UPDATE OF THE NUCLEAR CRITICALITY SLIDE RULE CALCULATIONS
–
INITIAL CONFIGURATIONS

IDENTIFICATION NUMBER: SR-U-UNREFLECTED-GROUND-001

KEY WORDS: Slide rule, initial configurations, uranium, unreflected

1 INTRODUCTION

In 1997, Oak Ridge National Laboratory published the reports "An updated Nuclear Criticality Slide rule" (ORNL/TM-13322/V1 and ORNL/TM-13322/V2), as a tool for emergency response to nuclear criticality accident. The "Slide Rule" is designed to provide estimates of the following:

- magnitude of the number of fissions based on personnel or field radiation measurements,
- neutron- and gamma-dose at variable unshielded distances from the accident,
- the skyshine component of the dose,
- time-integrated radiation dose estimates at variable times/distances from the accident,
- 1-minute gamma radiation dose integrals at variable times/distances from the accident,
- dose-reduction factors for variable thicknesses of steel, concrete, and water.

The Slide Rule provides estimates for five unreflected spherical systems that provide general characteristics of operations likely in facilities licensed by the US NRC.

This present document summarizes the input data necessary to update, with modern codes, the dose results of the initial configurations of the slide rules (prompt neutron and gamma doses, delayed gamma dose). Additional configurations might be simulated after this first effort.

2 DESCRIPTION OF THE INITIAL CONFIGURATION

The geometry for the initial configuration of the slide rule consists of an air-over-ground configuration with a source located at the center of a right-circular cylinder. The ground is made of concrete. The critical uranium systems selected were as follows:

- unreflected sphere of 4.95 wt % enriched aqueous uranyl fluoride, $U(4.95)O_2F_2@H_2O$, solution having a hydrogen-to-^{235}U ratio of 410 (solution density = 2.16 g/cm^3),
- unreflected sphere of damp 5 wt % enriched uranium dioxide, $U(5)O_2$, having a hydrogen-to- ^{235}U ratio of 200,
- unreflected sphere of 93.2 wt % enriched uranyl nitrate, $U(93.2)O_2(NO_3)2@6H_2O$, solution having a hydrogen to-^{235}U atom ratio of 500 (solution density = 1.075 g/cm^3),
- unreflected sphere of 93.2 wt % enriched uranium metal sphere (metal density = 18.85 g/cm^3),
- unreflected sphere of damp 93.2 wt % enriched uranium oxide, U_3O_8 plus water, having a hydrogen-to-^{235}U atom ratio of 10 (uranium oxide density = 4.15 g/cm^3).

Neutron and gamma doses were calculated as a function of distance from the surface of the critical event for 1 to 3000 feet (914 m).

2.1 Description of Model

The figures 2-1 and 2-2 present the model to be calculated. Additional information are given in the following paragraphs.

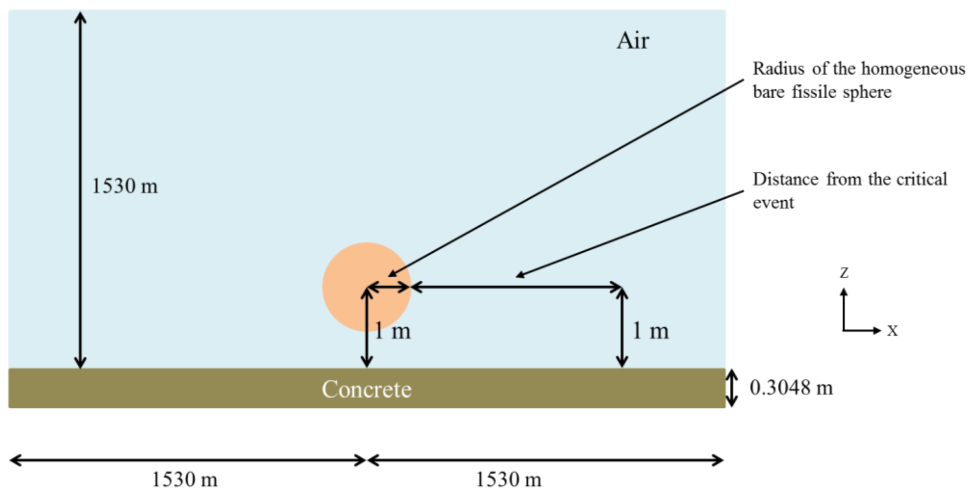


Figure 2-1. X-Z Plan view of the configuration.

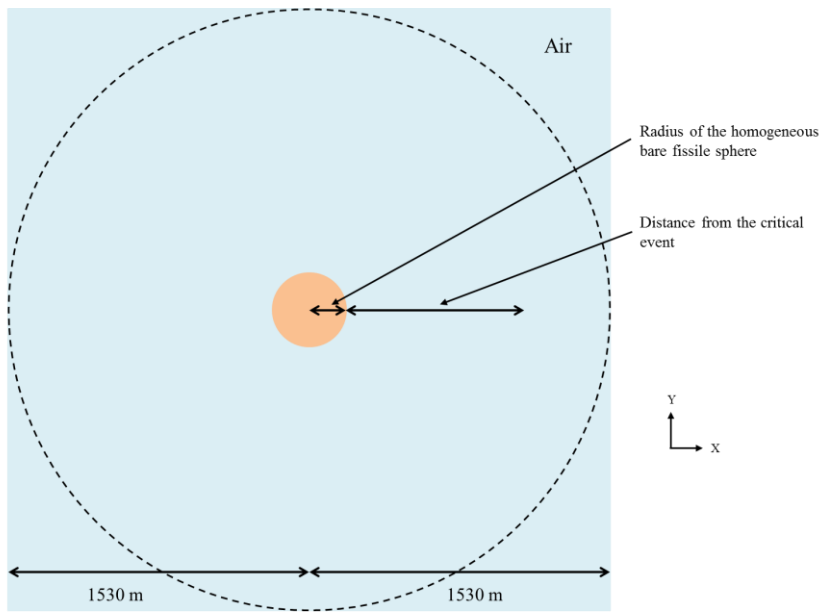


Figure 2-2. X-Y Plan view of the configuration.

2.2 Dimensions

Initially, the geometry for the 2-D slide-rule models consisted of a simple air-over-ground configuration with a source located at the center of a right-circular cylinder. The radius and the height of the air cylinder was 1530 m. With modern 3-D tools, a square with a half-side of 1530 m might be considered. The ground is modeled as 30.48 cm (1 ft) layer of concrete.

Five uranium systems are separately considered. The spherical radius (corresponding to a critical state) for each system is given in Table 2-1. No reflector is considered around the sphere.

Table 2-1. Radius of the homogeneous bare fissile spheres.

	Uranyl fluoride (4.95%)	Damp UO_2 (5%)	Uranyl nitrate solution (93.2%)	U metal (93.2%)	Damp U_3O_8 (93.2%)
Spherical radius (cm)	25.5476	23.2133	18.9435	8.6518	11.8841

2.3 Material and temperature Data

Only 3 media are simulated in the initial configurations:

- The air,
- One of the 5 homogeneous bare fissile spheres,
- The ground made of concrete.

Their atomic compositions are given in Table 2-2, Table 2-3 and Table 2-4.

Table 2-2. Composition of the homogeneous bare fissile spheres.

Number density (atom/barn-cm)	Uranyl fluoride (4.95%)	Damp UO_2 (5%)	Uranyl nitrate solution (93.2%)	U metal (93.2%)	Damp U_3O_8 (93.2%)
U-234	-	-	-	4.8503E-4	-
U-235	1.3173E-4	2.6060E-4	1.3154E-4	4.5012E-2	6.4361E-3
U-236	-	-	-	9.6182E-5	-
U-238	2.5342E-3	4.9592E-3	9.6010E-6	2.6704E-3	4.6956E-4
N	-	-	2.8205E-4	-	-
O	3.1989E-2	3.6544E-2	3.4012E-2	-	5.0641E-2
F	5.3345E-3	-	-	-	-
H	5.3314E-2	5.2203E-2	6.5769E-2	-	6.4460E-2

Table 2-3. Composition of air.

Number density (atom/barn-cm)	Air
N	4.00E-5
O	1.11E-5

Table 2-4. Composition of concrete (SCALE material REG-CONCRETE).

Number density (atom/barn-cm)	Concrete
Fe-54	2.02958E-05
Fe-56	3.18600E-04
Fe-57	7.35787E-06
Fe-58	9.79198E-07
H	1.37433E-02
Al-27	1.74538E-03
Ca-40	1.47412E-03
Ca-42	9.83851E-06
Ca-43	2.05286E-06
Ca-44	3.17205E-05
Ca-46	6.08254E-08
Ca-48	2.84359E-06
O	4.60690E-02
Si-28	1.53273E-02
Si-29	7.78639E-04
Si-30	5.13885E-04
Na-23	1.74720E-03

The temperatures for all media are 300 K (26.85 °C).

2.4 Source Strength and Spectra

The magnitude of each source is normalized to correspond to 1.E+17 fissions.

This single information means that the intensity (nubar for neutron) and the energy and space repartition of prompt neutron, prompt gamma and delayed gamma inside the sphere has to be determined. A subsequent case may consider a homogeneous repartition of the fissions inside the sphere.

2.5 Delayed gamma

Delayed gamma doses rate are calculated assuming an instantaneous event. Then the expected dose rates for periods of 1, 5, and 10 s and 1, 5, 10, 50, 100, 500, and 1000 min after the event are tabulated for all five critical systems.

2.6 Response Functions

Doses at 1 m (3.30 ft) above the ground as a function of distance from the surface of the critical event for 1 to 3000 feet are calculated using the Henderson flux-to-dose factors (B. J. Henderson, *Conversion of Neutron or Gamma-Ray Flux to Absorbed Dose Rate*, XDC 59-8-179, 1959).

3 RESULTS

The results will be written in the following tables. All options and data necessary to analyze the results (for instance, cross section libraries, delayed gamma data, kind of detector, use of variance reduction technic, etc.) might be specified.

For more clarity, a common file naming convention may be adopted. An example is the following:

- SR-U-UN-G1-C1-d03-DG10s.inp stands for:
  - SR: slide rule,
  - U: uranium,
  - UN: unreflected (no shielding),
  - G1: first case with a ground,
  - C1: first case with the uranium system (Uranyl fluoride (4.95%))[1],
  - d03: distance 0.3 m,
  - DG10s: delayed gamma (after 10 seconds)[2].

[1] C2 is Damp UO2 (5%); C3 is Uranyl nitrate solution (93.2%); C4 is U metal (93.2%); C5 is Damp U3O8 (93.2%).

[2] Instead of « DG », « N » and « G » may be used, for respectively prompt neutron and prompt gamma.

Table 3-1. Prompt neutron dose.

Prompt neutron dose	Case 1	Case 2	Case 3	Case 4	Case 5
Distance (m)	Uranyl fluoride (4.95%)	Damp UO_2 (5%)	Uranyl nitrate solution (93.2%)	U metal (93.2%)	Damp U_3O_8 (93.2%)
0.3					
0.5					
1					
2					
5					
10					
20					
50					
100					
200					
300					
500					
700					
1000					
1200					

Table 3-2. Prompt gamma dose.

Prompt gamma dose	Case 1	Case 2	Case 3	Case 4	Case 5
Distance (m)	Uranyl fluoride (4.95%)	Damp UO_2 (5%)	Uranyl nitrate solution (93.2%)	U metal (93.2%)	Damp U_3O_8 (93.2%)
0.3					
0.5					
1					
2					
5					
10					
20					
50					
100					
200					
300					
500					
700					
1000					
1200					

Table 3-3. Delayed gamma dose rate (after 1 s).

Delayed gamma dose rate (after 1 s)	Case 1	Case 2	Case 3	Case 4	Case 5
Distance (m)	Uranyl fluoride (4.95%)	Damp UO_2 (5%)	Uranyl nitrate solution (93.2%)	U metal (93.2%)	Damp U_3O_8 (93.2%)
0.3					
0.5					
1					
2					
5					
10					

20					
50					
100					
200					
300					
500					
700					
1000					
1200					

Table 3-4. Delayed gamma dose rate (after 5 s).

Delayed gamma dose rate (after 5 s)	Case 1	Case 2	Case 3	Case 4	Case 5
Distance (m)	Uranyl fluoride (4.95%)	Damp UO_2 (5%)	Uranyl nitrate solution (93.2%)	U metal (93.2%)	Damp U_3O_8 (93.2%)
0.3					
0.5					
1					
2					
5					
10					
20					
50					
100					
200					
300					
500					
700					
1000					
1200					

Table 3-5. Delayed gamma dose rate (after 10 s).

Delayed gamma dose rate (after 10 s)	Case 1	Case 2	Case 3	Case 4	Case 5
Distance (m)	Uranyl fluoride (4.95%)	Damp UO_2 (5%)	Uranyl nitrate solution (93.2%)	U metal (93.2%)	Damp U_3O_8 (93.2%)
0.3					
0.5					
1					
2					
5					
10					
20					
50					
100					
200					
300					
500					
700					
1000					
1200					

Table 3-6. Delayed gamma dose rate (after 1 min).

Delayed gamma dose rate (after 1 min)	Case 1	Case 2	Case 3	Case 4	Case 5
Distance (m)	Uranyl fluoride (4.95%)	Damp UO_2 (5%)	Uranyl nitrate solution (93.2%)	U metal (93.2%)	Damp U_3O_8 (93.2%)
0.3					
0.5					
1					
2					
5					
10					
20					
50					
100					
200					
300					
500					
700					
1000					
1200					

Table 3-7. Delayed gamma dose rate (after 5 min).

Delayed gamma dose rate (after 5 min)	Case 1	Case 2	Case 3	Case 4	Case 5
Distance (m)	Uranyl fluoride (4.95%)	Damp UO_2 (5%)	Uranyl nitrate solution (93.2%)	U metal (93.2%)	Damp U_3O_8 (93.2%)
0.3					
0.5					
1					
2					
5					
10					
20					
50					
100					
200					
300					
500					
700					
1000					
1200					

Table 3-8. Delayed gamma dose rate (after 10 min).

Delayed gamma dose rate (after 10 min)	Case 1	Case 2	Case 3	Case 4	Case 5
Distance (m)	Uranyl fluoride (4.95%)	Damp UO_2 (5%)	Uranyl nitrate solution (93.2%)	U metal (93.2%)	Damp U_3O_8 (93.2%)
0.3					
0.5					
1					
2					
5					
10					
20					
50					

100					
200					
300					
500					
700					
1000					
1200					

Table 3-9. Delayed gamma dose rate (after 50 min).

Delayed gamma dose rate (after 50 min)	Case 1	Case 2	Case 3	Case 4	Case 5
Distance (m)	Uranyl fluoride (4.95%)	Damp UO_2 (5%)	Uranyl nitrate solution (93.2%)	U metal (93.2%)	Damp U_3O_8 (93.2%)
0.3					
0.5					
1					
2					
5					
10					
20					
50					
100					
200					
300					
500					
700					
1000					
1200					

Table 3-10. Delayed gamma dose rate (after 100 min).

Delayed gamma dose rate (after 100 min)	Case 1	Case 2	Case 3	Case 4	Case 5
Distance (m)	Uranyl fluoride (4.95%)	Damp UO_2 (5%)	Uranyl nitrate solution (93.2%)	U metal (93.2%)	Damp U_3O_8 (93.2%)
0.3					
0.5					
1					
2					
5					
10					
20					
50					
100					
200					
300					
500					
700					
1000					
1200					

Table 3-11. Delayed gamma dose rate (after 500 min).

Delayed gamma dose	Case 1	Case 2	Case 3	Case 4	Case 5

rate (after 500 min)					
Distance (m)	Uranyl fluoride (4.95%)	Damp UO_2 (5%)	Uranyl nitrate solution (93.2%)	U metal (93.2%)	Damp U_3O_8 (93.2%)
0.3					
0.5					
1					
2					
5					
10					
20					
50					
100					
200					
300					
500					
700					
1000					
1200					

Table 3-12. Delayed gamma dose rate (after 1000 min).

Delayed gamma dose rate (after 1000 min)	Case 1	Case 2	Case 3	Case 4	Case 5
Distance (m)	Uranyl fluoride (4.95%)	Damp UO_2 (5%)	Uranyl nitrate solution (93.2%)	U metal (93.2%)	Damp U_3O_8 (93.2%)
0.3					
0.5					
1					
2					
5					
10					
20					
50					
100					
200					
300					
500					
700					
1000					
1200					

UPDATE OF THE NUCLEAR CRITICALITY SLIDE RULE CALCULATIONS
–
PLUTONIUM CONFIGURATIONS

IDENTIFICATION NUMBER: SR-Pu-UNREFLECTED-GROUND-001 and SR-Pu-STEEL-GROUND-001
KEY WORDS: Slide rule, additional configurations, plutonium, reflector, cylinder

1 INTRODUCTION

In 1997, Oak Ridge National Laboratory published the reports "An updated Nuclear Criticality Slide rule" (ORNL/TM-13322/V1 and ORNL/TM-13322/V2), as a tool for emergency response to nuclear criticality accident. The "Slide Rule" is designed to provide estimates of the following:

- magnitude of the number of fissions based on personnel or field radiation measurements,
- neutron- and gamma-dose at variable unshielded distances from the accident,
- the skyshine component of the dose,
- time-integrated radiation dose estimates at variable times/distances from the accident,
- 1-minute gamma radiation dose integrals at variable times/distances from the accident,
- dose-reduction factors for variable thicknesses of steel, concrete, and water.

The Slide Rule provides estimates for five unreflected spherical systems that provide general characteristics of operations likely in facilities licensed by the US NRC. AWE (UK), IRSN (France), LLNL (USA) and ORNL (USA) began a long term collaboration effort in 2015 to update this document. Calculations for initial configurations were performed using modern tools such as MCNP, SCALE and COG.

This present document summarizes the input data necessary to calculate additional configurations that combine new fissile media (plutonium systems, §2.2), new source geometries (cylinder, §2.3) and also reflectors (made of steel, §2.4).

2 DESCRIPTION OF THE ADDITIONAL CONFIGURATIONS

2.1 GEOMETRY

The geometry for the additional configurations, derived from the initial configuration of the slide rule (described in the document SR-U-UNREFLECTED-GROUND-001), is presented hereafter.

The geometry consists of a simple air-over-ground configuration with a source located at the center of a right-circular cylinder. The radius and the height of the air cylinder is 1530 m. With modern 3-D tools, a square with a half-side of 1530 m might be considered. The ground is modeled as 50 cm layer of concrete.

The figures 1 and 2 present the model to be calculated. Additional information is given in the following paragraphs.

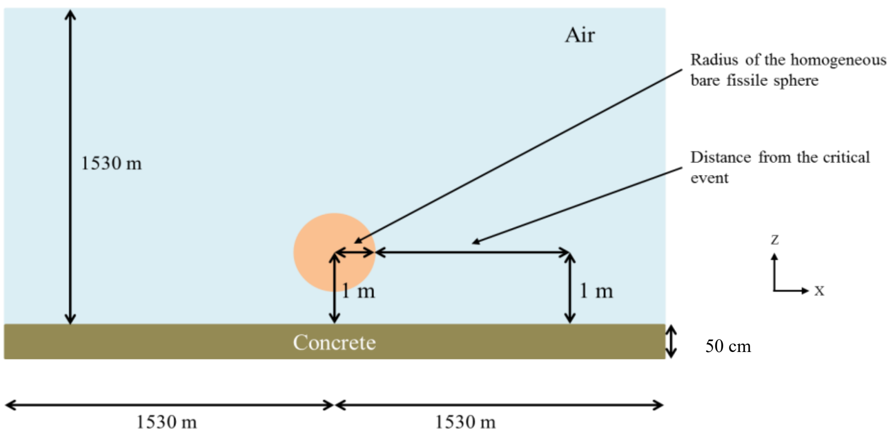


Figure 1 : X-Z Plan view of the configuration

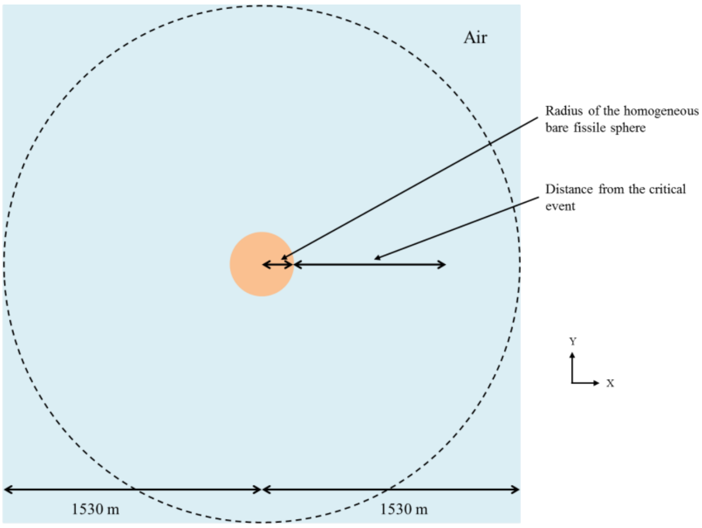


Figure 2 : X-Y Plan view of the configuration

2.2 PLUTONIUM SYSTEMS (BARE SPHERE)

New bare fissile media, with plutonium at various moderation ratios (H/Pu), is added for the additional configurations. No reflector is considered around the sphere. The following table gives atomic concentration and critical radius of each media.

Table 1 : Compositions for the new fissile media, Pu

Number density (atom/barn-cm)	Pu (H/Pu = 0)	Pu (H/Pu = 10)	Pu (H/Pu = 100)	Pu (H/Pu = 900)	Pu (H/Pu = 2000)
Pu-239	5.00305E-02	5.88706E-03	6.58436E-04	7.40255E-05	3.33386E-05
O-16	0	2.94353E-02	3.29218E-02	3.33115E-02	3.33386E-02
H-1	0	5.88706E-02	6.58436E-02	6.66230E-02	6.66772E-02

The following table gives critical radii for these five media. They are calculated using MCNP6.1 with ENDF/B-VII.1 cross sections library.

Table 2 : Spherical radii for bare Pu configurations

	Pu H/Pu = 0	Pu H/Pu = 10	Pu H/Pu = 100	Pu H/Pu = 900	Pu H/Pu = 2000
Spherical radius (cm)	4.93	12.53	15.36	19.50	29.17

2.3 NEW GEOMETRY SOURCE (CYLINDERS)

The initial configurations of the Slide Rule considered bare spherical systems for the source. In these additional configurations, critical cylinders are also considered. No reflector is considered around the cylinder. Three types of vertical cylinder, with various height-to-diameter ratios, are considered. The following table gives critical dimensions for plutonium systems.

Table 3 : Critical dimensions for Pu cylinders

	Height-to-diameter ratio	Pu H/Pu = 0	Pu H/Pu = 10	Pu H/Pu = 100	Pu H/Pu = 900	Pu H/Pu = 2000
Radius 1 (cm)	1	4.42	-	-	-	26.62
Height 1 (cm)		8.84	-	-	-	53.24
Radius 2 (cm)	0.5	5.81	-	-	-	36.09
Height 2 (cm)		5.81	-	-	-	36.09
Radius 3 (cm)	2	3.775	-	-	-	23.25
Height 3 (cm)		15.10	-	-	-	93.00

2.4 REFLECTOR (STEEL)

The initial configurations of the Slide Rule considered bare spherical systems for the source. In these additional configurations, steel reflector is added around the plutonium sphere, which modifies the critical radius of Plutonium.

The reflector's atomic composition is presented in the following table. The "Steel 304" from the PNNL document[1] is arbitrarily chosen. The thickness of the reflector will be **0.1 cm**, **0.3 cm**, **1 cm, 5 cm, 10 cm and 20 cm**.

The distance between the source and the detector is measured from the external surface of the steel to the center of the detector.

Table 4 : Composition of the reflector

Number density (atom/barn-cm)	Steel 304 PNNL
C-12	1.6000E-04
Si-28	7.9133E-04
Si-29	4.0180E-05
Si-30	2.6490E-05
P-31	3.6000E-05
S-32	2.1834E-05
S-33	1.7480E-07
S-34	9.8670E-07
S-36	4.5000E-09
Cr-50	7.6494E-04
Cr-52	1.4751E-02
Cr-53	1.6727E-03
Cr-54	4.1636E-04
Mn-55	8.7700E-04

[1] PNNL-15870 Rev. 1, "Compendium of Material Composition Data for Radiation Transport Modeling," (2011).

Number density (atom/barn-cm)	Steel 304 PNNL
Fe-54	3.5380E-03
Fe-56	5.5546E-02
Fe-57	1.2830E-03
Fe-58	1.7100E-04
Ni-58	5.1691E-03
Ni-60	1.9911E-03
Ni-61	8.6500E-05
Ni-62	2.7600E-04
Ni-64	7.0300E-05

Critical radii for each configuration are given in the following table. They are calculated using MCNP6.1 with ENDF/B-VII.1 cross sections library.

Table 5 : Critical radii for Pu sphere with a reflector

Reflector composition	Thickness of the reflector	Critical radius of Plutonium (cm)				
		Pu H/Pu = 0	Pu H/Pu = 10	Pu H/Pu = 100	Pu H/Pu = 900	Pu H/Pu = 2000
Steel 304 PNNL	0.1 cm	4.89	-	-	-	29.10
	0.3 cm	4.82	-	-	-	29.01
	1 cm	4.62	-	-	-	28.31
	5 cm	4.22	-	-	-	26.31
	10 cm	4.05	-	-	-	25.31
	20 cm	3.95	-	-	-	24.31

3 ADDITIONAL INFORMATION

3.1 SOURCE STRENGTH AND SPECTRA

The magnitude of each source is normalized to correspond to 1.E+17 fissions. This single information means that the intensity (nubar for neutron) and the energy and space repartition of prompt neutron and prompt gamma inside the sphere/cylinder has to be determined.

3.2 MATERIAL AND TEMPERATURE DATA

Depending on the case, only 3 or 4 media are simulated in the additional configurations:

- The air,
- One of the homogeneous plutonium spheres or cylinders,
- The reflector made of steel, for the reflector cases,
- The ground made of concrete.

The atomic compositions of the air and the ground made of concrete are given in the following tables.

Table 6 : Composition of air.

Number density (atom/barn-cm)	Air
N-14	4.00E-5
O-16	1.11E-5

Table 7 : Composition of concrete (SCALE material REG-CONCRETE).

Number density (atom/barn-cm)	Concrete
Fe-54	2.02958E-05
Fe-56	3.18600E-04
Fe-57	7.35787E-06
Fe-58	9.79198E-07
H-1	1.37433E-02
Al-27	1.74538E-03
Ca-40	1.47412E-03
Ca-42	9.83851E-06
Ca-43	2.05286E-06
Ca-44	3.17205E-05
Ca-46	6.08254E-08
Ca-48	2.84359E-06
O-16	4.60690E-02
Si-28	1.53273E-02
Si-29	7.78639E-04
Si-30	5.13885E-04
Na-23	1.74720E-03

The temperatures for all media and for all cases are 300 K (26.85 °C).

3.3 DELAYED GAMMA

For these configurations, the delayed gamma are not considered. Only prompt doses are calculated.

3.4 RESPONSE FUNCTION AND DETECTORS

Henderson flux to dose conversion factors was used for the initial configurations. These factors have a significant impact on the final dose and are likely to change in the future. That is why, the additional configurations should be performed using the following conversion factors[2]:

- ANSI/HPS N13.3-2013 conversion factors (personal adsorbed dose per neutron unit fluence, Table B1 p. 18 and personal adsorbed dose per photon unit fluence, Table B2 p. 19),
- IAEA Technical Reports series n° 211 (1982) conversion factors (tissue kerma in air per neutron unit fluence, Table XIV pp. 138-139),
- ICRU report 47 (1992) conversion factors (air kerma in free air per photon unit fluence, Table A.1 p. 23),
- a fine group structure for neutron and gamma spectra, provided in annex 1. With these structures, it will be possible to apply any kind of flux to dose conversion factors in the future.

Doses are calculated (see figure 1) at 1 m above the ground as a function of distance (between 30 cm and 1 200 m) from the external surface of the source to the center of the detector. The detector used (type and geometry) might be specified. By default, the detector geometry is a shape of a cylindrical shell with a square cross-section of 5 cm x 5 cm. The center of the detector is also at a height of 1 m above the ground.

4 RESULTS

The results will be written in the following tables. All options and data necessary to analyze the results (for instance, cross section libraries, kind of detector, use of variance reduction technique, etc.) might be specified.

For more clarity, a common file naming convention may be adopted. An example is the following:

- SR-Pu-S-UN-G1-C1-d03-N.inp stands for:
  - SR: slide rule,
  - Pu: Plutonium[3],
  - S : sphere[4]
  - UN: unreflected (no shielding)[5],
  - G1: first case with a ground[6],
  - C1: first case with the plutonium system (H/Pu = 0)[7],
  - d03: distance 0.3 m,
  - N: prompt neutron[8].

[2] Henderson flux to dose conversion factors might be used for some cases to compare the impact of the various conversion factors and the impact of the additional configurations compared to the initial configurations.

[3] Pu is for Plutonium

[4] CYL1, CYL2 or CYL3 stands for cylinders

[5] R stands for reflected configurations (steel here).

[6] G1 is for concrete ground.

[7] C2 is H/Pu = 10; C3 is H/Pu = 100; C4 is H/Pu = 900; C5 is H/Pu = 2000.

[8] « G » stands for prompt gamma.

Table 8 : Prompt neutron dose for bare plutonium configuration

Prompt neutron dose	Case 1	Case 2	Case 3	Case 4	Case 5
Distance (m)	Pu H/Pu = 0	Pu H/Pu = 10	Pu H/Pu = 100	Pu H/Pu = 900	Pu H/Pu = 2000
0.3					
0.5					
1					
2					
5					
10					
20					
50					
100					
200					
300					
500					
700					
1000					
1200					

Table 9 : Prompt gamma dose for bare plutonium configuration.

Prompt gamma dose	Case 1	Case 2	Case 3	Case 4	Case 5
Distance (m)	Pu H/Pu = 0	Pu H/Pu = 10	Pu H/Pu = 100	Pu H/Pu = 900	Pu H/Pu = 2000
0.3					
0.5					
1					
2					
5					
10					
20					
50					
100					
200					
300					
500					
700					
1000					
1200					

Table 10 : Prompt neutron dose for cylinder plutonium configuration.

Prompt neutron dose	Case 1	Case 5	Case 1	Case 5	Case 1	Case 5
Cylinder	Cylinder 1		Cylinder 2		Cylinder 3	
Distance (m)	Pu H/Pu = 0	Pu H/Pu = 2000	Pu H/Pu = 0	Pu H/Pu = 2000	Pu H/Pu = 0	Pu H/Pu = 2000
0.3						
0.5						
1						
2						
5						
10						
20						
50						
100						
200						
300						
500						
700						
1000						
1200						

Table 11 : Prompt gamma dose for cylinder plutonium configuration.

Prompt gamma dose	Case 1	Case 5	Case 1	Case 5	Case 1	Case 5
Cylinder	Cylinder 1		Cylinder 2		Cylinder 3	
Distance (m)	Pu H/Pu = 0	Pu H/Pu = 2000	Pu H/Pu = 0	Pu H/Pu = 2000	Pu H/Pu = 0	Pu H/Pu = 2000
0.3						
0.5						
1						
2						
5						
10						
20						
50						
100						
200						
300						
500						
700						
1000						
1200						

Table 12 : Prompt neutron dose for reflected plutonium configuration.

Prompt neutron dose	Case 1	Case 5	Case 1	Case 5	Case 1	Case 5	Case 1	Case 5	Case 1	Case 5	Case 1	Case 5
Reflector	0.1 cm	0.1 cm	0.3 cm	0.3 cm	1 cm	1 cm	5 cm	5 cm	10 cm	10 cm	20 cm	20 cm
Distance (m)	Pu H/Pu = 0	Pu H/Pu=2000	Pu H/Pu = 0	Pu H/Pu=2000	Pu H/Pu = 0	Pu H/Pu=2000	Pu H/Pu = 0	Pu H/Pu=2000	Pu H/Pu = 0	Pu H/Pu=2000	Pu H/Pu = 0	Pu H/Pu=2000
0.3												
0.5												
1												
2												
5												
10												
20												
50												
100												
200												
300												
500												
700												
1000												
1200												

Table 13 : Prompt gamma dose for reflected plutonium configuration.

Prompt gamma dose	Case 1	Case 5	Case 1	Case 5	Case 1	Case 5	Case 1	Case 5	Case 1	Case 5	Case 1	Case 5
Reflector	0.1 cm	0.1 cm	0.3 cm	0.3 cm	1 cm	1 cm	5 cm	5 cm	10 cm	10 cm	20 cm	20 cm
Distance (m)	Pu H/Pu = 0	Pu H/Pu=2000	Pu H/Pu = 0	Pu H/Pu=2000	Pu H/Pu = 0	Pu H/Pu=2000	Pu H/Pu = 0	Pu H/Pu=2000	Pu H/Pu = 0	Pu H/Pu=2000	Pu H/Pu = 0	Pu H/Pu=2000
0.3												
0.5												
1												
2												
5												
10												
20												
50												
100												
200												
300												
500												
700												
1000												
1200												

Annex 1: group structure for neutron and gamma spectra

UPDATE OF THE NUCLEAR CRITICALITY SLIDE RULE CALCULATIONS
–
SENSITIVITY STUDIES

IDENTIFICATION NUMBER: SR-U-MOISTURE-GROUND-001,
SR-U-UNREFLECTED-GROUND-002,
SR-U-SKYSHINE-GROUND-001,
SR-U-SCREEN-GROUND-001,

KEY WORDS: Slide rule, uranium, radiological screen

1 INTRODUCTION

In 1997, Oak Ridge National Laboratory published the reports “An updated Nuclear Criticality Slide rule” (ORNL/TM-13322/V1 and ORNL/TM-13322/V2), as a tool for emergency response to nuclear criticality accident. The “Slide Rule” is designed to provide estimates of the following:

- magnitude of the number of fissions based on personnel or field radiation measurements,
- neutron- and gamma-dose at variable unshielded distances from the accident,
- the skyshine component of the dose,
- time-integrated radiation dose estimates at variable times/distances from the accident,
- 1-minute gamma radiation dose integrals at variable times/distances from the accident,
- dose-reduction factors for variable thicknesses of steel, concrete, and water.

The Slide Rule provides estimates for five unreflected spherical systems that provide general characteristics of operations likely in facilities licensed by the US NRC. AWE (UK), IRSN (France), LLNL (USA) and ORNL (USA) began a long term collaboration effort in 2015 to update this document. Calculations for initial configurations were performed using modern tools such as MCNP, SCALE and COG.

This present document summarizes the input data necessary to update and complete the Slide Rule.

2 DESCRIPTION OF THE CONFIGURATIONS

2.1 GEOMETRY

The geometry for the configuration of the slide rule (described in the document SR-U-UNREFLECTED-GROUND-001), is presented hereafter.

The geometry consists of a simple air-over-ground configuration with a source located at the center of a right-circular cylinder. The radius and the height of the air cylinder is 1530 m. With modern 3-D tools, a square with a half-side of 1530 m might be considered. The ground is now modeled as 50 cm layer of concrete.

The figures 1 and 2 present the model to be calculated. Additional information is given in the following paragraphs.

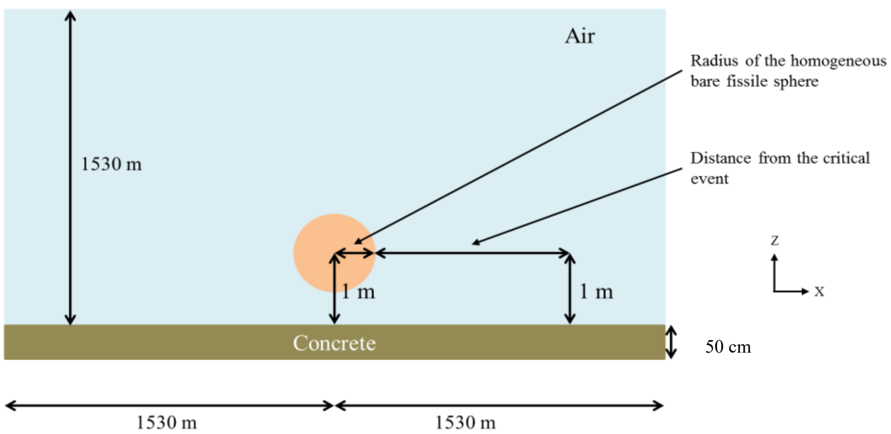


Figure 1 : X-Z Plan view of the configuration

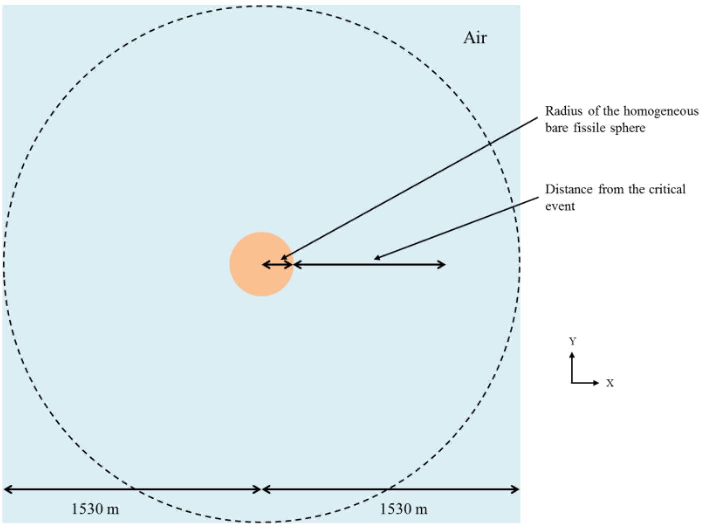


Figure 2 : X-Y Plan view of the configuration

Five uranium systems are separately considered. The spherical radius (corresponding to a critical state) for each system is given in Table 1. No reflector is considered around the sphere.

Table 1: Radius of the homogeneous bare fissile spheres.

	Uranyl fluoride (4.95%)	Damp UO_2 (5%)	Uranyl nitrate solution (93.2%)	U metal (93.2%)	Damp U_3O_8 (93.2%)
Spherical radius (cm)	25.5476	23.2133	18.9435	8.6518	11.8841

2.2 MATERIAL AND TEMPERATURE DATA

3 media are simulated in the initial configuration:

- The air,
- One of the 5 homogeneous bare fissile spheres,
- The ground made of concrete.

Their atomic compositions are given in Table 2, Table 3 and Table 5.

Table 2: Composition of the homogeneous bare fissile spheres.

Number density (atom/barn-cm)	Uranyl fluoride (4.95%)	Damp UO_2 (5%)	Uranyl nitrate solution (93.2%)	U metal (93.2%)	Damp U_3O_8 (93.2%)
U-234	-	-	-	4.8503E-4	-
U-235	1.3173E-4	2.6060E-4	1.3154E-4	4.5012E-2	6.4361E-3
U-236	-	-	-	9.6182E-5	-
U-238	2.5342E-3	4.9592E-3	9.6010E-6	2.6704E-3	4.6956E-4
N	-	-	2.8205E-4	-	-
O	3.1989E-2	3.6544E-2	3.4012E-2	-	5.0641E-2
F	5.3345E-3	-	-	-	-
H	5.3314E-2	5.2203E-2	6.5769E-2	-	6.4460E-2

Table 3: Composition of air.

Number density (atom/barn-cm)	Air
N	4.00E-5
O	1.11E-5

The temperatures for all media are 300 K (26.85 °C).

3 DESCRIPTION OF THE SENSITIVITY STUDIES

This part presents the sensitivity studies to perform for the initial configurations of the Slide Rule.

3.1 MOISTURE IN AIR

Neutron and gamma prompt dose calculations will be performed with a humidity of 10% and 100%, at the room temperature. The air composition to be used[1] is given in the following table:

Table 4 : Composition of air – humidity of 10% and 100%

Number density (atom/barn-cm)	Air Humidity 10%	Air Humidity 100%
N-14	3.9214E-05	3.8397E-05
O-16	1.0798E-05	1.1094E-05
H-1	1.1559E-07	1.1559E-06

3.2 GROUND COMPOSITION AND DIMENSIONS

Calculations will be performed with the regulatory concrete composition, cf. Table 5. Nevertheless, a dry soil composition (without hydrogen) will be also tested for the case 1 and case 4, cf. Table 6. In each case, neutron and gamma prompt dose calculations should be performed. Moreover, the dimension for the ground is changed from **30.48 cm (initial configurations) to 50 cm**. The following tables give atomic concentration of the concrete and the soil[2].

[1] The air composition is based on the reference "Air humide – Notions de base et mesures. Réf : BZ8025 V1. Bernard CRETINON, Bertrand BLANQUART".

[2] Soil composition is taken from the Pacific Northwest National Laboratory "Compendium of Material Composition Data for Radiation Transport Modeling" Revision 1 March, 2011. Concrete composition was defined by the Nuclear Regulatory Commission and it is the standard concrete in SCALE.

Table 5 : Composition of concrete (REGULAR-CONCRETE-NRC)

Number density (atom/barn-cm)	Concrete
Fe-54	2.02958E-05
Fe-56	3.18600E-04
Fe-57	7.35787E-06
Fe-58	9.79198E-07
H	1.37433E-02
Al-27	1.74538E-03
Ca-40	1.47412E-03
Ca-42	9.83851E-06
Ca-43	2.05286E-06
Ca-44	3.17205E-05
Ca-46	6.08254E-08
Ca-48	2.84359E-06
O	4.60690E-02
Si-28	1.53273E-02
Si-29	7.78639E-04
Si-30	5.13885E-04
Na-23	1.74720E-03

Table 6 : Composition of soil (EARTH US average - PNNL)

Number density (atom/barn-cm)	Soil
O-16	2.9391E-02
Na-23	2.4400E-04
Mg-24	3.9053E-04
Mg-25	5.1503E-05
Mg-26	5.8968E-05
Mg-27	2.3260E-03
Mg-28	8.1191E-03
Mg-29	4.2723E-04
Si-30	2.9165E-04
K-39	3.1134E-04
K-40	4.0200E-08
K-41	2.3621E-05
Ca-40	1.1300E-03
Ca-42	7.9141E-06
Ca-43	1.6951E-06

Number density (atom/barn-cm)	Soil
Ca-44	2.6747E-05
Ca-46	5.8450E-08
Ca-48	2.6186E-06
Ti-46	6.9696E-06
Ti-47	6.4222E-06
Ti-48	6.4984E-05
Ti-49	4.8682E-06
Ti-50	4.7564E-06
Mn-55	1.2000E-05
Fe-54	5.2113E-05
Fe-56	8.4826E-04
Fe-57	1.9937E-05
Fe-58	2.7044E-06

3.3 SKYSHINE

The contribution of the skyshine will be determined for height superior to 10 m in each configuration. It means that calculations of the 5 cases will be done again with a height of 10 m (instead of 1530 m). The effect of the skyshine is the different between the two calculations.

3.4 RADIOLOGICAL SCREEN

A radiological screen will be added in each configuration. This screen will be placed at various distances between the source and the detector. The position of the radiological screen is measured from the external surface of the source to the internal face of the screen. The detector has a spherical shape with default radius of 20 cm.

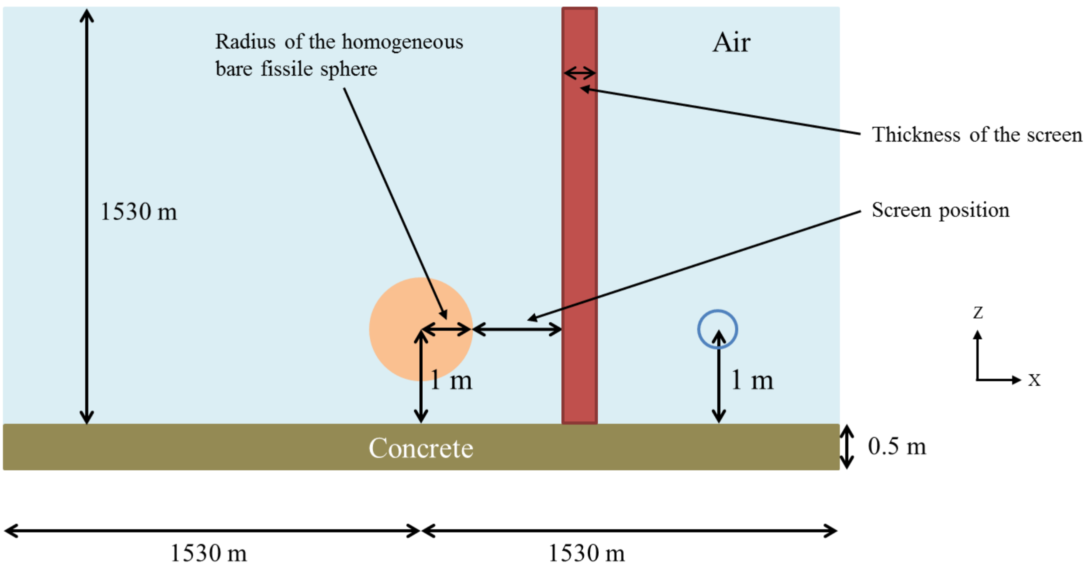


Figure 3 : X-Z Plan view of the configuration with a radiological screen

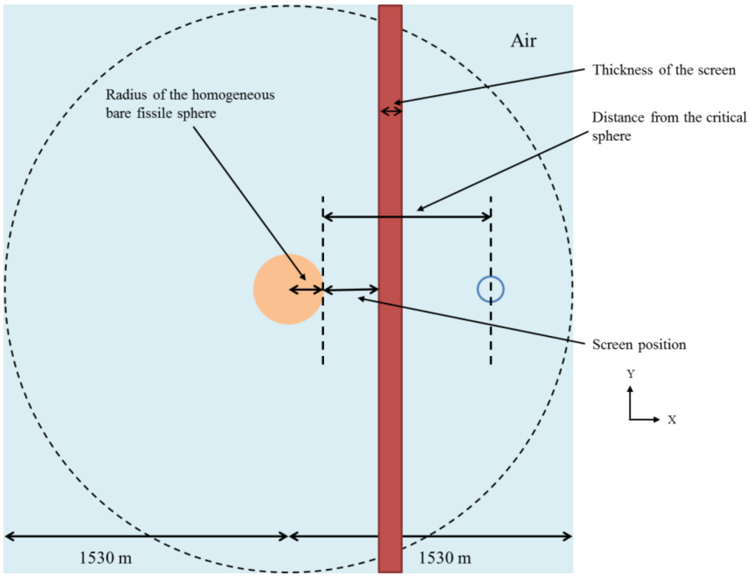


Figure 4 : X-Y Plan view of the configuration with a radiological screen

The following table presents screen positions for each detector distance.

Table 7 : Screen position for each detector

Detector position (m)	Screen position (m)
0.3	
0.5	
1	0.50
2	1.00
5	2.50
10	5.00
20	10.00
50	25.00
100	50.00
200	100.00
300	150.00
500	250.00
700	350.00
1000	500.00
1200	600.00

Compositions[3] for the radiological screen are presented in the following table.

[3] Compositions (except concrete) are taken from the Pacific Northwest National Laboratory 'Compendium of Material Composition Data for Radiation Transport Modeling' Revision 1 March, 2011

Table 8 : Compositions for the radiological screen

Number density (atom/barn-cm)	Steel 304 PNNL	Number density (atom/barn-cm)	Water PNNL	Number density (atom/barn-cm)	Lead PNNL	Number density (atom/barn-cm)	Concrete
C-6	1.6000E-04	H	6.6733E-02	Pb-204	4.6183E-04	Fe-54	2.02958E-05
P-31	3.6000E-05	O-16	3.3368E-02	Pb-206	7.9501E-03	Fe-56	3.18600E-04
Mn-55	8.7700E-04			Pb-207	7.2903E-03	Fe-57	7.35787E-06
Si-28	7.8821E-04			Pb-208	1.7286E-02	Fe-58	9.79198E-07
Si-29	4.1476E-05					H	1.37433E-02
Si-30	2.8314E-05					Al-27	1.74538E-03
S-32	2.1784E-05					Ca-40	1.47412E-03
S-33	1.7733E-07					Ca-42	9.83851E-06
S-34	1.0355E-06					Ca-43	2.05286E-06
S-35	2.5300E-09					Ca-44	3.17205E-05
Cr-50	7.6494E-04					Ca-46	6.08254E-08
Cr-52	1.4751E-02					Ca-48	2.84359E-06
Cr-53	1.6727E-03					O	4.60690E-02
Cr-54	4.1636E-04					Si-28	1.53273E-02
Fe-54	3.4180E-03					Si-29	7.78639E-04
Fe-56	5.5636E-02					Si-30	5.13885E-04
Fe-57	1.3076E-03					Na-23	1.74720E-03
Fe-58	1.7738E-04						
Ni-58	5.1691E-03						
Ni-60	1.9911E-03						
Ni-61	8.6553E-05						
Ni-62	2.7597E-04						
Ni-64	7.0281E-05						

The thickness of the screen is related to its composition. The following table presents those thicknesses.

Table 9 : Thickness of the radiological screen

Composition of the screen	Thickness (cm)			
Steel 304 PNNL	1	5	10	20
Lead PNNL	1	5	10	20
Water	1	5	10	20
Concrete	20	40		

Those thicknesses are representative of the different kind of wall, tank etc., that could be found in a nuclear facility

3.5 RESPONSE FUNCTIONS

Henderson flux to dose conversion factors was used for the initial configurations. These factors have a significant impact on the final dose and are likely to change in the future. That is why, the additional configurations should be performed using the following conversion factors :

- ANSI/HPS N13.3-2013 conversion factors (personal adsorbed dose per neutron unit fluence, Table B1 p. 18 and personal adsorbed dose per photon unit fluence, Table B2 p. 19),
- Group structures defined in the Table 7 and Table 8 (only a measurement of the flux with these factors).

Table 10 : Upper bounds for neutron fine group structures (from left to right and top to bottom)

Upper bounds in MeV						
1.00E-11	1.00E-09	2.15E-09	4.64E-09	1.00E-08	2.15E-08	2.50E-08
2.60E-08	3.00E-08	4.64E-08	5.00E-08	1.00E-07	2.00E-07	2.15E-07
2.25E-07	3.25E-07	4.15E-07	4.64E-07	5.00E-07	8.00E-07	1.00E-06
1.13E-06	1.30E-06	1.86E-06	2.00E-06	2.15E-06	3.06E-06	4.64E-06
5.00E-06	1.00E-05	1.07E-05	1.10E-05	2.00E-05	2.15E-05	2.90E-05
3.60E-05	4.64E-05	5.00E-05	6.30E-05	1.00E-04	1.01E-04	1.10E-04
2.00E-04	2.15E-04	3.60E-04	4.64E-04	5.00E-04	5.83E-04	6.30E-04
1.00E-03	1.10E-03	2.00E-03	2.15E-03	3.04E-03	3.60E-03	4.64E-03
5.00E-03	6.30E-03	1.00E-02	1.10E-02	1.25E-02	1.50E-02	1.58E-02
2.00E-02	2.51E-02	3.00E-02	3.16E-02	3.60E-02	3.98E-02	5.00E-02
5.01E-02	6.30E-02	7.00E-02	7.94E-02	8.20E-02	8.60E-02	9.00E-02
9.40E-02	9.80E-02	1.00E-01	1.05E-01	1.11E-01	1.15E-01	1.25E-01
1.35E-01	1.45E-01	1.50E-01	1.55E-01	1.58E-01	1.65E-01	1.75E-01
1.85E-01	1.95E-01	2.00E-01	2.10E-01	2.30E-01	2.50E-01	2.51E-01
2.70E-01	2.90E-01	3.00E-01	3.10E-01	3.16E-01	3.30E-01	3.50E-01
3.70E-01	3.90E-01	3.98E-01	4.00E-01	4.08E-01	4.20E-01	4.50E-01
4.60E-01	5.00E-01	5.01E-01	5.40E-01	5.50E-01	5.80E-01	6.00E-01
6.20E-01	6.30E-01	6.60E-01	7.00E-01	7.40E-01	7.80E-01	7.94E-01
8.00E-01	8.20E-01	8.60E-01	9.00E-01	9.07E-01	9.40E-01	9.80E-01
1.00E+00	1.05E+00	1.10E+00	1.15E+00	1.20E+00	1.25E+00	1.30E+00
1.35E+00	1.40E+00	1.43E+00	1.45E+00	1.50E+00	1.55E+00	1.58E+00
1.60E+00	1.65E+00	1.70E+00	1.75E+00	1.80E+00	1.83E+00	1.85E+00
1.90E+00	1.95E+00	2.00E+00	2.10E+00	2.20E+00	2.30E+00	2.40E+00
2.50E+00	2.60E+00	2.70E+00	2.80E+00	2.90E+00	3.00E+00	3.10E+00
3.15E+00	3.20E+00	3.30E+00	3.40E+00	3.50E+00	3.60E+00	3.70E+00
3.75E+00	3.80E+00	3.90E+00	4.00E+00	4.10E+00	4.20E+00	4.30E+00
4.50E+00	4.60E+00	4.70E+00	4.80E+00	4.90E+00	5.00E+00	5.10E+00
5.20E+00	5.30E+00	5.40E+00	5.50E+00	5.60E+00	5.80E+00	6.00E+00
6.20E+00	6.30E+00	6.40E+00	6.50E+00	6.60E+00	6.70E+00	7.00E+00
7.30E+00	7.40E+00	7.50E+00	7.70E+00	7.80E+00	7.94E+00	8.00E+00

Upper bounds in MeV						
8.20E+00	8.30E+00	8.50E+00	8.60E+00	9.00E+00	9.40E+00	9.80E+00
1.00E+01	1.05E+01	1.10E+01	1.15E+01	1.20E+01	1.25E+01	1.30E+01
1.35E+01	1.40E+01	1.45E+01	1.50E+01	1.60E+01	1.70E+01	1.80E+01
2.00E+01						

Table 11 : Upper bounds for gamma fine group structures (from left to right and top to bottom)

Upper bounds in MeV						
1.00E-02	1.25E-02	1.50E-02	1.75E-02	2.00E-02	2.50E-02	3.00E-02
4.00E-02	4.50E-02	5.00E-02	6.00E-02	7.00E-02	8.00E-02	1.00E-01
1.25E-01	1.50E-01	2.00E-01	2.50E-01	3.00E-01	3.50E-01	4.00E-01
4.50E-01	5.00E-01	5.50E-01	6.00E-01	6.50E-01	7.00E-01	8.00E-01
1.00E+00	1.10E+00	1.20E+00	1.33E+00	1.40E+00	1.50E+00	1.66E+00
1.80E+00	2.00E+00	2.20E+00	2.50E+00	2.60E+00	2.80E+00	3.00E+00
3.25E+00	3.50E+00	3.75E+00	4.00E+00	4.25E+00	4.50E+00	4.75E+00
5.00E+00	5.25E+00	5.50E+00	5.75E+00	6.00E+00	6.25E+00	6.50E+00
6.75E+00	7.50E+00	8.00E+00	8.50E+00	9.00E+00	9.50E+00	1.00E+01
1.10E+01	1.30E+01	1.50E+01	2.00E+01			

Doses are calculated (see figure 1) at 1 m above the ground as a function of distance (between 30 cm and 1 200 m) from the external surface of the source to the center of the detector. The detector used (type and geometry) might be specified. By default (for configurations without a radiological screen), the detector geometry is a shape of a cylindrical shell with a square cross-section of 5 cm x 5 cm. The center of the detector is also at a height of 1 m above the ground.

4 RESULTS

The results will be written in the following tables. All options and data necessary to analyze the results (for instance, cross section libraries, delayed gamma data, kind of detector, use of variance reduction technique, etc.) might be specified.

For more clarity, a common file naming convention may be adopted. An example is the following:

- SR-U-UN-G1-C1-d03-DG10s.inp stands for:
  - SR: slide rule,
  - U: uranium[4],
  - UN: unreflected (no shielding)[5],
  - G1: first case with a ground[6],
  - C1: first case with the uranium system (Uranyl fluoride (4.95%))[7],
  - d03: distance 0.3 m,
  - DG10s: delayed gamma (after 10 seconds)[8].

---

[4] Pu is for Plutonium

[5] R stand for reflected configurations.

[6] G1 is for concrete ground, G2 stand for a soil ground.

[7] C2 is Damp UO2 (5%); C3 is Uranyl nitrate solution (93.2%); C4 is U metal (93.2%); C5 is Damp U3O8 (93.2%); C6 is Pu.

[8] Instead of « DG », « N » and « G » may be used, for respectively prompt neutron and prompt gamma.

UPDATE OF THE NUCLEAR CRITICALITY SLIDE RULE CALCULATIONS
–
PLUTONIUM CONFIGURATIONS – DELAYED GAMMA

IDENTIFICATION NUMBER: SR-Pu-UNREFLECTED-GROUND-002
KEY WORDS: Slide rule, plutonium, delayed gamma

1 INTRODUCTION

In 1997, Oak Ridge National Laboratory published the reports "An updated Nuclear Criticality Slide rule" (ORNL/TM-13322/V1 and ORNL/TM-13322/V2), as a tool for emergency response to nuclear criticality accident. The "Slide Rule" is designed to provide estimates of the following:

- magnitude of the number of fissions based on personnel or field radiation measurements,
- neutron- and gamma-dose at variable unshielded distances from the accident,
- the skyshine component of the dose,
- time-integrated radiation dose estimates at variable times/distances from the accident,
- 1-minute gamma radiation dose integrals at variable times/distances from the accident,
- dose-reduction factors for variable thicknesses of steel, concrete, and water.

The Slide Rule provides estimates for five unreflected spherical systems that provide general characteristics of operations likely in facilities licensed by the US NRC. AWE (UK), IRSN (France), LLNL (USA) and ORNL (USA) began a long term collaboration effort in 2015 to update this document. Calculations for initial configurations were performed using modern tools such as MCNP, SCALE and COG.

This present document summarizes the input data necessary to calculate additional configurations that combine new fissile media (plutonium systems, §2.2) for the delayed gamma dose. It completes the specifications provided earlier in the document "UPDATE OF THE NUCLEAR CRITICALITY SLIDE RULE CALCULATIONS – PLUTONIUM CONFIGURATIONS".

2 DESCRIPTION OF THE ADDITIONAL CONFIGURATIONS

2.1 GEOMETRY

The geometry for the additional configurations, derived from the initial configuration of the slide rule (described in the document SR-U-UNREFLECTED-GROUND-001), is presented hereafter.

The geometry consists of a simple air-over-ground configuration with a source located at the center of a right-circular cylinder. The radius and the height of the air cylinder are 1530 m. With modern 3-D tools, a square with a half-side of 1530 m might be considered. The ground is modeled as 50 cm layer of concrete.

The figures 1 and 2 present the model to be calculated. Additional information is given in the following paragraphs.

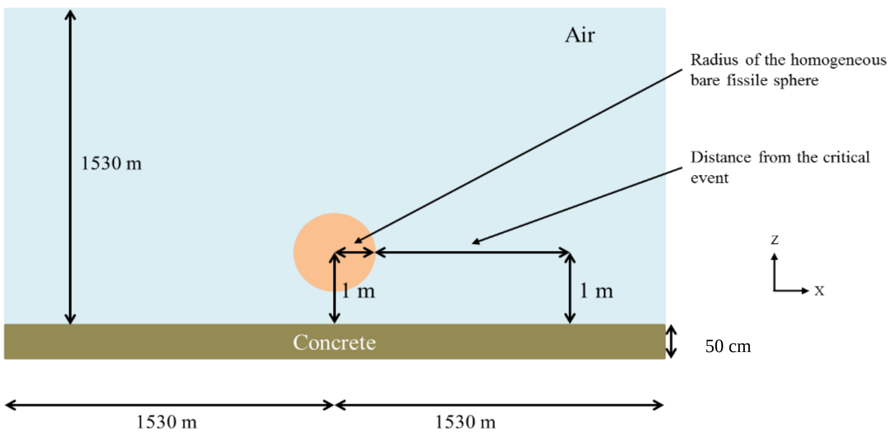


Figure 1: X-Z Plan view of the configuration

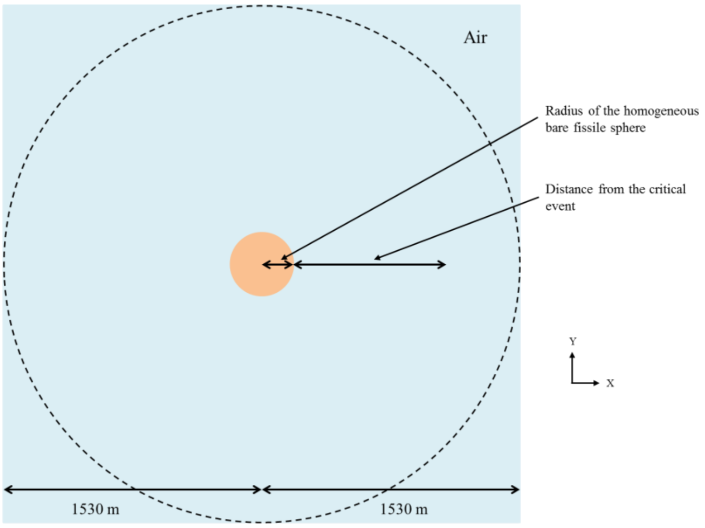


Figure 2: X-Y Plan view of the configuration

2.2 PLUTONIUM SYSTEMS (BARE SPHERE)

Bare fissile media, with plutonium at various moderation ratios (H/Pu), is considered for the additional configurations. No reflector is considered around the sphere. The following table gives atomic concentration and critical radius for each media.

Table 1 : Compositions for the new fissile media, Pu

Number density (atom/barn-cm)	Pu (H/Pu = 0)	Pu (H/Pu = 10)	Pu (H/Pu = 100)	Pu (H/Pu = 900)	Pu (H/Pu = 2000)
Pu-239	5.00305E-02	5.88706E-03	6.58436E-04	7.40255E-05	3.33386E-05
O-16	0	2.94353E-02	3.29218E-02	3.33115E-02	3.33386E-02
H-1	0	5.88706E-02	6.58436E-02	6.66230E-02	6.66772E-02

The following table gives critical radii for these five media. They are calculated using MCNP6.1 with ENDF/B-VII.1 cross sections library.

Table 2 : Spherical radii for bare Pu configurations

	Pu H/Pu = 0	Pu H/Pu = 10	Pu H/Pu = 100	Pu H/Pu = 900	Pu H/Pu = 2000
Spherical radius (cm)	4.93	12.53	15.36	19.50	29.17

3 ADDITIONAL INFORMATION

3.1 SOURCE STRENGTH AND SPECTRA

The magnitude of each source is normalized to correspond to 1.E+17 fissions. This single information means that the intensity (nubar for neutron) and the energy and space repartition of prompt neutron and prompt gamma inside the sphere/cylinder has to be determined.

3.2 DELAYED GAMMA

Delayed gamma doses rates are calculated assuming an instantaneous event. Then the expected dose rates for periods of 1, 5 and 10 s and 1, 5, 10, 50, 100, 500 and 1000 min after the event are tabulated for all five critical systems.

For these configurations, prompt doses have already been calculated. Only the delayed gamma need to be calculated.

3.3 MATERIAL AND TEMPERATURE DATA

Only 3 media are simulated in the additional configurations:

- The air,
- One of the homogeneous plutonium spheres or cylinders,
- The ground made of concrete.

The atomic compositions of the air and the ground made of concrete are given in the following tables.

Table 3 : Composition of air**.**

Number density (atom/barn-cm)	Air
N-14	4.00E-5
O-16	1.11E-5

Table 4 : Composition of concrete (SCALE material REG-CONCRETE).

Number density (atom/barn-cm)	Concrete
Fe-54	2.02958E-05
Fe-56	3.18600E-04
Fe-57	7.35787E-06
Fe-58	9.79198E-07
H-1	1.37433E-02
Al-27	1.74538E-03
Ca-40	1.47412E-03
Ca-42	9.83851E-06
Ca-43	2.05286E-06
Ca-44	3.17205E-05
Ca-46	6.08254E-08
Ca-48	2.84359E-06
O-16	4.60690E-02
Si-28	1.53273E-02
Si-29	7.78639E-04
Si-30	5.13885E-04
Na-23	1.74720E-03

The temperature for all media and for all cases is 300 K (26.85 °C).

3.4 RESPONSE FUNCTION AND DETECTORS

Henderson flux to dose conversion factors were used for the initial configurations. These factors have a significant impact on the final dose and are likely to change in the future. That is why, the additional configurations should be performed using the following conversion factors[1]:

- ANSI/HPS N13.3-2013 conversion factors (personal adsorbed dose per neutron unit fluence, Table B1 p. 18 and personal adsorbed dose per photon unit fluence, Table B2 p. 19),
- IAEA Technical Reports series n° 211 (1982) conversion factors (tissue kerma in air per neutron unit fluence, Table XIV pp. 138-139),
- ICRU report 47 (1992) conversion factors (air kerma in free air per photon unit fluence, Table A.1 p. 23).

Doses are calculated (see figure 1) at 1 m above the ground as a function of distance (between 30 cm and 1200 m) from the external surface of the source to the center of the detector. The detector used might be specified (type and geometry). By default, the detector geometry is a shape of a cylindrical shell with a square cross-section of 5 cm x 5 cm. The center of the detector is also at a height of 1 m above the ground.

4 RESULTS

The results will be written in the following tables. All options and data necessary to analyze the results (for instance, cross section libraries, kind of detector, use of variance reduction technique, etc.) might be specified.

For more clarity, a common file naming convention may be adopted. An example is the following:

- SR-Pu-S-UN-G1-C1-d03-DG10s.inp stands for:
    - SR: slide rule,
    - Pu: Plutonium[2],
    - S: sphere,
    - UN: unreflected (no shielding),
    - G1: first case with a ground[3],
    - C1: first case with the plutonium system (H/Pu = 0)[4],
    - d03: distance 0.3 m,
    - DG10s: delayed gamma (after 10 seconds).

[1] Henderson flux to dose conversion factors might be used in some cases to compare the impact of the various conversion factors and the impact of the additional configurations compared to the initial configurations.

[2] Pu is for Plutonium.

[3] G1 is for concrete ground.

[4] C2 is H/Pu = 10; C3 is H/Pu = 100; C4 is H/Pu = 900; C5 is H/Pu = 2000.

Table 5 : Delayed gamma doses for bare plutonium configuration – 1 second

Delayed gamma dose	Case 1	Case 2	Case 3	Case 4	Case 5
Distance (m)	Pu H/Pu = 0	Pu H/Pu = 10	Pu H/Pu = 100	Pu H/Pu = 900	Pu H/Pu = 2000
0.3					
0.5					
1					
2					
5					
10					
20					
50					
100					
200					
300					
500					
700					
1000					
1200					

Table 6 : Delayed gamma doses for bare plutonium configuration – 5 seconds

Delayed gamma dose	Case 1	Case 2	Case 3	Case 4	Case 5
Distance (m)	Pu H/Pu = 0	Pu H/Pu = 10	Pu H/Pu = 100	Pu H/Pu = 900	Pu H/Pu = 2000
0.3					
0.5					
1					
2					
5					
10					
20					
50					
100					
200					
300					
500					
700					
1000					
1200					

Table 7 : Delayed gamma doses for bare plutonium configuration – 10 seconds

Delayed gamma dose	Case 1	Case 2	Case 3	Case 4	Case 5
Distance (m)	Pu H/Pu = 0	Pu H/Pu = 10	Pu H/Pu = 100	Pu H/Pu = 900	Pu H/Pu = 2000
0.3					
0.5					
1					
2					
5					
10					
20					
50					
100					
200					
300					
500					
700					
1000					
1200					

Table 8 : Delayed gamma doses for bare plutonium configuration – 1 minute

Delayed gamma dose	Case 1	Case 2	Case 3	Case 4	Case 5
Distance (m)	Pu H/Pu = 0	Pu H/Pu = 10	Pu H/Pu = 100	Pu H/Pu = 900	Pu H/Pu = 2000
0.3					
0.5					
1					
2					
5					
10					
20					
50					
100					
200					
300					
500					
700					
1000					
1200					

Table 9 : Delayed gamma doses for bare plutonium configuration – 5 minutes

Delayed gamma dose	Case 1	Case 2	Case 3	Case 4	Case 5
Distance (m)	Pu H/Pu = 0	Pu H/Pu = 10	Pu H/Pu = 100	Pu H/Pu = 900	Pu H/Pu = 2000
0.3					
0.5					
1					
2					
5					
10					
20					
50					
100					
200					
300					
500					
700					
1000					
1200					

Table 10 : Delayed gamma doses for bare plutonium configuration – 10 minutes

Delayed gamma dose	Case 1	Case 2	Case 3	Case 4	Case 5
Distance (m)	Pu H/Pu = 0	Pu H/Pu = 10	Pu H/Pu = 100	Pu H/Pu = 900	Pu H/Pu = 2000
0.3					
0.5					
1					
2					
5					
10					
20					
50					
100					
200					
300					
500					
700					
1000					
1200					

Table 11 : Delayed gamma doses for bare plutonium configuration – 50 minutes

Delayed gamma dose	Case 1	Case 2	Case 3	Case 4	Case 5
Distance (m)	Pu H/Pu = 0	Pu H/Pu = 10	Pu H/Pu = 100	Pu H/Pu = 900	Pu H/Pu = 2000
0.3					
0.5					
1					
2					
5					
10					
20					
50					
100					
200					
300					
500					
700					
1000					
1200					

Table 12 : Delayed gamma doses for bare plutonium configuration – 100 minutes

Delayed gamma dose	Case 1	Case 2	Case 3	Case 4	Case 5
Distance (m)	Pu H/Pu = 0	Pu H/Pu = 10	Pu H/Pu = 100	Pu H/Pu = 900	Pu H/Pu = 2000
0.3					
0.5					
1					
2					
5					
10					
20					
50					
100					
200					
300					
500					
700					
1000					
1200					

Table 13 : Delayed gamma doses for bare plutonium configuration – 500 minutes

Delayed gamma dose	Case 1	Case 2	Case 3	Case 4	Case 5
Distance (m)	Pu H/Pu = 0	Pu H/Pu = 10	Pu H/Pu = 100	Pu H/Pu = 900	Pu H/Pu = 2000
0.3					
0.5					
1					
2					
5					
10					
20					
50					
100					
200					
300					
500					
700					
1000					
1200					

Table 14 : Delayed gamma doses for bare plutonium configuration – 1000 minutes

Delayed gamma dose	Case 1	Case 2	Case 3	Case 4	Case 5
Distance (m)	Pu H/Pu = 0	Pu H/Pu = 10	Pu H/Pu = 100	Pu H/Pu = 900	Pu H/Pu = 2000
0.3					
0.5					
1					
2					
5					
10					
20					
50					
100					
200					
300					
500					
700					
1000					
1200					

UPDATE OF THE NUCLEAR CRITICALITY SLIDE RULE CALCULATIONS
–
SENSITIVITY STUDIES FOR PLUTONIUM SYSTEMS

IDENTIFICATION NUMBER: SR-Pu-UNREFLECTED-GROUND-002, SR-Pu-MOISTURE-GROUND-001, SR-Pu-SKYSHINE-GROUND-001, SR-Pu-SCREEN-GROUND-001,

KEY WORDS: Slide-Rule, plutonium, radiological screen, sensitivity

1 INTRODUCTION

In 1997, Oak Ridge National Laboratory published the reports "An updated Nuclear Criticality Slide rule" (ORNL/TM-13322/V1 and ORNL/TM-13322/V2), as a tool for emergency response to nuclear criticality accident. The "Slide Rule" is designed to provide estimates of the following:

- Magnitude of the number of fissions based on personnel or field radiation measurements,
- Neutron- and gamma-dose at variable unshielded distances from the accident,
- Skyshine component of the dose,
- Time-integrated radiation dose estimates at variable times/distances from the accident,
- 1-minute gamma radiation dose integrals at variable times/distances from the accident,
- Dose-reduction factors for variable thicknesses of steel, concrete, and water.

The initial Slide Rule included five unreflected spherical uranium systems. This document updates and expands the Slide Rule to include five plutonium systems, calculated using modern tools such as MCNP, SCALE, and COG.

2 DESCRIPTION OF THE CONFIGURATIONS

2.1 GEOMETRY

The geometry for the configuration of the slide rule is presented hereafter.

The geometry consists of a simple air-over-ground configuration with a source located at the center of a right-circular cylinder. The radius and the height of the air cylinder is 1530 m. With modern 3-D tools, a square with a half-side of 1530 m might be considered. The ground is now modeled as 50 cm layer of concrete.

The Figure 1 and Figure 2 present the model to be calculated. Additional information is given in the following paragraphs.

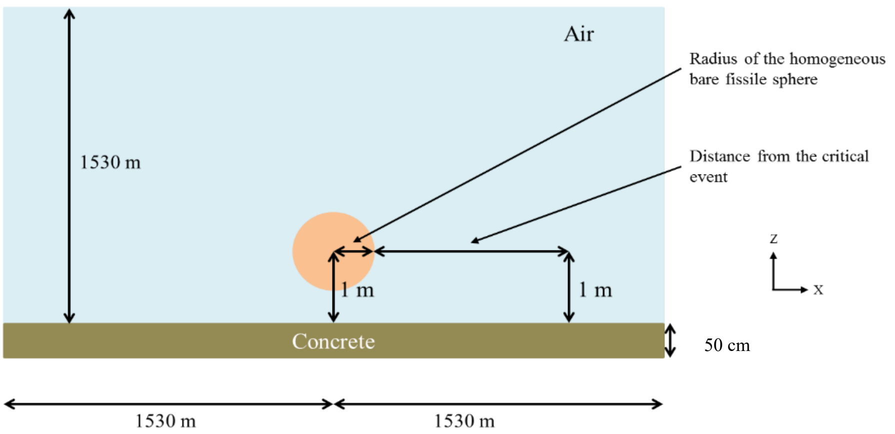


Figure 1: X-Z Plan view of the configuration.

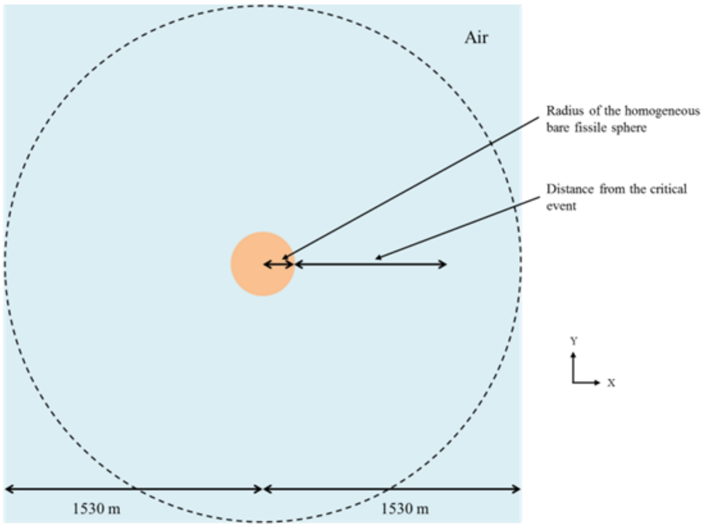


Figure 2: X-Y Plan view of the configuration.

2.2 PLUTONIUM SYSTEMS (BARE SPHERE)

Five fissile media are separately considered, with plutonium at various moderation ratios (H/Pu). The following table gives atomic concentration of each media.

Table 1: Composition of the homogeneous Pu media.

Number density (atom/barn-cm)	Pu (H/Pu = 0)	Pu (H/Pu = 10)	Pu (H/Pu = 100)	Pu (H/Pu = 900)	Pu (H/Pu = 2000)
Pu-239	5.00305E-02	5.88706E-03	6.58436E-04	7.40255E-05	3.33386E-05
O-16	0	2.94353E-02	3.29218E-02	3.33115E-02	3.33386E-02
H-1	0	5.88706E-02	6.58436E-02	6.66230E-02	6.66772E-02

The following table gives critical radii for these five media. They are calculated using MCNP6.1 with ENDF/B-VII.1 cross sections library. No reflector is considered around the sphere.

Table 2: Radii the bare Pu bare critical spheres

	Pu H/Pu = 0	Pu H/Pu = 10	Pu H/Pu = 100	Pu H/Pu = 900	Pu H/Pu = 2000
Spherical radius (cm)	4.93	12.53	15.36	19.50	29.17

2.3 MATERIAL AND TEMPERATURE DATA

3 media are simulated in the initial configuration:

- One of the 5 homogeneous bare fissile spheres,
- The air,
- The ground made of concrete.

Their atomic compositions are given in Table 1, Table 3 and Table 5.

Table 3: Composition of air.

Number density (atom/barn-cm)	Air
N	4.00E-5
O	1.11E-5

The temperatures for all media are 300 K (26.85 °C).

2.4 SOURCE STRENGTH AND SPECTRA

The magnitude of each source is normalized to correspond to 1.0E+17 fissions. This single information means that the intensity (nubar for neutron) and the energy and space repartition of prompt neutron and prompt gamma inside the sphere must be determined.

3 DESCRIPTION OF THE SENSITIVITY STUDIES

This part presents the sensitivity studies to perform for the additional configurations of the Slide Rule.

3.1 MOISTURE IN AIR

Neutron and gamma prompt dose calculations will be performed with a humidity of 10% and 100%, at the room temperature. The air composition to be used[1] is given in the following table:

Table 4: Composition of air – humidity of 10% and 100%

Number density (atom/barn-cm)	Air Humidity 10%	Air Humidity 100%
N-14	3.9214E-05	3.8397E-05
O-16	1.0798E-05	1.1094E-05
H-1	1.1559E-07	1.1559E-06

3.2 GROUND COMPOSITION AND DIMENSIONS

Calculations will be performed with the regulatory concrete composition, cf. Table 5. Nevertheless, a dry soil composition (without hydrogen) will be also tested for the case 1 and case 4, cf. Table 6. In each case, neutron and gamma prompt dose calculations should be performed. Moreover, the dimension for the ground is changed from **30.48 cm (initial configurations) to 50 cm**. The following tables give atomic concentration of the concrete and the soil[2].

[1] The air composition is based on the reference "Air humide – Notions de base et mesures. Réf : BZ8025 V1. Bernard CRETINON, Bertrand BLANQUART".

[2] Soil composition is taken from the Pacific Northwest National Laboratory "Compendium of Material Composition Data for Radiation Transport Modeling" Revision 1 March, 2011. Concrete composition was defined by the Nuclear Regulatory Commission and it is the standard concrete in SCALE.

Table 5: Composition of concrete (REGULAR-CONCRETE-NRC)

Number density (atom/barn-cm)	Concrete
Fe-54	2.02958E-05
Fe-56	3.18600E-04
Fe-57	7.35787E-06
Fe-58	9.79198E-07
H	1.37433E-02
Al-27	1.74538E-03
Ca-40	1.47412E-03
Ca-42	9.83851E-06
Ca-43	2.05286E-06
Ca-44	3.17205E-05
Ca-46	6.08254E-08
Ca-48	2.84359E-06
O	4.60690E-02
Si-28	1.53273E-02
Si-29	7.78639E-04
Si-30	5.13885E-04
Na-23	1.74720E-03

Table 6: Composition of soil (EARTH US average - PNNL)

Number density (atom/barn-cm)	Soil
O-16	2.9391E-02
Na-23	2.4400E-04
Mg-24	3.9053E-04
Mg-25	5.1503E-05
Mg-26	5.8968E-05
Mg-27	2.3260E-03
Mg-28	8.1191E-03
Mg-29	4.2723E-04
Si-30	2.9165E-04
K-39	3.1134E-04
K-40	4.0200E-08
K-41	2.3621E-05
Ca-40	1.1300E-03
Ca-42	7.9141E-06
Ca-43	1.6951E-06

Number density (atom/barn-cm)	Soil
Ca-44	2.6747E-05
Ca-46	5.8450E-08
Ca-48	2.6186E-06
Ti-46	6.9696E-06
Ti-47	6.4222E-06
Ti-48	6.4984E-05
Ti-49	4.8682E-06
Ti-50	4.7564E-06
Mn-55	1.2000E-05
Fe-54	5.2113E-05
Fe-56	8.4826E-04
Fe-57	1.9937E-05
Fe-58	2.7044E-06

3.3 SKYSHINE

The contribution of the skyshine will be determined for height superior to 10 m in each configuration. It means that calculations of the 5 cases will be done again with a height of 10 m (instead of 1530 m). The effect of the skyshine is the different between the two calculations.

3.4 RADIOLOGICAL SCREEN

A radiological screen will be added in each configuration. This screen will be modeled at halfway between the source and the detector[3]. The position of the radiological screen is measured from the external surface of the source to the internal face of the screen. The detector has a spherical shape with default radius of 20 cm.

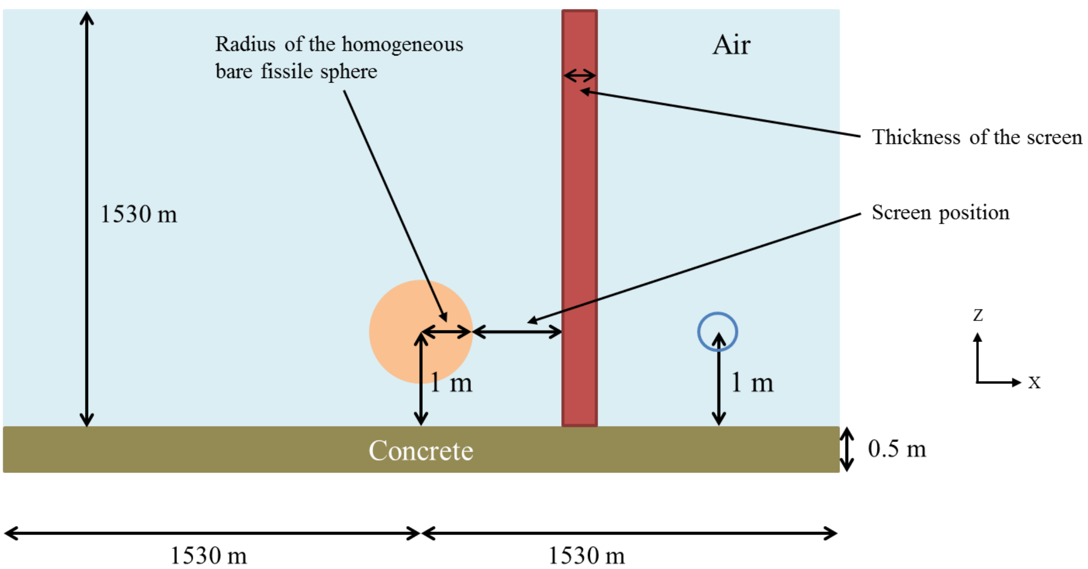


Figure 3: X-Z Plan view of the configuration with a radiological screen.

[3] The distance edge-to-edge between the source and the screen is half the edge-to-edge distance between the source and the detector.

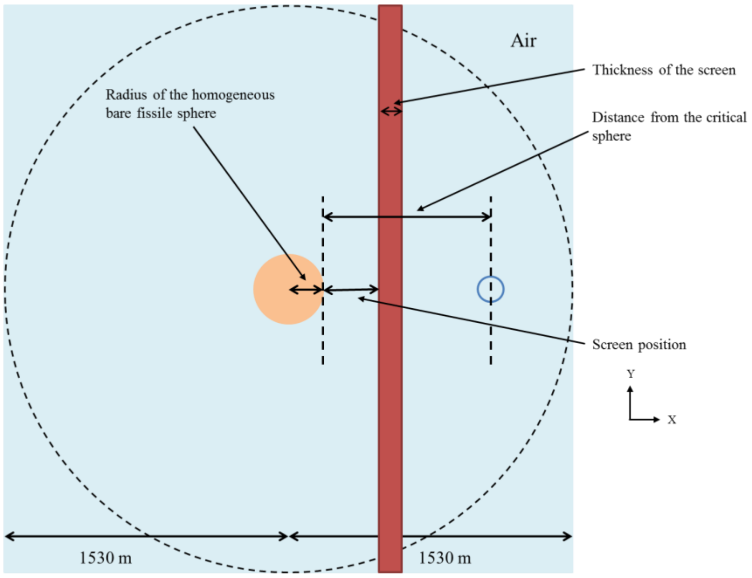


Figure 4: X-Y Plan view of the configuration with a radiological screen.

The following table presents screen positions for each detector distance.

Table 7: Screen position for each detector

Detector position (m)	Screen position (m)
0.3	
0.5	
1	0.50
2	1.00
5	2.50
10	5.00
20	10.00
50	25.00
100	50.00
200	100.00
300	150.00
500	250.00
700	350.00
1000	500.00
1200	600.00

Compositions[4] for the radiological screen are presented in the following table.

[4] Compositions (except concrete) are taken from the Pacific Northwest National Laboratory 'Compendium of Material Composition Data for Radiation Transport Modeling' Revision 1 March, 2011

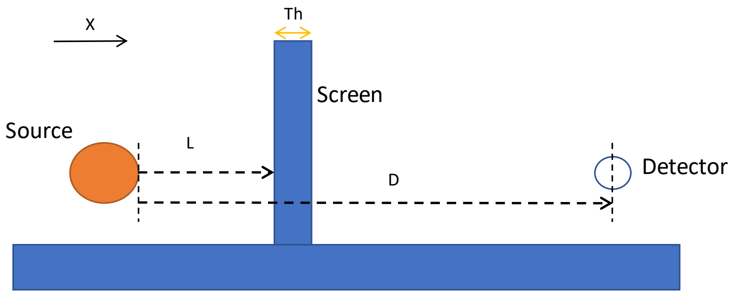
Table 8: Compositions for the radiological screen

Number density (atom/barn-cm)	Steel 304 PNNL	Number density (atom/barn-cm)	Water PNNL	Number density (atom/barn-cm)	Lead PNNL	Number density (atom/barn-cm)	Concrete
C-6	1.6000E-04	H	6.6733E-02	Pb-204	4.6183E-04	Fe-54	2.02958E-05
P-31	3.6000E-05	O-16	3.3368E-02	Pb-206	7.9501E-03	Fe-56	3.18600E-04
Mn-55	8.7700E-04			Pb-207	7.2903E-03	Fe-57	7.35787E-06
Si-28	7.8821E-04			Pb-208	1.7286E-02	Fe-58	9.79198E-07
Si-29	4.1476E-05					H	1.37433E-02
Si-30	2.8314E-05					Al-27	1.74538E-03
S-32	2.1784E-05					Ca-40	1.47412E-03
S-33	1.7733E-07					Ca-42	9.83851E-06
S-34	1.0355E-06					Ca-43	2.05286E-06
S-35	2.5300E-09					Ca-44	3.17205E-05
Cr-50	7.6494E-04					Ca-46	6.08254E-08
Cr-52	1.4751E-02					Ca-48	2.84359E-06
Cr-53	1.6727E-03					O	4.60690E-02
Cr-54	4.1636E-04					Si-28	1.53273E-02
Fe-54	3.4180E-03					Si-29	7.78639E-04
Fe-56	5.5636E-02					Si-30	5.13885E-04
Fe-57	1.3076E-03					Na-23	1.74720E-03
Fe-58	1.7738E-04						
Ni-58	5.1691E-03						
Ni-60	1.9911E-03						
Ni-61	8.6553E-05						
Ni-62	2.7597E-04						
Ni-64	7.0281E-05						

The thickness of the screen is related to its composition. The thicknesses of the radiological screen to be considered will be 1, 5, 10, 20, and 40 cm for each type of screen. Those thicknesses are representative of the different kind of wall, tank etc., that could be found in a nuclear facility.

Impact of Radiological Screen Position Study

In addition to initially modeling the radiological screen halfway between the source and the detector, this study will evaluate the impact of the screen's position on radiation protection effectiveness. The results will help evaluate the influence of the screen position on the measured doses.



The screen will be placed at six different positions relative to the total distance "D" (distance between the source edge and the center of the detector), corresponding respectively to 1/4, 1/3, 1/2, 2/3, 3/4, and 4/5 of "D". These positions will be numbered from 1 to 6. The neutron and gamma (prompt) dose will be determined for six detector distances: 1 m, 2 m, 5 m, 10 m, 50 m, and 100 m. Calculations will be performed for screen thickness of 20 cm. These calculations will only be conducted for cases 1 and 4.

3.5 RESPONSE FUNCTIONS AND DETECTORS

The additional configurations should be performed using the following conversion factors:

- ANSI/HPS N13.3-2013 conversion factors (personal adsorbed dose per neutron unit fluence, Table B1 p. 18 and personal adsorbed dose per photon unit fluence, Table B2 p. 19),
- Fine group structures for neutron and gamma spectra, defined in the Table **9** and
- Table **10** (only a measurement of the flux with these factors). With these structures, it will be possible to apply any kind of flux-to-dose conversion factors in the future.

Table 9: Upper bounds for neutron fine group structures (from left to right and top to bottom)

Upper bounds in MeV						
1.00E-11	1.00E-09	2.15E-09	4.64E-09	1.00E-08	2.15E-08	2.50E-08
2.60E-08	3.00E-08	4.64E-08	5.00E-08	1.00E-07	2.00E-07	2.15E-07
2.25E-07	3.25E-07	4.15E-07	4.64E-07	5.00E-07	8.00E-07	1.00E-06
1.13E-06	1.30E-06	1.86E-06	2.00E-06	2.15E-06	3.06E-06	4.64E-06
5.00E-06	1.00E-05	1.07E-05	1.10E-05	2.00E-05	2.15E-05	2.90E-05
3.60E-05	4.64E-05	5.00E-05	6.30E-05	1.00E-04	1.01E-04	1.10E-04
2.00E-04	2.15E-04	3.60E-04	4.64E-04	5.00E-04	5.83E-04	6.30E-04
1.00E-03	1.10E-03	2.00E-03	2.15E-03	3.04E-03	3.60E-03	4.64E-03
5.00E-03	6.30E-03	1.00E-02	1.10E-02	1.25E-02	1.50E-02	1.58E-02
2.00E-02	2.51E-02	3.00E-02	3.16E-02	3.60E-02	3.98E-02	5.00E-02
5.01E-02	6.30E-02	7.00E-02	7.94E-02	8.20E-02	8.60E-02	9.00E-02
9.40E-02	9.80E-02	1.00E-01	1.05E-01	1.11E-01	1.15E-01	1.25E-01
1.35E-01	1.45E-01	1.50E-01	1.55E-01	1.58E-01	1.65E-01	1.75E-01
1.85E-01	1.95E-01	2.00E-01	2.10E-01	2.30E-01	2.50E-01	2.51E-01
2.70E-01	2.90E-01	3.00E-01	3.10E-01	3.16E-01	3.30E-01	3.50E-01
3.70E-01	3.90E-01	3.98E-01	4.00E-01	4.08E-01	4.20E-01	4.50E-01
4.60E-01	5.00E-01	5.01E-01	5.40E-01	5.50E-01	5.80E-01	6.00E-01
6.20E-01	6.30E-01	6.60E-01	7.00E-01	7.40E-01	7.80E-01	7.94E-01
8.00E-01	8.20E-01	8.60E-01	9.00E-01	9.07E-01	9.40E-01	9.80E-01
1.00E+00	1.05E+00	1.10E+00	1.15E+00	1.20E+00	1.25E+00	1.30E+00
1.35E+00	1.40E+00	1.43E+00	1.45E+00	1.50E+00	1.55E+00	1.58E+00
1.60E+00	1.65E+00	1.70E+00	1.75E+00	1.80E+00	1.83E+00	1.85E+00
1.90E+00	1.95E+00	2.00E+00	2.10E+00	2.20E+00	2.30E+00	2.40E+00
2.50E+00	2.60E+00	2.70E+00	2.80E+00	2.90E+00	3.00E+00	3.10E+00
3.15E+00	3.20E+00	3.30E+00	3.40E+00	3.50E+00	3.60E+00	3.70E+00
3.75E+00	3.80E+00	3.90E+00	4.00E+00	4.10E+00	4.20E+00	4.30E+00

Upper bounds in MeV						
4.50E+00	4.60E+00	4.70E+00	4.80E+00	4.90E+00	5.00E+00	5.10E+00
5.20E+00	5.30E+00	5.40E+00	5.50E+00	5.60E+00	5.80E+00	6.00E+00
6.20E+00	6.30E+00	6.40E+00	6.50E+00	6.60E+00	6.70E+00	7.00E+00
7.30E+00	7.40E+00	7.50E+00	7.70E+00	7.80E+00	7.94E+00	8.00E+00
8.20E+00	8.30E+00	8.50E+00	8.60E+00	9.00E+00	9.40E+00	9.80E+00
1.00E+01	1.05E+01	1.10E+01	1.15E+01	1.20E+01	1.25E+01	1.30E+01
1.35E+01	1.40E+01	1.45E+01	1.50E+01	1.60E+01	1.70E+01	1.80E+01
2.00E+01						

Table 10: Upper bounds for gamma fine group structures (from left to right and top to bottom)

Upper bounds in MeV						
1.00E-02	1.25E-02	1.50E-02	1.75E-02	2.00E-02	2.50E-02	3.00E-02
4.00E-02	4.50E-02	5.00E-02	6.00E-02	7.00E-02	8.00E-02	1.00E-01
1.25E-01	1.50E-01	2.00E-01	2.50E-01	3.00E-01	3.50E-01	4.00E-01
4.50E-01	5.00E-01	5.50E-01	6.00E-01	6.50E-01	7.00E-01	8.00E-01
1.00E+00	1.10E+00	1.20E+00	1.33E+00	1.40E+00	1.50E+00	1.66E+00
1.80E+00	2.00E+00	2.20E+00	2.50E+00	2.60E+00	2.80E+00	3.00E+00
3.25E+00	3.50E+00	3.75E+00	4.00E+00	4.25E+00	4.50E+00	4.75E+00
5.00E+00	5.25E+00	5.50E+00	5.75E+00	6.00E+00	6.25E+00	6.50E+00
6.75E+00	7.50E+00	8.00E+00	8.50E+00	9.00E+00	9.50E+00	1.00E+01
1.10E+01	1.30E+01	1.50E+01	2.00E+01			

Doses are calculated (see Figure 1) at 1 m above the ground as a function of distance (between 30 cm and 1 200 m) from the external surface of the source to the center of the detector. The detector used (type and geometry) might be specified. By default (for configurations without a radiological screen), the detector geometry is a shape of a cylindrical shell with a square cross-section of 5 cm x 5 cm. The center of the detector is also at a height of 1 m above the ground.

4 RESULTS

All options and data necessary to analyze the results (for instance, cross section libraries, kind of detector, use of variance reduction technique, etc.) might be specified.

For more clarity, a common file naming convention may be adopted. An example is the following:

SR-Pu-S-UN-G1-C1-D10-L1-N.inp stands for:

- SR: Slide-Rule,
- Pu: plutonium[5],
- S: sphere[6],
- UN: unreflected (no shielding)[7],
- G1: first case with a ground[8],
- C1: first case with the plutonium system (H/Pu = 0)[9],
- D10: distance 10 m,
- L1: screen position corresponding to ¼ of the distance 'D',
- N: prompt neutron[10].

[5] Pu is for Plutonium.

[6] CYL1, CYL2 or CYL3 stands for cylinders.

[7] R stands for reflected configurations.

[8] G1 is for concrete ground, G2 stand for a soil ground.

[9] C2 is H/Pu = 10; C3 is H/Pu = 100; C4 is H/Pu = 900; C5 is H/Pu = 2000.

[10] « G » stands for prompt gamma.