = -77 + 1643/(\rho R)$	$d\dot{X}/d(\rho R) = -1643/(\rho R)^2$
6 - 20	$\dot{X} = -28 + 724/(\rho R) + 3759/(\rho R)^2$	$d\dot{X}/d(\rho R) = -724/(\rho R)^2 - 7518/(\rho R)^3$
20 - 45	$\dot{X} = 5.24 - 546/(\rho R) + 16091/(\rho R)^2$	$d\dot{X}/d(\rho R) = +546/(\rho R)^2 - 32182/(\rho R)^3$

Appendix D

Sample COG11.3 Input File: ksu1

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KSU Co-60 Skyshine Benchmark: Detailed model without collimator and lead bricks and source 2" above apex
$
$  References:
$    1. Murray Lee Roseberry, "Benchmark Skyshine Exposure Rates," Master's Thesis, Kansas
$       State University, 1980.
$    2. Health Physics, Vol. 46, No. 4, pp. 891-914, 1984, "Fluence to Dose Equivalent
$       Conversion Factors Calculated with EGS3 for Electrons from 100 keV to 20 GeV and
$       Photons from 11 keV to 20 GeV," D. W. O. Rogers, National Research Council of
$       Canada, Ottawa.
$
basic
  photon MEV
source
  npart=1E+8                                        $ Source location 2" above apex = 198.12 + 2(2.54)
  define position = 1 point 0 0 203.20              $ Point source
  define energy   = 1 photon line 1.173 0.5 1.332 0.5  $ Co-60
  define time     = 1 steady                        $
  define angle    = 1 isotropic                     $
  increment 7.4E+10 position=1 energy=1 time=1 angle=1 $ (1 Ci)(3.7E+10 dps/Ci)(2 photons/dis)
mix nlib=ENDFB8R0, ptlib=PT.ENDFB8R0.ACE sablib=T.ENDFB8R0
   mat=1 a-f 1.7 (h.h2o) 16 o16 57 si 19 al 8                              $ Ground
   mat=2 a-f 0.001096      c 0.0150 n 78.4429 o16 21.0750 ar 0.4671        $ Dry air
$  mat=2 a-f 0.001096      c 0.014  n 73.621  o16 21.999  ar 0.438   h 3.928  $ Humid air, 4% H2O
   mat=3 a-f 2.17 (h.h2o) 30.5322   c  0.2880 o16 50.0410 na 0.9212 mg 0.0725 $ Ordinary concrete
                       al  1.0298  si 15.1046   k  0.3578 ca 1.4924 fe 0.1605 $  - Silo
   mat=4 a-f 1.93 (h.h2o) 30.5322   c  0.2880 o16 50.0410 na 0.9212 mg 0.0725 $ Ordinary concrete
                       al  1.0298  si 15.1046   k  0.3578 ca 1.4924 fe 0.1605 $  - Collimator wedges
   mat=5 w-p 7.85 c 0.2 fe 99.8                                            $ Steel
assign-m
   201 2 202 2 203 2 204 2 205 2 206 2 207 2 208 2
assign-mc
   1 brown 2 white 3 green 4 lime 5 black 201 pink 202 red 203 sky 204 blue 205 purple 206 orange 207 gray
 208 yellow
geometry
  sector   1 ground   -1 -2
  sector   5 caskplate 2 -3 -9
  sector   3 basepad   2 -3  9
  sector   3 sidepads  2  3 -4
  sector   3 sidepads  2  3  4 -5
  sector   3 crnrpads  2  3  4  5 -6
  sector   3 silo      3  7 -8 10
  use unit 2 collmtr -10  21  22                        $ Q1
  use unit 2 collmtr -10 -21  22 tr 0 0 0  0  1 0 -1  0 0 $ Q2
  use unit 2 collmtr -10 -21 -22 tr 0 0 0 -1  0 0  0 -1 0 $ Q3
  use unit 2 collmtr -10  21 -22 tr 0 0 0  0 -1 0  1  0 0 $ Q4
  sector 201 det050m -201
  sector 202 det100m -202
  sector 203 det200m -203
  sector 204 det300m -204
  sector 205 det400m -205
  sector 206 det500m -206
  sector 207 det600m -207
  sector 208 det700m -208
  fill     2 $ air
  boundary vacuum      1
define unit 1 $ One collimator wedge
  sector   4 wedge   -10 11 -12 -13 -14 -15
  fill     2 $ air
define unit 2 $ One quadrant of collimator wedges
  use unit 1 wedge   -10      -101                                          $  0.0 degrees
  use unit 1 wedge   -10  101 -102 tr 0 0 0 0.99144 0.13053 0 -0.13053 0.99144 0 $  7.5 degrees
  use unit 1 wedge   -10  102 -103 tr 0 0 0 0.96593 0.25882 0 -0.25882 0.96593 0 $ 15.0 degrees
  use unit 1 wedge   -10  103 -104 tr 0 0 0 0.92388 0.38268 0 -0.38268 0.92388 0 $ 22.5 degrees
  use unit 1 wedge   -10  104 -105 tr 0 0 0 0.86603 0.50000 0 -0.50000 0.86603 0 $ 30.0 degrees
  use unit 1 wedge   -10  105 -106 tr 0 0 0 0.79335 0.60876 0 -0.60876 0.79335 0 $ 37.5 degrees
  use unit 1 wedge   -10  106 -107 tr 0 0 0 0.70711 0.70711 0 -0.70711 0.70711 0 $ 45.0 degrees
```

```
  use unit 1 wedge   -10  107 -108 tr 0 0 0 0.60876 0.79335 0 -0.79335 0.60876 0 $ 52.5 degrees
  use unit 1 wedge   -10  108 -109 tr 0 0 0 0.50000 0.86603 0 -0.86603 0.50000 0 $ 60.0 degrees
  use unit 1 wedge   -10  109 -110 tr 0 0 0 0.38268 0.92388 0 -0.92388 0.38268 0 $ 67.5 degrees
  use unit 1 wedge   -10  110 -111 tr 0 0 0 0.25882 0.96593 0 -0.96593 0.25882 0 $ 75.0 degrees
  use unit 1 wedge   -10  111 -112 tr 0 0 0 0.13053 0.99144 0 -0.99144 0.13053 0 $ 82.5 degrees
  use unit 1 wedge   -10  112      tr 0 0 0 0.0     1.0     0 -1.0     0.0     0 $ 90.0 degrees
picture cs sector color
  -10000 0  300 -10000  0 -100 10000  0 -100 title="x/z view showing detectors at 50m"
picture cs material color
  -800   0  300 -800    0 -100 800    0 -100 title="x/z view"
picture cs material color
  -800 800 -0.5 -800 -800 -0.5 800 -800 -0.5 title="x/y view of cask plate"
picture cs material color
  -800 800  -20 -800 -800  -20 800 -800  -20 title="x/y view of pads"
picture cs material color
  -250 250  100 -250 -250  100 250 -250  100 title="x/y detail of silo"
picture cs material color
  -250 250  230 -250 -250  230 250 -250  230 title="x/y detail of wedges"
surfaces
  1 c z 100000.0 -99.06 100198.12 $ BCD
  2 p z  -22.86                   $ Ground
  3 rpp -228.60 228.60 -228.60 228.60 -22.86   0.0  $ Base pad,  9" thick
  4 rpp -228.60 228.60 -774.24 774.24 -22.86 -12.70 $ Side pads, 4" thick
  5 rpp -774.24 774.24 -304.80 304.80 -22.86 -12.70 $ Side pads, 4" thick, and aprons
  6 box  890.84 890.84   10.16 tr 0 0 -17.78 1 1 -17.78 -1 1 -17.78 $ Corner pads, 4" thick
  7 pri 12 33.35 -124.46   91.11  -91.11  124.46 -33.35  124.46  33.35   91.11   91.11  33.35  124.46 $ Silo,
          -33.35  124.46  -91.11   91.11 -124.46  33.35 -124.46 -33.35  -91.11  -91.11 -33.35 -124.46 $  inner
            0.0   228.60  tr 0 0 0 0 0 0 1 0 1 0                                                     $
  8 pri 12 57.85 -215.90  158.05 -158.05  215.90 -57.85  215.90  57.85  158.05  158.05  57.85  215.90 $ Silo,
          -57.85  215.90 -158.05  158.05 -215.90  57.85 -215.90 -57.85 -158.05 -158.05 -57.85 -215.90 $  outer
            0.0   228.60  tr 0 0 0 0 0 0 1 0 1 0                                                     $
  9 rpp -106.68 106.68 -45.72 45.72 -0.79375 0 $ Steel cask plate

 10 c z  250.0  228.60  248.6025 $ Arbitrary cylinder subsuming all collimator wedges
 11 p x  124.46
 12 p x  185.42
 13 p    124.46  7.9772 999.99 124.46  7.9772 228.60 185.42  11.9856 124.46   150  999 228.60
 14 p    124.46 -7.9772 999.99 124.46 -7.9772 228.60 185.42 -11.9856 124.46   150 -999 228.60
 15 p    124.46  7.9772 231.14 124.46 -7.9772 231.14 185.42 -11.9856 248.6025 150    0 999.99

 21 p x 0
 22 p y 0

101 p 0 0 9 0 0 0 9 0 0 1 1 0 tr 0 0 0 0.99786 0.06540 0 -0.06540 0.99786 0 $   3.75 degrees
102 p 0 0 9 0 0 0 9 0 0 1 1 0 tr 0 0 0 0.98079 0.19509 0 -0.19509 0.98079 0 $  11.25 degrees
103 p 0 0 9 0 0 0 9 0 0 1 1 0 tr 0 0 0 0.94693 0.32144 0 -0.32144 0.94693 0 $  18.75 degrees
104 p 0 0 9 0 0 0 9 0 0 1 1 0 tr 0 0 0 0.89687 0.44229 0 -0.44229 0.89687 0 $  26.25 degrees
105 p 0 0 9 0 0 0 9 0 0 1 1 0 tr 0 0 0 0.83147 0.55557 0 -0.55557 0.83147 0 $  33.75 degrees
106 p 0 0 9 0 0 0 9 0 0 1 1 0 tr 0 0 0 0.75184 0.65935 0 -0.65935 0.75184 0 $  41.25 degrees
107 p 0 0 9 0 0 0 9 0 0 1 1 0 tr 0 0 0 0.65935 0.75184 0 -0.75184 0.65935 0 $  48.75 degrees
108 p 0 0 9 0 0 0 9 0 0 1 1 0 tr 0 0 0 0.55557 0.83147 0 -0.83147 0.55557 0 $  56.25 degrees
109 p 0 0 9 0 0 0 9 0 0 1 1 0 tr 0 0 0 0.44229 0.89687 0 -0.89687 0.44229 0 $  63.75 degrees
110 p 0 0 9 0 0 0 9 0 0 1 1 0 tr 0 0 0 0.32144 0.94693 0 -0.94693 0.32144 0 $  71.25 degrees
111 p 0 0 9 0 0 0 9 0 0 1 1 0 tr 0 0 0 0.19509 0.98079 0 -0.98079 0.19509 0 $  78.75 degrees
112 p 0 0 9 0 0 0 9 0 0 1 1 0 tr 0 0 0 0.06540 0.99786 0 -0.99786 0.06540 0 $  86.25 degrees

201 torus  5000 30.48 tr 0 0 198.12 0 0 999 0 999 198.12 $ Detector at  50 m =  5,000 cm
202 torus 10000 30.48 tr 0 0 198.12 0 0 999 0 999 198.12 $ Detector at 100 m = 10,000 cm
203 torus 20000 30.48 tr 0 0 198.12 0 0 999 0 999 198.12 $ Detector at 200 m = 20,000 cm
204 torus 30000 30.48 tr 0 0 198.12 0 0 999 0 999 198.12 $ Detector at 300 m = 30,000 cm
205 torus 40000 30.48 tr 0 0 198.12 0 0 999 0 999 198.12 $ Detector at 400 m = 40,000 cm
206 torus 50000 30.48 tr 0 0 198.12 0 0 999 0 999 198.12 $ Detector at 500 m = 50,000 cm
207 torus 60000 30.48 tr 0 0 198.12 0 0 999 0 999 198.12 $ Detector at 600 m = 60,000 cm
208 torus 70000 30.48 tr 0 0 198.12 0 0 999 0 999 198.12 $ Detector at 700 m = 70,000 cm

detector
  number=#0000001 title="Photon exposure at 50m, R.cm2/s.Ci"
    reaction 201 9.16916E+7   $ Reaction detector in air, V=(2*PI*5,000)(PI*(30.48**2))
    drf-e photon              $ Exposure in R/cm2.s per Rogers
       0.01 8.54-10 0.015 3.59-10 0.02 1.94-10 0.03 8.29-11 0.04 4.93-11 0.05 3.71-11 0.06 3.32-11 0.08 3.52-11
       0.10 4.26-11 0.15  6.88-11 0.2  9.82-11 0.3  1.58-10 0.4  2.17-10 0.5  2.73-10 0.6  3.25-10 0.8  4.24-10
       1.0  5.12-10 1.25  6.11-10 1.5  7.02-10 2.0  8.61-10 3.0  1.18-9  4.0  1.37-9  5.0  1.60-9  6.0  1.82-9
       8.0  2.24-9 10.0   2.66-9 20.0  4.80-9
```

```
  number=#0000002 title="Photon exposure at 100m, R.cm2/s.Ci"
    reaction 202 1.83383E+8   $ Reaction detector in air, V=(2*PI*10,000)(PI*(30.48**2))
    drf-e photon              $ Exposure in R/cm2.s per Rogers
       0.01 8.54-10 0.015 3.59-10 0.02 1.94-10 0.03 8.29-11 0.04 4.93-11 0.05 3.71-11 0.06 3.32-11 0.08 3.52-11
       0.10 4.26-11 0.15  6.88-11 0.2  9.82-11 0.3  1.58-10 0.4  2.17-10 0.5  2.73-10 0.6  3.25-10 0.8  4.24-10
       1.0  5.12-10 1.25  6.11-10 1.5  7.02-10 2.0  8.61-10 3.0  1.18-9  4.0  1.37-9  5.0  1.60-9  6.0  1.82-9
       8.0  2.24-9 10.0   2.66-9 20.0  4.80-9
  number=#0000003 title="Photon exposure at 200m, R.cm2/s.Ci"
    reaction 203 3.66767E+8   $ Reaction detector in air, V=(2*PI*20,000)(PI*(30.48**2))
    drf-e photon              $ Exposure in R/cm2.s per Rogers
       0.01 8.54-10 0.015 3.59-10 0.02 1.94-10 0.03 8.29-11 0.04 4.93-11 0.05 3.71-11 0.06 3.32-11 0.08 3.52-11
       0.10 4.26-11 0.15  6.88-11 0.2  9.82-11 0.3  1.58-10 0.4  2.17-10 0.5  2.73-10 0.6  3.25-10 0.8  4.24-10
       1.0  5.12-10 1.25  6.11-10 1.5  7.02-10 2.0  8.61-10 3.0  1.18-9  4.0  1.37-9  5.0  1.60-9  6.0  1.82-9
       8.0  2.24-9 10.0   2.66-9 20.0  4.80-9
  number=#0000004 title="g/cm2.s.Ci and spectrum at 50m"
    reaction 201 9.16916E+7   $ Reaction detector in air
    drf-e neutron number-flux $ Fluence in photon/cm2.s.Ci
    bin energy photon
       0.930 1.054 1.194 1.353 1.534 1.738 1.969 2.231 2.528 2.865
       3.247 3.679 4.169 4.724 5.353 6.065 6.873 7.788 8.825 10.0
end
```

Appendix E

Sample COG11.3 Input File: ksua

```
KSU Co-60 Skyshine Benchmark: Detailed model with 42.8 cm concrete and source 2" above apex
$
$  References:
$    1. Murray Lee Roseberry, "Benchmark Skyshine Exposure Rates," Master's Thesis, Kansas
$       State University, 1980.
$    2. Health Physics, Vol. 46, No. 4, pp. 891-914, 1984, "Fluence to Dose Equivalent
$       Conversion Factors Calculated with EGS3 for Electrons from 100 keV to 20 GeV and
$       Photons from 11 keV to 20 GeV," D. W. O. Rogers, National Research Council of
$       Canada, Ottawa.
$
basic
  photon MEV
source
  npart=1E+9                                          $ Source location at apex = 198.12
  define position = 1 point 0 0 198.12                $ Point source
  define energy   = 1 photon line 1.173 0.5 1.332 0.5  $ Co-60
  define time     = 1 steady                          $
  define angle    = 1 isotropic                       $
  increment 7.4E+13 position=1 energy=1 time=1 angle=1 $ (1 Ci)(3.7E+13 dps/kCi)(2 photons/dis)
mix nlib=ENDFB8R0, ptlib=PT.ENDFB8R0.ACE sablib=T.ENDFB8R0
   mat=1 a-f 1.7 (h.h2o) 16 o16 57 si 19 al 8                             $ Ground
   mat=2 a-f 0.001114      c 0.0150 n 78.4429 o16 21.0750 ar 0.4671          $ Dry air
$  mat=2 a-f 0.001114      c 0.014  n 73.621  o16 21.999  ar 0.438   h 3.928  $ Humid air, 4% H2O
   mat=3 a-f 2.17 (h.h2o) 30.5322   c  0.2880 o16 50.0410 na 0.9212 mg 0.0725 $ Ordinary concrete
                       al  1.0298  si 15.1046   k  0.3578 ca 1.4924 fe 0.1605 $  - Silo
   mat=4 a-f 2.13 (h.h2o) 30.5322   c  0.2880 o16 50.0410 na 0.9212 mg 0.0725 $ Ordinary concrete
                       al  1.0298  si 15.1046   k  0.3578 ca 1.4924 fe 0.1605 $  - Roof shields
   mat=5 w-p 7.85 c 0.2 fe 99.8                                              $ Steel
assign-m
   201 2 202 2
assign-mc
   1 brown 2 white 3 green 4 lime 5 black 201 orange 202 pink
geometry
  sector   1 ground   -1 -2
  sector   5 caskplate 2 -3 -9
  sector   3 basepad   2 -3  9
  sector   3 sidepads  2  3 -4
  sector   3 sidepads  2  3  4 -5
  sector   3 crnrpads  2  3  4  5 -6
  sector   3 silo      3  7 -8

$ Roof #10
  sector   5 steel    11 -12  41 -42  54 -57
  sector   5 steel    12 -13  41 -42  54 -55
  sector   5 steel    13 -14  41 -42  51 -55
  sector   5 steel    14 -15  41 -42  51 -52
  sector   4 roof     15 -16  41 -42  51 -52
  sector   4 roof     14 -17  41 -42  52 -55
  sector   4 roof     12 -20  41 -42  55 -57
  sector   5 steel    16 -17  41 -42  51 -52
  sector   5 steel    17 -18  41 -42  51 -55
  sector   5 steel    18 -20  41 -42  54 -55
  sector   5 steel    20 -21  41 -42  54 -57

$ Roof #12
  sector   5 steel    18 -19  41 -42  51 -54
  sector   5 steel    19 -21  41 -42  53 -54
  sector   5 steel    21 -22  41 -42  53 -57
  sector   5 steel    22 -23  41 -42  56 -57
  sector   4 roof     19 -28  41 -42  51 -53
  sector   4 roof     22 -25  41 -42  53 -56
  sector   4 roof     23 -24  41 -42  56 -57
  sector   5 steel    24 -25  41 -42  56 -57
  sector   5 steel    25 -26  41 -42  53 -57
  sector   5 steel    26 -28  41 -42  53 -54
  sector   5 steel    28 -29  41 -42  51 -54
```

```
$ Roof #11
  sector   5 steel    26 -27  41 -42  54 -57
  sector   5 steel    27 -29  41 -42  54 -55
  sector   5 steel    29 -30  41 -42  51 -55
  sector   5 steel    30 -31  41 -42  51 -52
  sector   4 roof     31 -32  41 -42  51 -52
  sector   4 roof     30 -33  41 -42  52 -55
  sector   4 roof     27 -35  41 -42  55 -57
  sector   5 steel    32 -33  41 -42  51 -52
  sector   5 steel    33 -34  41 -42  51 -55
  sector   5 steel    34 -35  41 -42  54 -55
  sector   5 steel    35 -36  41 -42  54 -57

$ Roof #8
  sector   5 steel  111 -112  41 -42  60 -63
  sector   5 steel  112 -113  41 -42  60 -61
  sector   5 steel  113 -114  41 -42  57 -61
  sector   5 steel  114 -115  41 -42  57 -58
  sector   4 roof   115 -116  41 -42  57 -58
  sector   4 roof   114 -117  41 -42  58 -61
  sector   4 roof   112 -120  41 -42  61 -63
  sector   5 steel  116 -117  41 -42  57 -58
  sector   5 steel  117 -118  41 -42  57 -61
  sector   5 steel  118 -120  41 -42  60 -61
  sector   5 steel  120 -121  41 -42  60 -63

$ Roof #9
  sector   5 steel  118 -119  41 -42  57 -60
  sector   5 steel  119 -121  41 -42  59 -60
  sector   5 steel  121 -122  41 -42  59 -63
  sector   5 steel  122 -123  41 -42  62 -63
  sector   4 roof   119 -128  41 -42  57 -59
  sector   4 roof   122 -125  41 -42  59 -62
  sector   4 roof   123 -124  41 -42  62 -63
  sector   5 steel  124 -125  41 -42  62 -63
  sector   5 steel  125 -126  41 -42  59 -63
  sector   5 steel  126 -128  41 -42  59 -60
  sector   5 steel  128 -129  41 -42  57 -60

$ Roof #7
  sector   5 steel  126 -127  41 -42  60 -63
  sector   5 steel  127 -129  41 -42  60 -61
  sector   5 steel  129 -130  41 -42  57 -61
  sector   5 steel  130 -131  41 -42  57 -58
  sector   4 roof   131 -132  41 -42  57 -58
  sector   4 roof   130 -133  41 -42  58 -61
  sector   4 roof   127 -135  41 -42  61 -63
  sector   5 steel  132 -133  41 -42  57 -58
  sector   5 steel  133 -134  41 -42  57 -61
  sector   5 steel  134 -135  41 -42  60 -61
  sector   5 steel  135 -136  41 -42  60 -63

$ Roof #5
  sector   5 steel    11 -12  41 -42  154 -157
  sector   5 steel    12 -13  41 -42  154 -155
  sector   5 steel    13 -14  41 -42  151 -155
  sector   5 steel    14 -15  41 -42  151 -152
  sector   4 roof     15 -16  41 -42  151 -152
  sector   4 roof     14 -17  41 -42  152 -155
  sector   4 roof     12 -20  41 -42  155 -157
  sector   5 steel    16 -17  41 -42  151 -152
  sector   5 steel    17 -18  41 -42  151 -155
  sector   5 steel    18 -20  41 -42  154 -155
  sector   5 steel    20 -21  41 -42  154 -157

$ Roof #6
  sector   5 steel    18 -19  41 -42  151 -154
  sector   5 steel    19 -21  41 -42  153 -154
  sector   5 steel    21 -22  41 -42  153 -157
  sector   5 steel    22 -23  41 -42  156 -157
  sector   4 roof     19 -28  41 -42  151 -153
  sector   4 roof     22 -25  41 -42  153 -156
```

```
  sector   4 roof     23 -24  41 -42  156 -157
  sector   5 steel    24 -25  41 -42  156 -157
  sector   5 steel    25 -26  41 -42  153 -157
  sector   5 steel    26 -28  41 -42  153 -154
  sector   5 steel    28 -29  41 -42  151 -154

$ Roof #4
  sector   5 steel    26 -27  41 -42  154 -157
  sector   5 steel    27 -29  41 -42  154 -155
  sector   5 steel    29 -30  41 -42  151 -155
  sector   5 steel    30 -31  41 -42  151 -152
  sector   4 roof     31 -32  41 -42  151 -152
  sector   4 roof     30 -33  41 -42  152 -155
  sector   4 roof     27 -35  41 -42  155 -157
  sector   5 steel    32 -33  41 -42  151 -152
  sector   5 steel    33 -34  41 -42  151 -155
  sector   5 steel    34 -35  41 -42  154 -155
  sector   5 steel    35 -36  41 -42  154 -157

$ Roof #3
  sector   5 steel  111 -112  41 -42  160 -163
  sector   5 steel  112 -113  41 -42  160 -161
  sector   5 steel  113 -114  41 -42  157 -161
  sector   5 steel  114 -115  41 -42  157 -158
  sector   4 roof   115 -116  41 -42  157 -158
  sector   4 roof   114 -117  41 -42  158 -161
  sector   4 roof   112 -120  41 -42  161 -163
  sector   5 steel  116 -117  41 -42  157 -158
  sector   5 steel  117 -118  41 -42  157 -161
  sector   5 steel  118 -120  41 -42  160 -161
  sector   5 steel  120 -121  41 -42  160 -163

$ Roof #1
  sector   5 steel  118 -119  41 -42  157 -160
  sector   5 steel  119 -121  41 -42  159 -160
  sector   5 steel  121 -122  41 -42  159 -163
  sector   5 steel  122 -123  41 -42  162 -163
  sector   4 roof   119 -128  41 -42  157 -159
  sector   4 roof   122 -125  41 -42  159 -162
  sector   4 roof   123 -124  41 -42  162 -163
  sector   5 steel  124 -125  41 -42  162 -163
  sector   5 steel  125 -126  41 -42  159 -163
  sector   5 steel  126 -128  41 -42  159 -160
  sector   5 steel  128 -129  41 -42  157 -160

$ Roof #2
  sector   5 steel  126 -127  41 -42  160 -163
  sector   5 steel  127 -129  41 -42  160 -161
  sector   5 steel  129 -130  41 -42  157 -161
  sector   5 steel  130 -131  41 -42  157 -158
  sector   4 roof   131 -132  41 -42  157 -158
  sector   4 roof   130 -133  41 -42  158 -161
  sector   4 roof   127 -135  41 -42  161 -163
  sector   5 steel  132 -133  41 -42  157 -158
  sector   5 steel  133 -134  41 -42  157 -161
  sector   5 steel  134 -135  41 -42  160 -161
  sector   5 steel  135 -136  41 -42  160 -163

  sector 201 det030m -201
  sector 202 det050m -202
  fill     2 $ air
  boundary vacuum      1
picture cs sector color
  -10000 0  300 -10000  0 -100 10000  0 -100 title="x/z view showing detectors at 50m"
picture cs material color
  -850   0  300 -850    0 -100 850    0 -100 title="x/z view"
picture cs material color
  -850 850 -0.5 -850 -850 -0.5 850 -850 -0.5 title="x/y view of cask plate"
picture cs material color
  -850 850  -20 -850 -850  -20 850 -850  -20 title="x/y view of pads"
picture cs material color
  -250 250  100 -250 -250  100 250 -250  100 title="x/y detail of silo"
picture cs material color
```

```
  -220 250  230 -220 -250  230 220 -250  230 title="x/y detail of roof shield"
picture cs material color
  -220   0  275 -220    0  220 -50    0  220 title="x/z detail of roof shield: lhs"
picture cs material color
    50   0  275   50    0  220 220    0  220 title="x/z detail of roof shield: rhs"
picture cs material color res=1500
  -220   0  275 -220    0  220 220    0  220 title="x/z detail of roof shield"
surfaces
  1 c z 100000.0 -99.06 100198.12 $ BCD
  2 p z  -22.86                    $ Ground
  3 rpp -228.60 228.60 -228.60 228.60 -22.86   0.0  $ Base pad,  9" thick
  4 rpp -228.60 228.60 -774.24 774.24 -22.86 -12.70 $ Side pads, 4" thick
  5 rpp -774.24 774.24 -304.80 304.80 -22.86 -12.70 $ Side pads, 4" thick, and aprons
  6 box  890.84 890.84   10.16 tr 0 0 -17.78 1 1 -17.78 -1 1 -17.78 $ Corner pads, 4" thick
  7 pri 12 33.35 -124.46   91.11  -91.11  124.46 -33.35  124.46  33.35   91.11   91.11  33.35  124.46 $ Silo,
          -33.35  124.46  -91.11   91.11 -124.46  33.35 -124.46 -33.35  -91.11  -91.11 -33.35 -124.46 $  inner
            0.0   228.60  tr 0 0 0 0 0 1 0 1 0                                                          $
  8 pri 12 57.85 -215.90  158.05 -158.05  215.90 -57.85  215.90  57.85  158.05  158.05  57.85  215.90 $ Silo,
          -57.85  215.90 -158.05  158.05 -215.90  57.85 -215.90 -57.85 -158.05 -158.05 -57.85 -215.90 $  outer
            0.0   228.60  tr 0 0 0 0 0 1 0 1 0                                                          $
  9 rpp -106.68 106.68 -45.72 45.72 -0.79375 0 $ Steel cask plate

 11 p x -193.0
 12 p x -192.7225
 13 p x -187.96
 14 p x -187.6425
 15 p x -182.88
 16 p x  -71.12
 17 p x  -66.3575
 18 p x  -66.04
 19 p x  -65.7225
 20 p x  -61.2775
 21 p x  -60.96
 22 p x  -60.6425
 23 p x  -55.88
 24 p x   55.88
 25 p x   60.6425
 26 p x   60.96
 27 p x   61.2775
 28 p x   65.7225
 29 p x   66.04
 30 p x   66.3575
 31 p x   71.12
 32 p x  182.88
 33 p x  187.6425
 34 p x  187.96
 35 p x  192.7225
 36 p x  193.0

 41 p y -182.88
 42 p y  182.88

 51 p z  228.60      151 p z 249.63
 52 p z  228.9175    152 p z 249.9475
 53 p z  233.3625    153 p z 254.3925
 54 p z  233.68      154 p z 254.71
 55 p z  233.9875    155 p z 255.0275
 56 p z  238.8625    156 p z 260.3425
 57 p z  239.18      157 p z 260.66
 58 p z  239.4975    158 p z 260.9775
 59 p z  243.9425    159 p z 265.4225
 60 p z  244.26      160 p z 265.74
 61 p z  244.5775    161 p z 266.0575
 62 p z  249.3126    162 p z 271.1125
 63 p z  249.63      163 p z 271.43

111 p x -193.0    tr -5.08 0 0
112 p x -192.7225 tr -5.08 0 0
113 p x -187.96   tr -5.08 0 0
114 p x -187.6425 tr -5.08 0 0
115 p x -182.88   tr -5.08 0 0
116 p x  -71.12   tr -5.08 0 0
117 p x  -66.3575 tr -5.08 0 0
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118 p x  -66.04   tr -5.08 0 0
119 p x  -65.7225 tr -5.08 0 0
120 p x  -61.2775 tr -5.08 0 0
121 p x  -60.96   tr -5.08 0 0
122 p x  -60.6425 tr -5.08 0 0
123 p x  -55.88   tr -5.08 0 0
124 p x   55.88   tr -5.08 0 0
125 p x   60.6425 tr -5.08 0 0
126 p x   60.96   tr -5.08 0 0
127 p x   61.2775 tr -5.08 0 0
128 p x   65.7225 tr -5.08 0 0
129 p x   66.04   tr -5.08 0 0
130 p x   66.3575 tr -5.08 0 0
131 p x   71.12   tr -5.08 0 0
132 p x  182.88   tr -5.08 0 0
133 p x  187.6425 tr -5.08 0 0
134 p x  187.96   tr -5.08 0 0
135 p x  192.7225 tr -5.08 0 0
136 p x  193.0    tr -5.08 0 0

201 torus  3000 30.48 tr 0 0 198.12 0 0 999 0 999 198.12 $ Detector at  30 m =  3,000 cm
202 torus  5000 30.48 tr 0 0 198.12 0 0 999 0 999 198.12 $ Detector at  50 m =  5,000 cm

detector
  number=#0000001 title="Photon exposure at 30m, R.cm2/s.Ci"
    reaction 201 5.50150E+7   $ Reaction detector in air, V=(2*PI*3,000)(PI*(30.48**2))
    drf-e photon              $ Exposure in R/cm2.s per Rogers
       0.01 8.54-10 0.015 3.59-10 0.02 1.94-10 0.03 8.29-11 0.04 4.93-11 0.05 3.71-11 0.06 3.32-11 0.08 3.52-11
       0.10 4.26-11 0.15  6.88-11 0.2  9.82-11 0.3  1.58-10 0.4  2.17-10 0.5  2.73-10 0.6  3.25-10 0.8  4.24-10
       1.0  5.12-10 1.25  6.11-10 1.5  7.02-10 2.0  8.61-10 3.0  1.18-9  4.0  1.37-9  5.0  1.60-9  6.0  1.82-9
       8.0  2.24-9 10.0   2.66-9 20.0  4.80-9
  number=#0000002 title="Photon exposure at 50m, R.cm2/s.Ci"
    reaction 202 9.16916E+7   $ Reaction detector in air, V=(2*PI*5,000)(PI*(30.48**2))
    drf-e photon              $ Exposure in R/cm2.s per Rogers
       0.01 8.54-10 0.015 3.59-10 0.02 1.94-10 0.03 8.29-11 0.04 4.93-11 0.05 3.71-11 0.06 3.32-11 0.08 3.52-11
       0.10 4.26-11 0.15  6.88-11 0.2  9.82-11 0.3  1.58-10 0.4  2.17-10 0.5  2.73-10 0.6  3.25-10 0.8  4.24-10
       1.0  5.12-10 1.25  6.11-10 1.5  7.02-10 2.0  8.61-10 3.0  1.18-9  4.0  1.37-9  5.0  1.60-9  6.0  1.82-9
       8.0  2.24-9 10.0   2.66-9 20.0  4.80-9
end
```