RAPPORT

IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

Faire avancer la sûreté nucléaire

Update of the Nuclear Criticality Slide Rule

Technical Basis

M. TROISNE

Report IRSN/2019-00266

Pôle sûreté des installations et des systèmes nucléaires
Service de Neutronique et des risques de Criticité

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RESUME

ABSTRACT

AWE (UK), IRSN (France), LLNL (USA) and ORNL (USA) began a long term collaboration effort in 2015 to update the Nuclear Criticality Slide Rule for the emergency response to a nuclear criticality accident. This document, published almost 20 years ago, gives order of magnitude estimates of key parameters, such as number of fissions and doses (neutron and gamma), useful for emergency response teams and public authorities.

This report gives:

- a calculation scheme and its application to the five fissile media considered in the "Slide Rule";
- comparisons between Monte-Carlo codes such as MCNP6.1, SCALE6.1, SCALE6.2 and COG11;
- comparisons between different Flux-to-dose conversion factors;
- an extension of the original "Slide Rule" configurations to plutonium systems.

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1 INTRODUCTION

In 1997 Oak Ridge National Laboratory published the report "An Updated Nuclear Criticality Slide Rule" [1-2] as a tool for emergency response to a nuclear criticality accident. A similar document was produced by the Institut de Radioprotection et de Sûreté Nucléaire in 2000 [3]. According to [1], this kind of document "permits continued updating of information during the evolution of emergency response, including exposure information about victims, estimates of potential exposures to emergency response re-entry personnel, estimates of future radiation field magnitudes, and number of fissions (fission yield) estimate" without precisely knowing the initial conditions leading to the criticality accident.

This document gives order of magnitude estimates of key parameters, useful for emergency response teams and public authorities. In practice, the "Slide Rule" provides estimates of the following information based upon variable times and distances from the accident:

- the magnitude of the number of fissions based on personnel or field radiation measurements,
- prompt neutron- and gamma-dose at variable unshielded distances from the accident,
- the skyshine component of the prompt dose,
- time-integrated total radiation dose estimates,
- accumulated one-minute gamma radiation dose as a function of time after the accident, and
- dose-reduction factors for variable thicknesses of steel, concrete and water.

The 1997 Slide Rule provides estimates for five unreflected spherical uranium systems that give general characteristics of operations typical of facilities licensed by the US Nuclear Regulatory Commission. An example of this Slide Rule is presented in Figure 1.

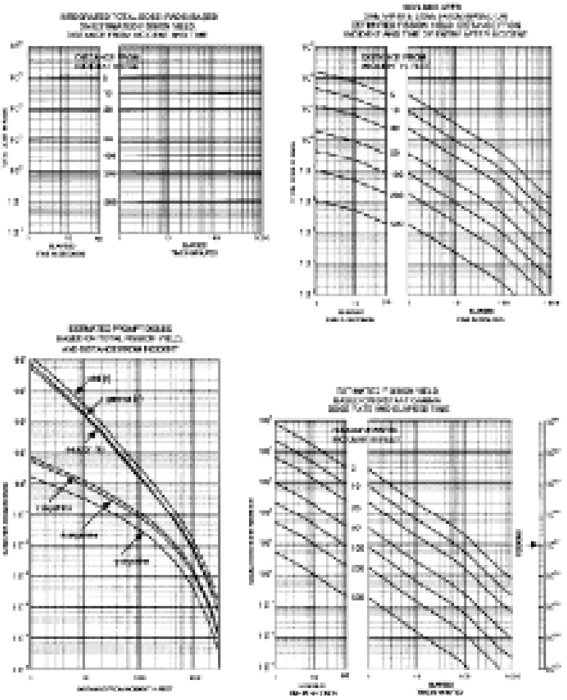

Figure 1: « 1997 Slide Rule » for the uranyl nitrate solution

Several laboratories have determined the need to review, update, and expand the contents of the 1997 Slide Rule. In particular, the conversion factors used to provide doses (Henderson flux-to-dose factors) are outdated, so additional conversion factors are used. Also, new configurations need to be added, especially plutonium systems. This document combines and completes the work presented in [4] and [5].

2 OBJECTIVES OF THIS UPDATE

A long term collaboration effort between AWE (UK), IRSN (France), LLNL (USA) and ORNL (USA) in the framework of the U.S DOE Nuclear Criticality Safety Program [6], began in order to update the Slide Rule with modern tools and add new configurations, taking into account the experience of several laboratories in using the 1997 Slide Rule. As a result, the complete work is envisioned to spread over many years and to be divided into five steps:

1. Redo with modern radiation transport tools and nuclear data libraries, for the same configurations and assumptions, the calculations performed initially for the 1997 estimation of the doses;
2. Perform additional calculations to improve the quality/quantity of information given to the user of the Slide Rule in order to not only give a value but also the possible variations and the area of applicability of this value. These additional calculations might include:
   a. new configurations (impact of the geometry and composition of the source, new fissile media including plutonium systems, multiple layers of shielding, etc.),
   b. new flux-to-dose conversion factors (for dosimetry, radiological protection and instrumentation purposes),
   c. impact of parameters on the result (sensitivity/uncertainty studies, such as thickness and composition of the ground, humidity and density of the air, etc.);
3. Review and improve the section regarding the estimation of the number of fissions;
4. Add other sections to the document like a section regarding actions to stop an on-going criticality accident (for example, standards with neutron poison);
5. Based on the previous work, the final task will be the development of a Slide Rule "application" for a handheld device (e.g. smartphone).

At the end, this work should improve the expertise for the real time response to a criticality accident in order to minimize the consequences of such an accident. In addition, this work will provide the opportunity to suggest experiments allowing the complete or partial validation of the tool results (benchmarking effort).

Another consequence of this collaborative effort might be the creation of “computational benchmarks” in order to test and verify the various variance reduction methods and to establish best practices when dealing with this kind of problem.

The first step was to redo with modern radiation transport tools, for the same configurations and assumptions, the calculations performed initially for the 1997 estimation of the doses. This effort is presented in chapter 4. Moreover, chapter 5 presents and discusses results for new configurations (step 2) including plutonium systems, calculated by modern 3D radiation transport codes, MCNP, SCALE and COG. Finally, chapter 6 presents preliminary studies on the impact of the flux-to-dose conversion factors.

3 CODES AND METHODS USED

3.1 MCNP

MCNP6.1 [7] was used with the continuous energy ENDF/B-VII.1 cross section library. An F4 tally (i.e. track length estimate of cell flux) was used. A two steps method was used to generate the source term and simulate the doses. The first step is a static calculation (KCODE mode) to determine the distribution of fission neutron production inside the fissile assembly. Many possibilities were considered but all the MCNP results presented were obtained with 20 meshes (SMESH for a sphere) or 20x20 meshes (CMESH for a cylinder), having the same volume, in which the fission reaction rate was tallied. The second step used the results of the first step to describe a fixed source (SDEF mode) of fission neutrons. A Watt spectrum was used for the energy distribution. The prompt gamma and neutron doses were determined in the same calculation, the gammas being produced by the neutron interactions inside the fissile assembly. Indeed, in the second step, the fission neutron production is turned off (treated as absorption) but all gammas, including fission gammas, are produced (NONU = 0). Weight windows, in space and energy, were used. To generate the weight windows and the biased source for the Monte Carlo fixed source calculation, ADVANTG, a 3D deterministic code [8], was used in order to obtain the adjoint flux. Additional information regarding this kind of calculations with MCNP might be found in references [9] and [10].

In order to produce the delayed gamma source, the coupling KENO/MONACO/COUPLE/ORIGEN from the SCALE package was used to calculate spectra and intensities. The criticality accident was assumed to occur in 1 µs. KENO calculates the distribution of fission neutron production inside the fissile assembly. MONACO uses the KENO result and calculates the neutron flux inside the fissile assembly. COUPLE uses the resulting MONACO neutron flux and creates problem dependent flux weighted cross sections to produce reaction rates. ORIGEN uses these reaction rates and performs the depletion and decay of the fissile systems. This method was used because it is very close to the method used to produce the 1997 Slide Rule. The MCNP calculations were performed on workstations[1]. The relative errors are below 5% and the 10 statistical checks from MCNP are passed except the Pareto slope check for some cases.

3.2 SCALE

SCALE 6.2.1 [11] was used with the continuous energy ENDF/B-VII.1 cross section library. The CAAS analysis capability, coupling KENO and MAVRIC/Monaco, was used for this analysis, which is nearly an identical two-step methodology than the one used for the MCNP analysis. First, KENO was run with a Cartesian mesh tally of the fission neutron production, which captured the asymmetry due to the ground 1 m below the center of each fissile assembly. Then MAVRIC/Monaco used the KENO tally as a fixed source, generated variance reduction parameters, and simulated the prompt doses. Region tallies were used in the model to calculate doses at the desired distances by introducing cells that were cylindrical shells in the actual problem geometry, as was done with MCNP. For the prompt dose calculations, total nu-bar was used just like the MCNP calculations.

The delayed gamma source was produced with the same coupling of KENO/MONACO/COUPLE/ORIGEN from the SCALE package that the MCNP calculations used. Once the delayed gamma intensities were obtained from the ORIGEN calculations, the fission mesh source was updated to represent delayed gammas instead of fission neutrons by changing particle type and energy spectrum. The spatial distribution of the fission neutron mesh source and delayed gamma mesh source are the same.

3.3 COG

COG 11.1 [12] was used with ENDF/B-VII.1 cross-section library data. COG is a general purpose, multi-particle, high-fidelity Monte Carlo code developed by Lawrence Livermore National Laboratory (LLNL). It provides accurate simulation results for complex 3-D shielding, criticality safety, and activation problems. A newly developed feature in COG 11.1 can generate, track and score delayed fission gamma (DFG) rays born between two given times [13]. Point-wise continuous cross-sections are used in COG and a full range of biasing options are available for speeding up solutions for deep penetration problems.

A direct one-step criticality/detector calculation method was applied for all neutrons and prompt and delayed gamma ray dose calculations. Each neutron and gamma particle is tracked from its birth from fission within the spherical fissile volume to its absorption in the system or score at the detectors at various distances in one single, massively parallel, COG supercomputer run with no variance reduction biasing applied. To activate the DFG option, DELAYEDPHOTONS (and associated time interval values) and DGLIB, are input in the BASIC and MIX blocks, respectively. A 1-cm high cylindrical boundary-crossing detector was used to score the dose calculations.

[1] For prompt doses calculation, the simulation for each distance lasted about 15 hours on one processor (for less than 1E8 histories).

4 INITIAL CONFIGURATIONS / URANIUM CONFIGURATIONS

The critical uranium systems considered for the initial configuration of the 1997 Slide Rule were:

- Unreflected sphere of 4.95 wt% enriched aqueous uranyl fluoride, $U(4.95)O_2F_2$ and 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, $U(93.2)O_2(NO_3)_2$ and H_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 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 1 to 3000 feet (0.3048 to 914.4 m) from the surface of the critical sphere.

4.1 MODEL DESCRIPTION

The geometry for the 1997 Slide Rule models consists of a simple 2-D air-over-ground configuration with the source located at the radial centre of a right-circular cylinder. The radius and the height of the air cylinder is 1530 m. The centre of the critical assemblies (spheres) are all 1 m above the ground. The ground is modelled as a 30.48 cm (1 ft) layer of concrete. The dimensions of the critical spheres and the composition of all materials can be found in Appendix 8.4 (references [1], [2] and [14]).

Figures 2 and 3 present the model for these initial calculations. For more clarity, all the information needed to calculate the initial configuration was written in a specific document using a "benchmark format" [14]. Furthermore, a common file naming convention for the various cases has been adopted. The same principle will be used, in the future, for additional configurations. An example is the following:

- SR-U-UN-G1-C1-d500-N.inp stands for:
  - SR: Slide Rule,
  - U: uranium,
  - UN: unreflected (no shielding),
  - G1: first case with ground (30.48 cm of concrete),
  - C1: first case with uranium system (Uranyl fluoride (4.95%)),
  - d500: distance of 500 m from the critical sphere,
  - N: prompt neutron dose.

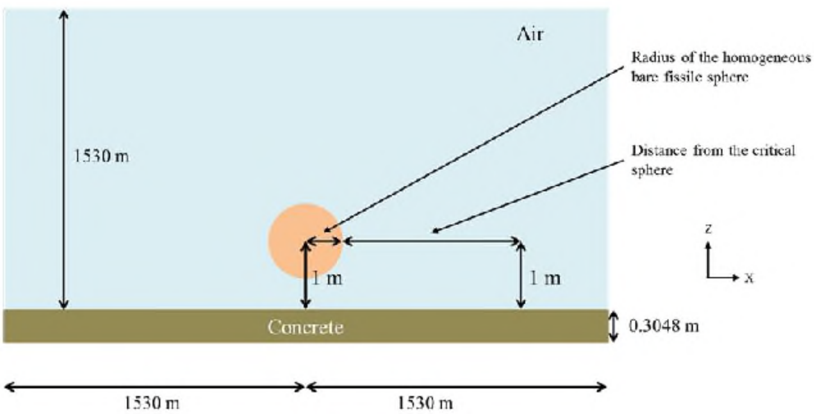

Figure 2: X-Z elevation view of the initial configuration

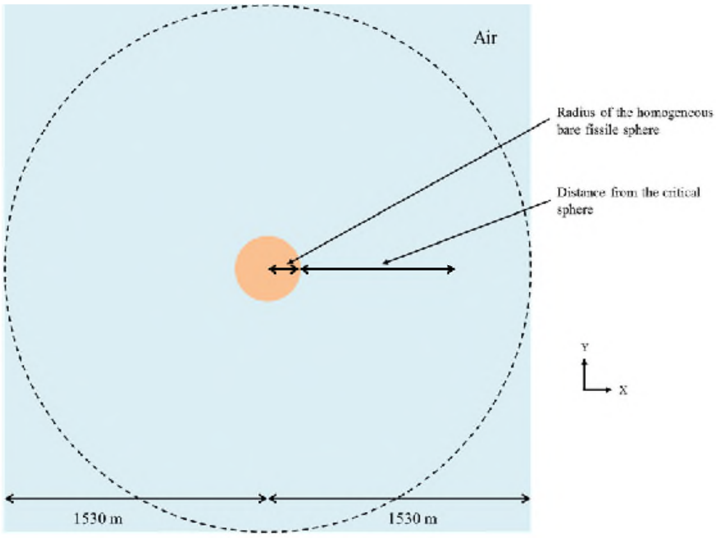

Figure 3: X-Y plan view of the initial configuration.

4.2 RESULTS

This section presents and discusses the simulation results for the cases described in the previous section as well as the comparison with the 1997 Slide Rule. As specified in reference [14], without taking into account the skyshine calculations, at least 900 results are needed to cover all the cases. The laboratories used the various codes and methods presented in chapter 3. Every laboratory used the Henderson flux-to-dose conversion factors [15] in order to compare the results with the 1997 Slide Rule results. The impact of flux-to-doses conversion factors are discussed in chapter 6. Doses are given for 1.E+17 fissions.

4.2.1 PROMPT CALCULATIONS

Prompt dose comparisons are performed between the 1997 Slide Rule and the modern codes. Doses results are presented in Appendix 8.1, from Table 6 to Table 11. Figure 4 to Figure 6 show comparisons for three cases and Figure 7 and Figure 8 are focused on the code to code comparison for all cases.

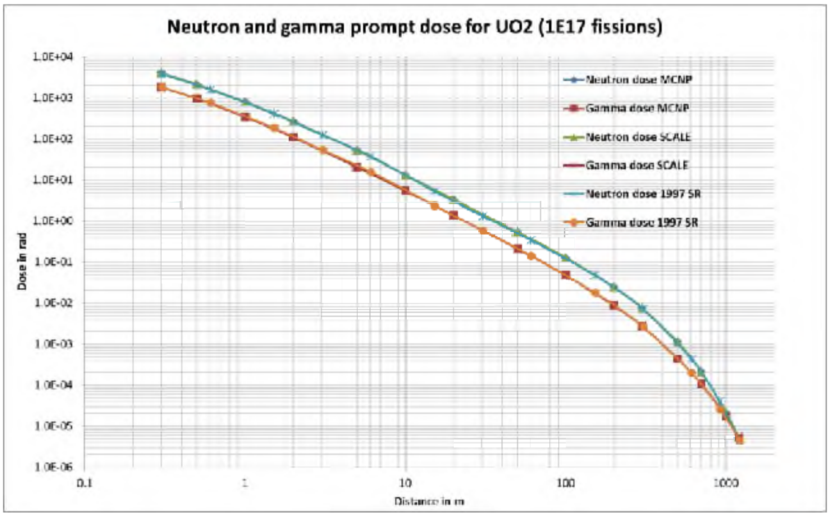

Figure 4: Prompt doses comparison for uranium dioxide

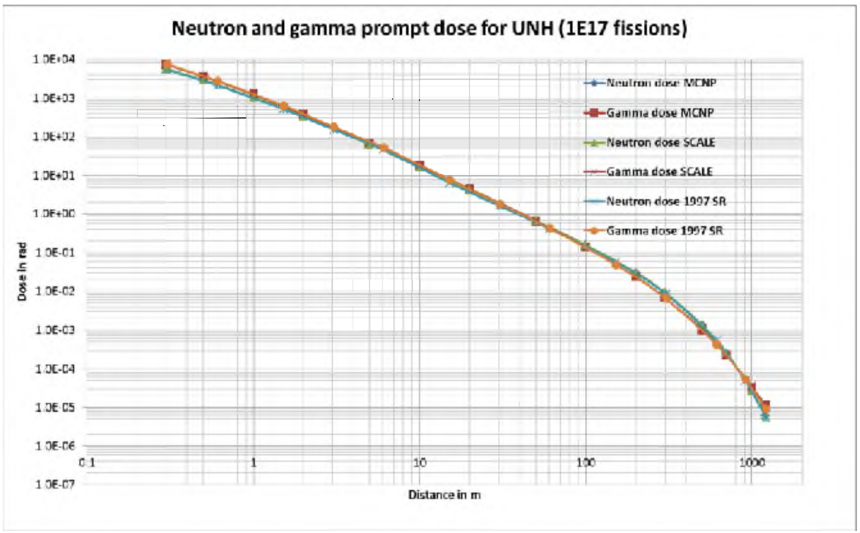

Figure 5: Prompt doses comparison for enriched uranyl nitrate

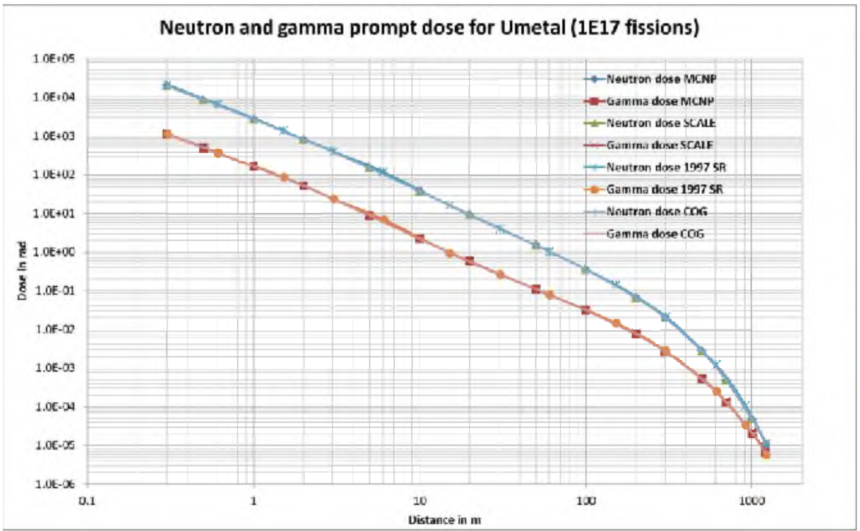

Figure 6: Prompt doses comparison for enriched uranium metal

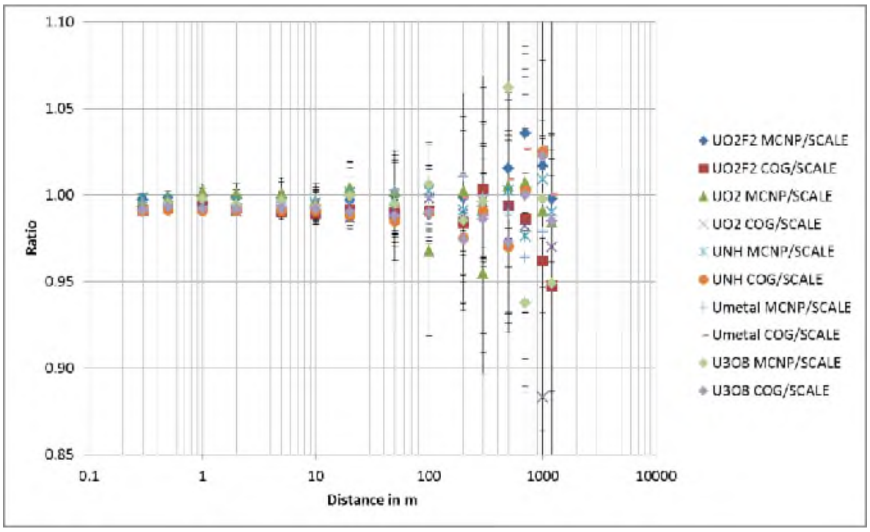

Figure 7: Code to code comparison for all cases (neutron)

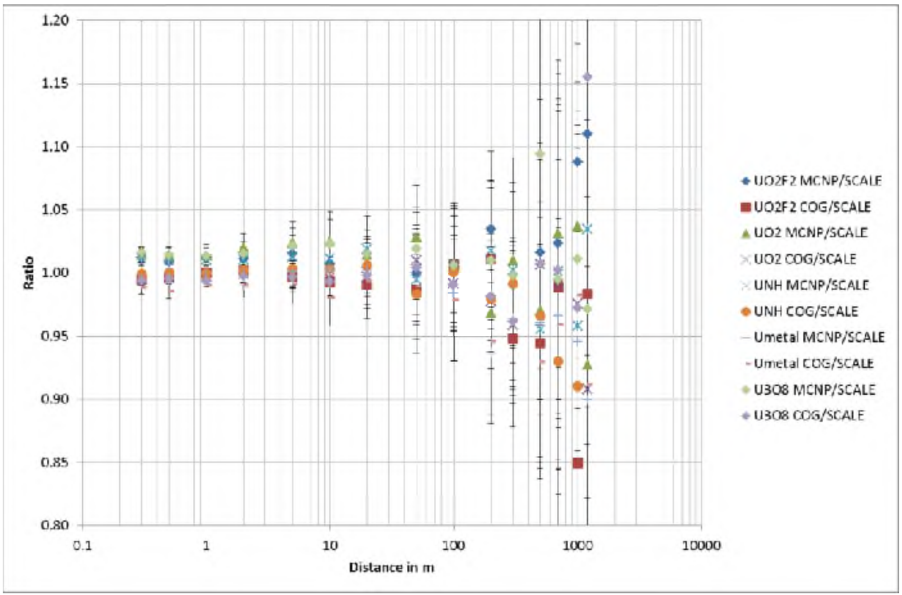

Figure 8: Code to code comparison for all cases (prompt gamma)

A good agreement is observed between the 1997 Slide Rule results and the modern codes results for both prompt neutron and gamma doses for all cases. The discrepancies between codes are generally below 5%.

The corresponding relative error (2 σ) on the ratio between two codes is generally lower than 13% for neutrons (whatever the distance) and for gammas for distance lower than 300 m. After 300 m, the corresponding relative error on the ratio for gamma increases and can reach 25% for the MCNP/SCALE comparison and 60% for the COG/SCALE comparison.

This discrepancy between codes seems relatively independent of the distance for neutrons but increases for gamma doses with the distance. A possible explanation is that the prompt gamma contribution from the uranium sphere decreases with the distance increase. The gammas being produced by neutrons in the concrete and air, far from the uranium sphere, need to be correctly taken into account. This problem requires very good convergence not only for gammas created inside the uranium sphere, but also for neutrons that create gamma (in the ground) close to the detector. This problem seems more complicated than neutron dose determination and leads to higher discrepancies between codes.

One known difference between MCNP and SCALE gamma transport is MCNP's thick target bremsstrahlung model. This model accounts for the electromagnetic cascade of gammas and electrons that produce many low energy bremsstrahlung gammas. The MCNP thick target bremsstrahlung model accounts for these gammas, and allows users to not perform electron transport for geometries with thick shielding materials. All of the SCALE fixed-source radiation transport codes use gamma production data based on ENDF, which does not include this sort of bremsstrahlung. Regarding COG, whenever an electron-producing photon reaction occurs, COG checks whether the reaction occurred in a region enabled by the user for electron transport. If not, which is the case here, then the electron energy is immediately deposited (no bremsstrahlung is transported).

Regarding the calculation of the prompt doses, the results from the modern tool used for this update are consistent. For the initial 2D configuration, the modern 3D tools results confirm the results obtained with the 2D tool used to create the 1997 Slide Rule. The impact of the use of new nuclear data is not visible on the update, with regard to the relative error (generally 5 %). The interest in 3D capabilities will become more important for new configurations that will break the symmetry of the problem.

4.2.2 DELAYED GAMMA DOSES

Delayed gamma dose comparisons are performed between the 1997 Slide Rule and the modern codes. Many decay times are considered in references [1] and [14]. So, only representative cases are presented hereafter. Figure 9 to Figure 14 show these comparisons. Doses results are presented in Appendix 8.1, from Table 12 to Table 41.

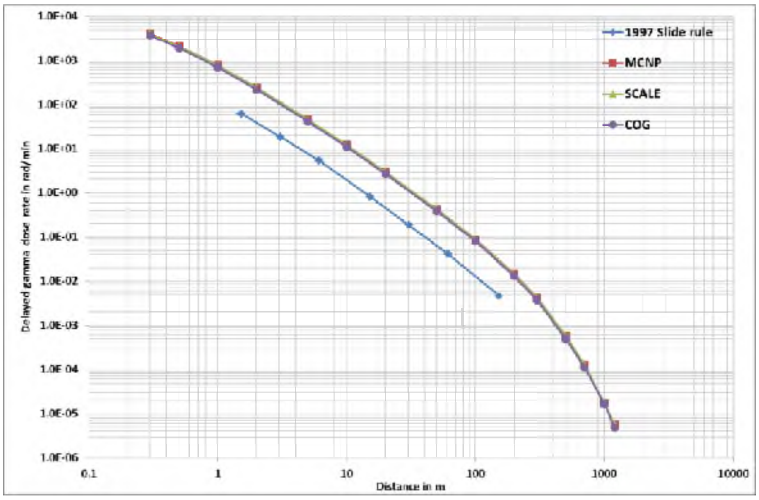

Figure 9: Delayed gamma doses comparison for uranyl fluoride 1 s after the criticality accident

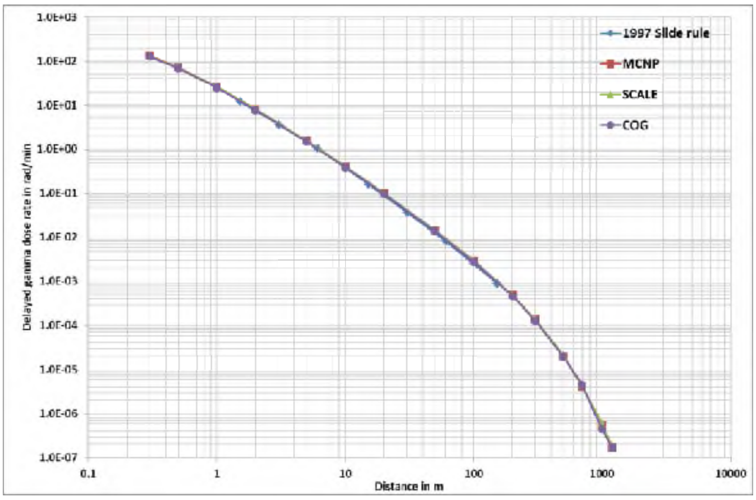

Figure 10: Delayed gamma doses comparison for uranyl fluoride 1 min after the criticality accident

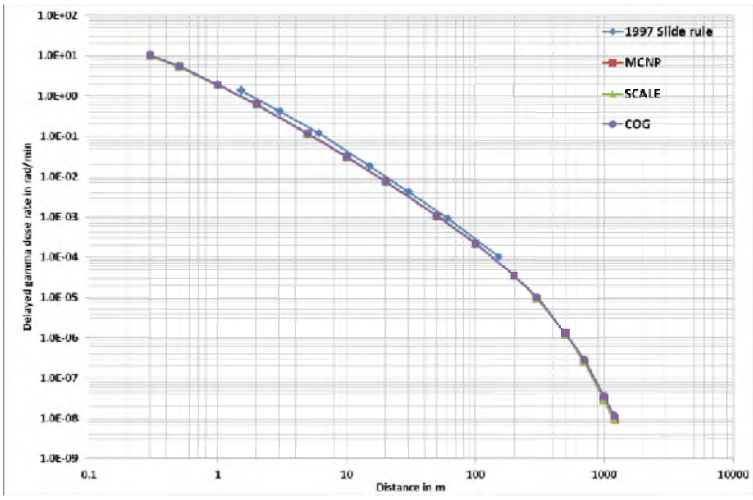

Figure 11: Delayed gamma doses comparison for uranyl fluoride 10 min after the criticality accident

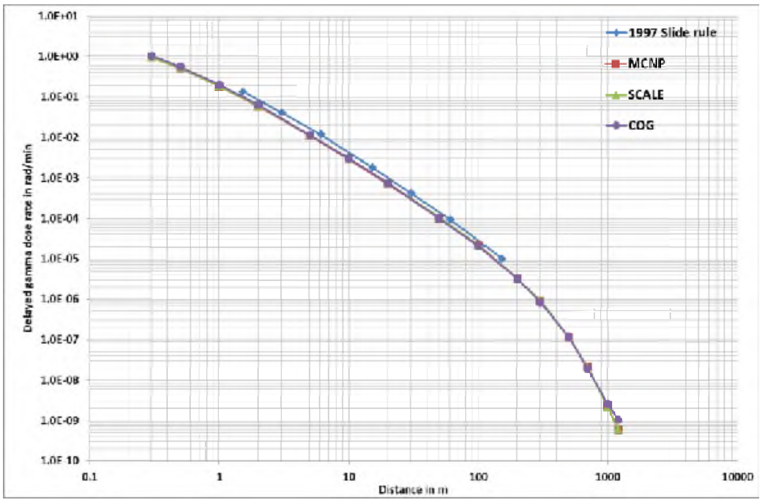

Figure 12: Delayed gamma doses comparison for uranyl fluoride 100 min after the criticality accident

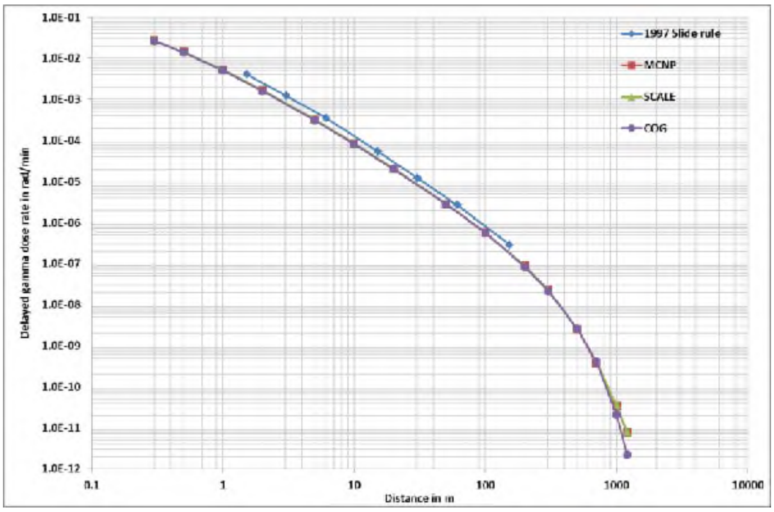

Figure 13: Delayed gamma doses comparison for uranyl fluoride 1000 min after the criticality accident

The previous figures present the results for the uranyl fluoride case but the following general observations are applicable for all cases:

- the modern code results are higher than the 1997 Slide Rule for times less than 1 minute but as time increases (to 1 minute), this difference decreases,
- at 1 minute, the delayed modern code results agree very well with the 1997 Slide Rule,
- at time greater than 1 minute, the modern code results are slightly smaller than the 1997 Slide Rule, but this difference is fairly constant and is not a function of time above 1 minute.

These general observations might be slightly different for the different fissile media, because the characteristics of these media (in particular the enrichment and the moderation ratio) have an impact on the evolution of the isotopic composition, so on the delayed gamma source, which leads to some variations (see Figure 14 for example).

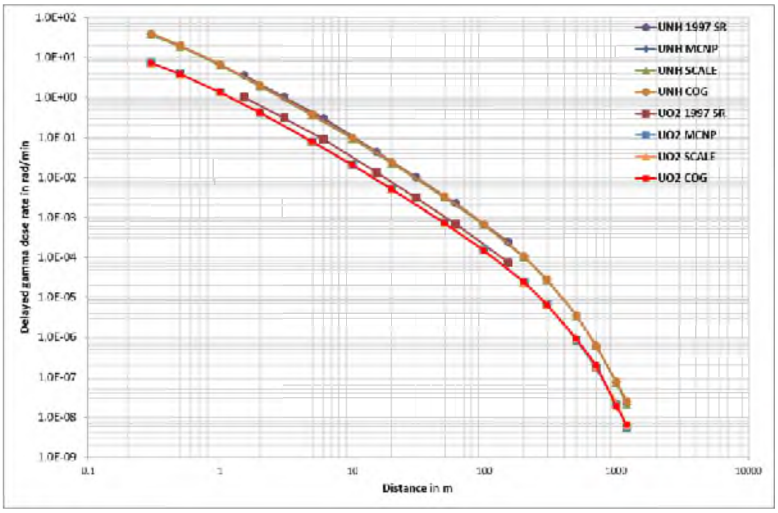

Figure 14: Delayed gamma doses comparison for uranyl nitrate and UO2 10 min after the criticality accident

The complete explanation of these discrepancies is difficult to find because some assumptions made for the 1997 Slide Rule are unknown. However, the following elements can be suggested.

The first possibility to explain the discrepancies is the fact that ORIGEN data between 1997 and today has changed, in particular with updated nuclear data. In particular for short decay times, the older gamma libraries were missing gamma spectral data for many of the short lived fission products [16]. This might be the best explanation for the discrepancies observed for results for times less than 1 minute. Use of 1997 nuclear data to run ORIGEN today was not tested here but could be done in the future in order to confirm and quantify the nuclear data effect.

It can also be noticed that, the modern code results are obtained by determining the instantaneous dose rate at a given time whereas the 1997 Slide Rule results considered an accumulated one minute dose, (integration of the dose rate over the next 60 s, which take into account the intensity decrease of the source). So, a part of the discrepancies between modern codes and 1997 Slide Rule may be explained because the intensity of delayed gamma greatly decreases for short decay time (in particular lower than 1 minute). As an illustration, the intensity of delayed gamma (given in gamma per second) as a function of the decay time after the accident is presented in Figure 15 for the uranyl fluoride case and shows that between 1 second and 1 minute, the intensity decreases by a factor ~30. Thus, comparing instantaneous dose rate and integrated dose rate induces a bias for the shortest decay periods.

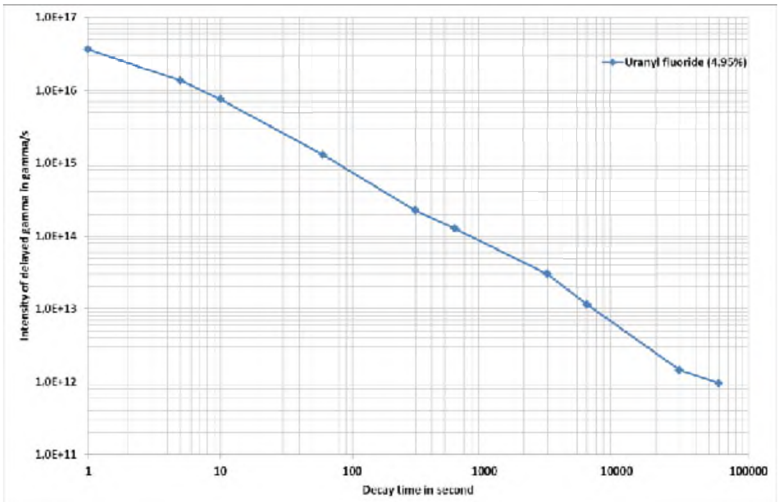

Figure 15: Intensity of delayed gamma as a function of the decay time for the uranyl fluoride

Finally, the 1997 Slide Rule states that “No delayed neutron contribution nor contributions from delayed gammas between 1 µs and 1 s were included in the dose curves”. This assumption should have an impact on the results for the short times. The code to code comparison is illustrated in Figure 16 to Figure 20.

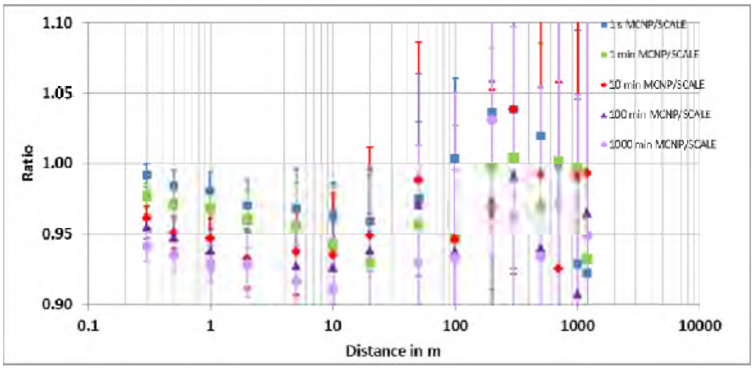

Figure 16: Comparison between MCNP and SCALE for enriched uranium metal

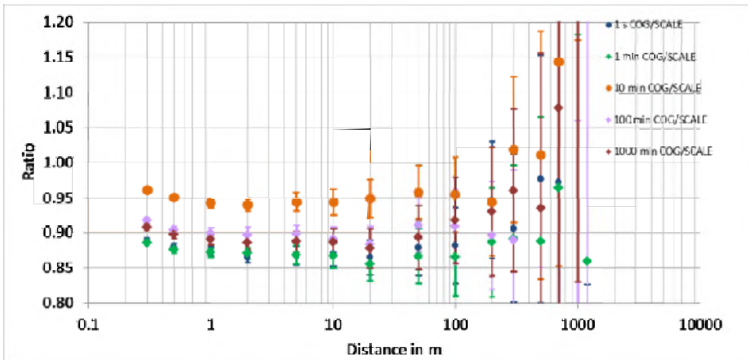

Figure 17: Comparison between COG and SCALE for enriched uranium metal

It can be seen that the discrepancies between codes increase with the distance after 500 meters. It may be explained by important uncertainties in the doses calculation results and not necessarily by a difference in the delayed gamma source. At 10 meters from the criticality accident (with no convergence issues and a relative error on the ratio less than 2 %), the Figure 20 shows the comparison for all cases. Two behaviors can be observed. The comparison between MCNP and SCALE results shows a slight decrease trend with decay time. A possible explanation is that the delayed gamma sources were determined with the same “method” but with different options (in particular the energy binning) and code versions, which have an impact in particular on the sources intensity for long decay time. The comparison between COG and SCALE shows an “up and down” behavior. The COG/SCALE parameter presents a slightly important discrepancy (0.81 – 0.94) for short time (less than 1 min), then a swing behavior (1 - 1.14) to finally come back to lower values (0.87 - 1). This behavior needs to be investigated.

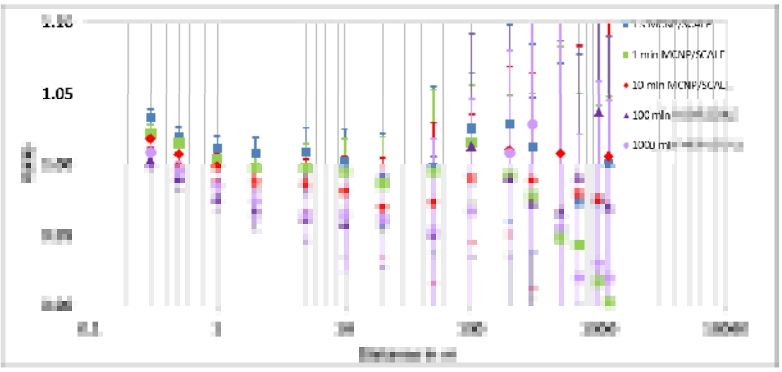

Figure 18: Comparison between MCNP and SCALE for uranyl fluoride

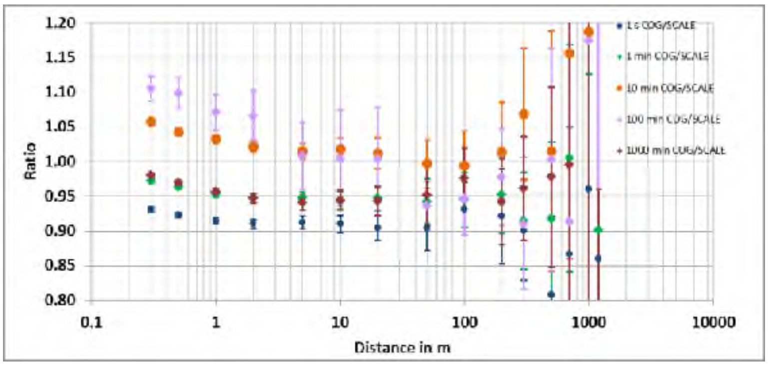

Figure 19: Comparison between COG and SCALE for uranyl fluoride

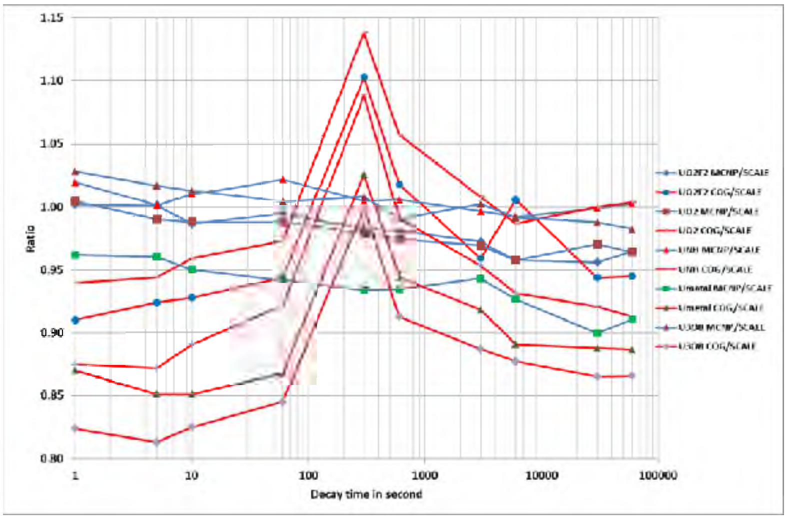

Figure 20: Code to code comparison for all cases at 10 meters from the criticality accident

Regarding the determination of the delayed gamma source, some discrepancies occurred between codes. The detail analysis of these discrepancies was not the main purpose of this paper but additional effort should be done in order to understand the discrepancies.

5 ADDITIONAL SYSTEMS/ PLUTONIUM CONFIGURATIONS

This chapter discusses the results for new configurations (step 2) including plutonium systems, calculated by modern 3D radiation transport codes, i.e. MCNP, SCALE and COG.

5.1 MODEL DESCRIPTION

The geometry for step 2 is derived from the 1997 Slide Rule model. It consists of a simple 2-D air-over-ground configuration with the source located at the radial center of a right-circular cylinder. The radius and the height of the air cylinder is 1530 m. The center of the critical assemblies (spheres or cylinders) are all 1 m above the ground. The ground is now modelled as a 50 cm layer of the same concrete (the initial configuration and the step 1 configuration considered 1 ft or 30.48 cm of concrete). Additional calculations not shown here demonstrated that this modification has no impact on dose results for a ground made of concrete.

Figure 2 and Figure 3 present the model for these initial calculations. For more clarity, all the information needed to calculate the step 2 configurations were written in specific documents using a “benchmark format” [14] [17] and are presented in Appendix 8.3.

Neutron and gamma doses were calculated as a function of distance from 0.3 m to 1200 m. The distance between the source and the detector is measured from the external surface of the source (either plutonium for bare geometry or steel when the reflector is considered) to the center of the detector. The detector used for step 2 was chosen to be a cylindrical shell with a square cross-section of 5 cm x 5 cm to take advantage of the symmetry of the problem. The center of the detector is also at a height of 1 m above the ground.

5.2 RESULTS

This section presents and discusses the simulation results for the plutonium cases described in the previous section. As specified in reference [17], 690 results are needed to cover all the cases for step 2. The laboratories used various codes and methods, presented in chapter 3. Every laboratory has used the flux-to-dose conversion factors provided in the ANSI/HPS N13.3 standard [18] to compare their results in this study. This standard is specifically dedicated to the dosimetry of a criticality accident and deals with deterministic consequences of a criticality accident. Other conversion factors will be used in the future to compare the results obtained. In addition, some laboratories have performed plutonium calculations with the Henderson flux-to-dose conversion factors to compare not only the dose given by uranium systems (step 1) and plutonium systems (step 2) but also the two flux-to-dose conversion factors (ANSI/HPS N13.3 and Henderson) applied to plutonium systems. Based on results from step 1, good agreement was observed between laboratories and the original Slide Rule on prompt doses (neutron and gamma). On the contrary, some discrepancies were found between laboratories and with the original

Slide Rule on delayed gamma doses, see chapter 4. Based on these observations, only prompt doses are considered for these new configurations whereas the complete analysis of discrepancies between laboratories for delayed gamma needs to be completed before performing additional calculations of this kind.

5.2.1 BARE SPHERE CALCULATIONS

Dose results are presented in Appendix 8.2, from Table 42 to Table 47. Figure 21 and Figure 22 show the neutron and gamma dose for the bare spherical plutonium systems calculated with MCNP with the ANSI/HPS N13.3 flux-to-dose conversion factors. For a given distance, the neutron dose is higher when the moderation ratio (H/Pu) is lower. The difference between the extreme cases goes from a factor 13 for short distances to a factor 4.5 for long distances. Regarding prompt gamma doses, the lowest dose is obtained for the metal plutonium system whereas the highest dose is obtained for an intermediate moderation ratio. At short distances, the difference between the extreme cases is a factor 5 on prompt gamma doses. After 500 meters, all the gamma curves become closer with a maximum ratio of 1.5. All these observations can be roughly explained by the various self-absorption inside the sphere and by the fact that neutrons are produced only in the plutonium sphere whereas prompt gammas are produced not only in the plutonium sphere but also by neutron with (n, gamma) reactions within the surrounding environment (ground mainly in these configurations).

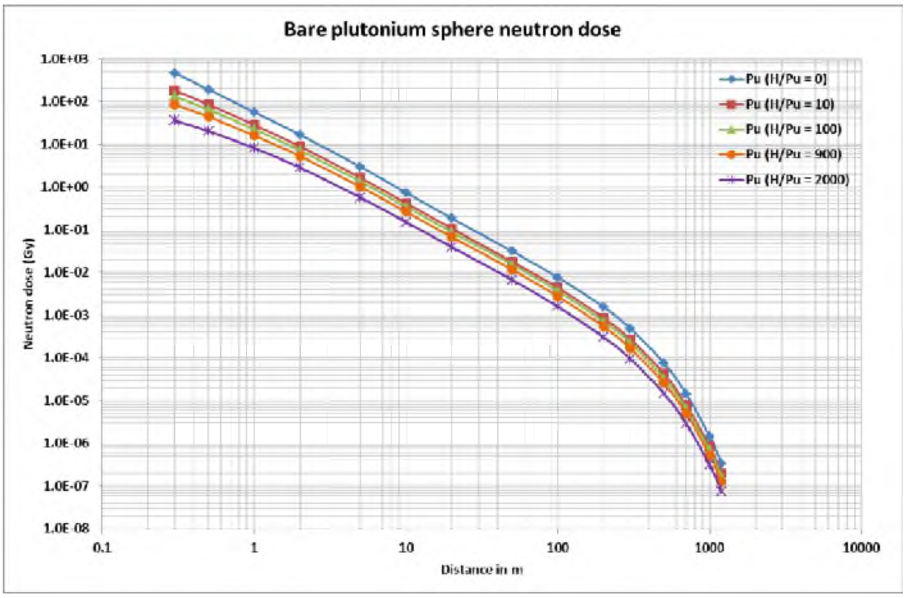

Figure 21: Neutron doses for bare plutonium sphere

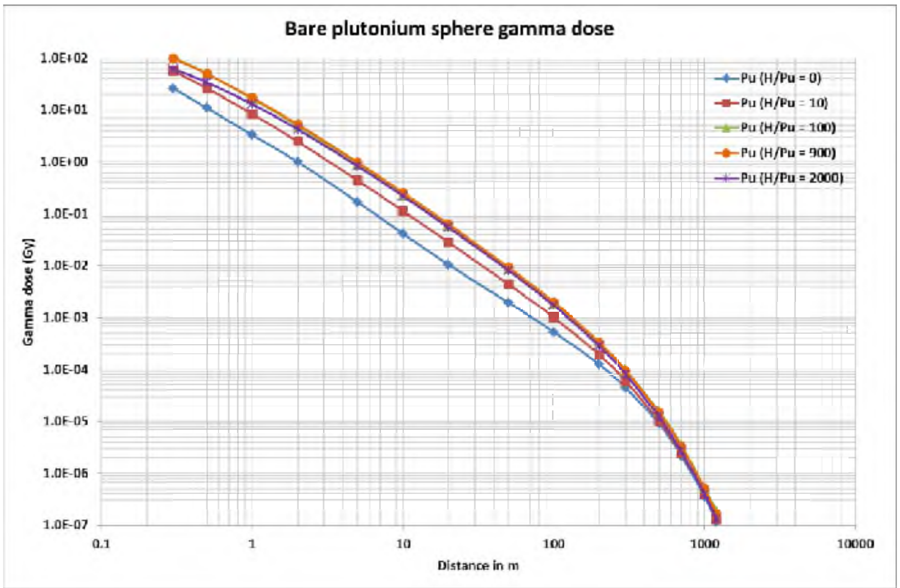

Figure 22: Prompt gamma doses for bare plutonium sphere

Figure 23 shows the neutron/gamma dose ratio for the bare spherical plutonium system. For all the moderation ratios, the neutron/gamma dose ratio is relatively constant from 0.3 cm up to 20 meters. Beyond 20 meters, the ratio constantly decreases for metal plutonium whereas it continues to increase then decreases after 500 meters for other configurations.

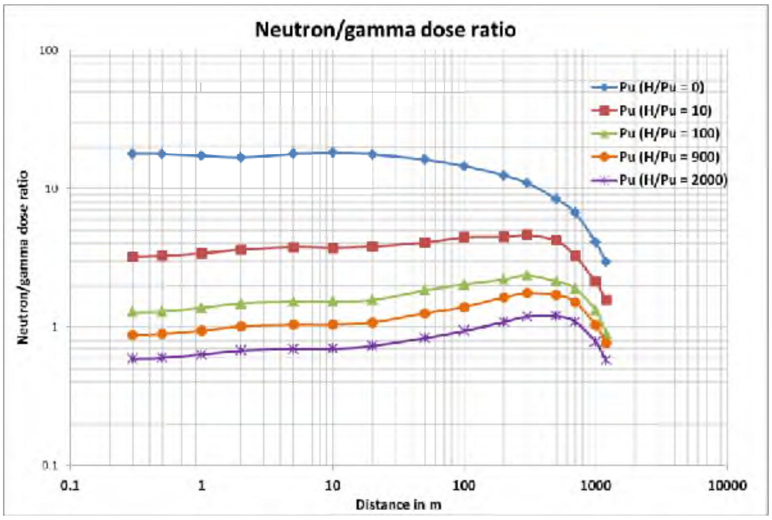

Figure 23: Neutron/gamma dose ratio for bare plutonium sphere

Figure 24 presents the code to code comparison of neutron and gamma doses for the bare plutonium sphere. Good agreement is observed between codes with discrepancies generally lower than 5 %. At long distances, the discrepancies between codes are higher (without any trend) but with higher uncertainties. Generally, the relative error (2 σ) on the code results is lower than 2 % until 500 meters and up to 10 % at long distances. For prompt gamma doses, a small discrepancy between codes is perceptible and might be due to the different treatment of bremsstrahlung by these codes. MCNP's thick target bremsstrahlung model accounts for the electromagnetic cascade of gammas and electrons that produce many low energy bremsstrahlung gammas, and allows users to not perform electron transport for geometries with thick shielding materials. All of SCALE's fixed-source radiation transport codes use gamma production data based on ENDF, which does not include this sort of bremsstrahlung. When this model is turned off (PHYS:P j 1), the MCNP and SCALE results are statistically the same. Regarding COG, whenever an electron-producing photon reaction occurs, COG checks whether the reaction occurred in a region enabled by the user for electron transport. If not, which is the case here, then the electron energy is immediately deposited. All these observations regarding code to code comparison could be applied to the other kind of calculations performed in this chapter (no bremsstrahlung is transported).

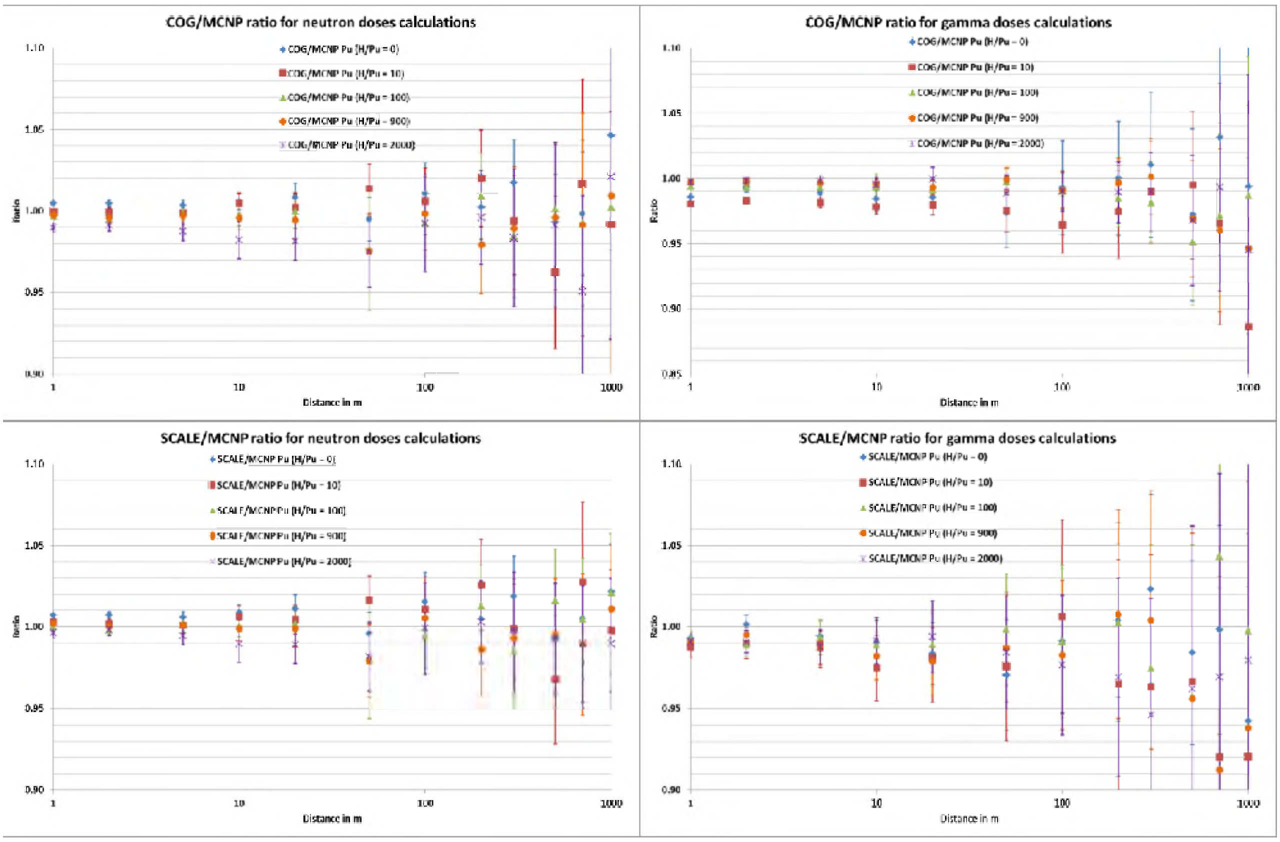

Figure 24: Code to code comparison for the bare plutonium sphere

Figure 25 presents the ratio between neutron and gamma doses calculated with MCNP for bare plutonium system with the Henderson flux-to-dose conversion factor (used in the original slide rule) and the ANSI/HPS N13.3 flux-to-dose conversion factor. It can be seen that the ANSI/HPS N13.3 flux-to-dose conversion factor is more penalizing than the Henderson flux-to-dose conversion factor (at least 20 % for neutron with an increase when the distance increases and about 10 % for gamma independent of the distance). Indeed, the ANSI/HPS N13.3 flux-to-dose conversion factor is always larger than the Henderson flux-to-dose conversion factor with an increasing difference for intermediate and low neutron energies. Figure 26 presents the ANSI/HPS N13.3 and the Henderson flux-to-dose conversion factors for neutrons.

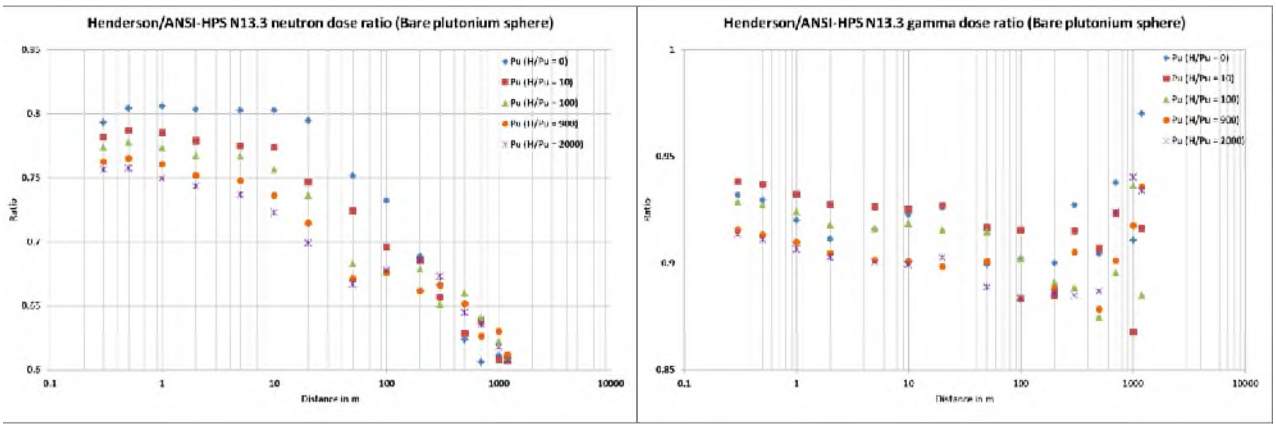

Figure 25: Henderson/ANSI-HPS N13.3 dose ratios for bare plutonium sphere (MCNP)

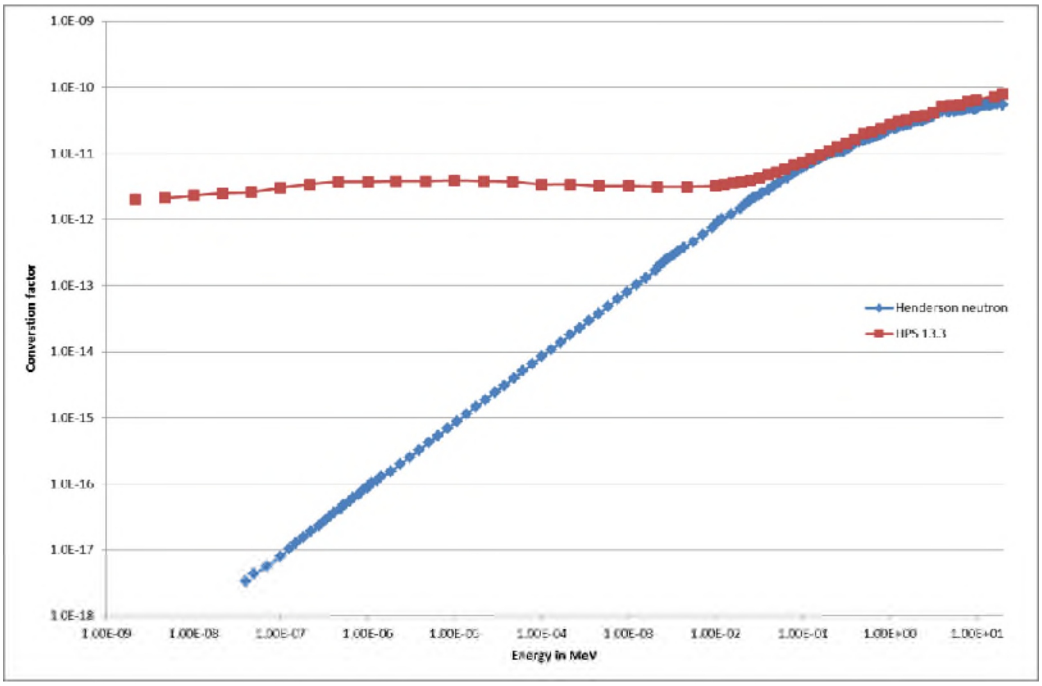

Figure 26: Conversions factors

Figure 27 presents the neutron and gamma doses for the uranium systems (considered in the original slide rule) and the plutonium system calculated with MCNP with the Henderson flux-to-dose conversion factor. These figures show that there are no major differences, in terms of trend, between plutonium and uranium systems. The extreme cases (max/min) for doses are:

- for neutron, plutonium metal and moderated plutonium (H/Pu = 2000),
- for prompt gamma, intermediate plutonium system (H/Pu=100 or 900) and uranium metal.

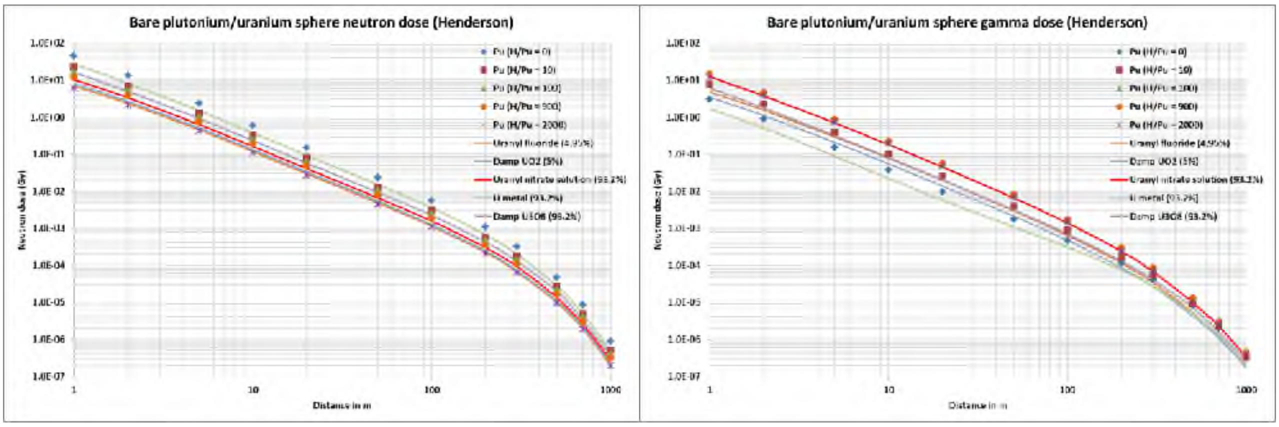

Figure 27: Bare sphere doses using Henderson flux-to-dose conversion factors (MCNP)

It can be seen that, on average for the Henderson flux-to-dose conversion factors, the plutonium metal configuration generates doses 70 % higher than the uranium metal configuration (for both neutrons and prompt gamma). This kind of result shows the interest to update the original slide rule to include plutonium systems.

5.2.2 BARE CYLINDER CALCULATIONS

The Figure 28 shows, for neutron and prompt gamma, the ratio between the doses calculated with the critical bare plutonium cylinders (with three different height-to-diameter ratios (0.5, 1 or 2)) and with the critical bare plutonium sphere. The results are shown for two moderation ratios, H/Pu=0 and H/Pu=2000. Dose results are presented in the Appendix 8.2, from Table 48 to Table 53. The discrepancies between the three cylinders and the sphere are within 30 % and decrease with increasing distance. The solid angle of the various geometries from the detector explains the behavior of the ratio. The ratio tends to approach one for long distances but is not completely reached for gamma dose for H/Pu=2000 and a cylinder with a height-to-diameter ratio of 0.5 (but with important relative errors for long distance).

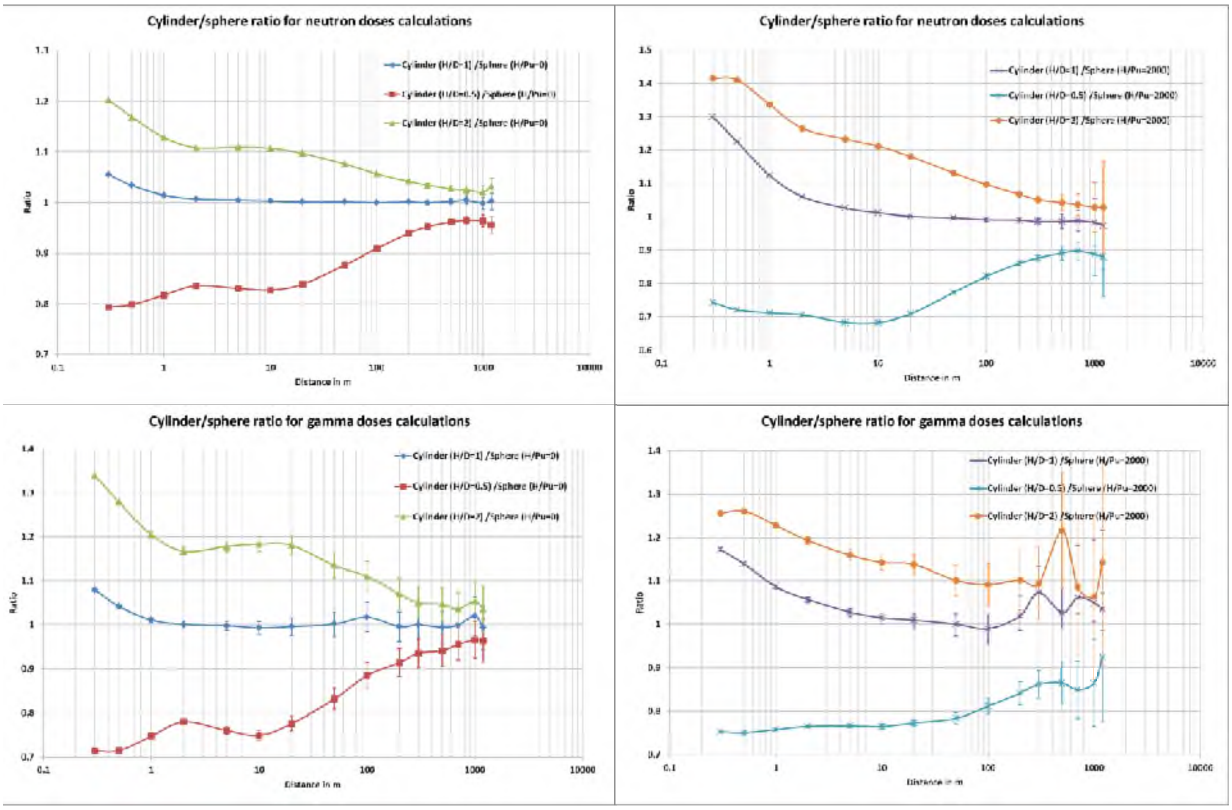

Figure 28: Bare Cylinder/sphere dose ratios (SCALE)

5.2.3 REFLECTED SPHERE CALCULATIONS

Figure 29 shows, for neutron and prompt gamma, the ratio between the doses calculated with the steel reflected plutonium sphere (with various thicknesses) and with the bare plutonium sphere. The results are shown for two moderation ratios, H/Pu=0 and H/Pu=2000. Dose results are presented in the Appendix 8.2, from Table 54 to Table 65**.**

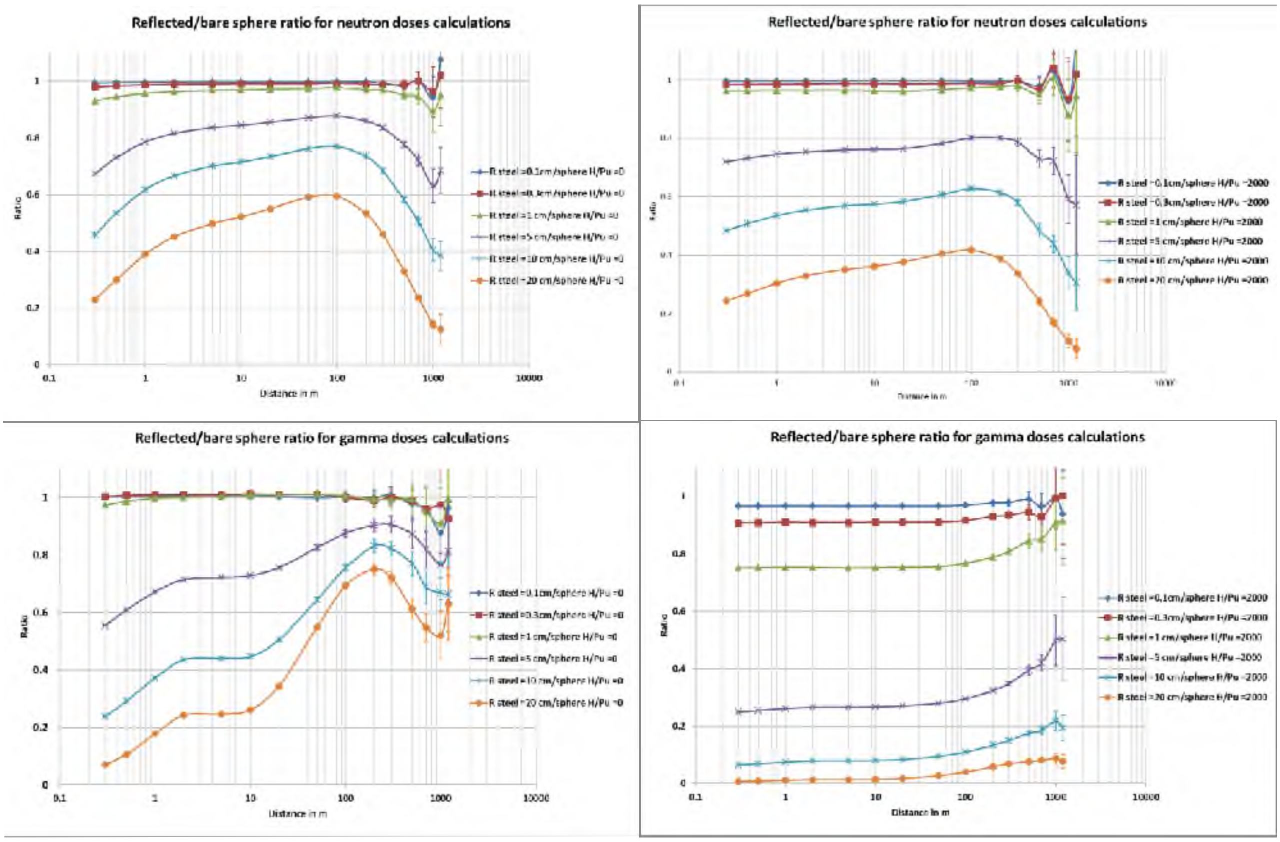

Figure 29: Reflected/bare sphere dose ratios (COG)

For these reflector and fissile material configurations, the bare sphere is the most penalizing configuration. The decrease of the size of the critical plutonium sphere (implying less absorption inside the plutonium sphere) does not compensate for the attenuation of the dose due to the reflector. The attenuation effect is not constant with distance and depends on the moderation ratio and the type of incident particle (neutron / gamma). The steel reflector is particularly efficient against the gamma dose for the moderated plutonium (H/Pu=2000).

6 FLUX-TO-DOSE CONVERSION FACTORS

Henderson and ANSI/HPS N13.3 flux-to-dose conversion factors were used for the previous studies. These conversion factors allow one to make order of magnitude estimates of prompt and delay doses. Nevertheless, dose coefficients evolve with time and can be contrasted. In order to expand the area of applicability of the Slide Rule, flux calculations will be performed in addition of dose calculations. The energy mesh used for these calculations will allow the Slide Rule user to apply any kind of flux-to-dose conversion factors.

This chapter shows the energy meshes used for the flux calculations. Comparisons are performed between results obtained with theses energy meshes and results obtained by a direct calculation.

6.1 ENERGY MESH FOR FLUX CALCULATIONS

Multiple references, [15] and [18] to [23], were used to create the energy mesh presented in Table 1 and Table 2, the lower boundary of the first group should be zero. This discretisation of the flux increases the calculation time, because each energy bin must be converged rather than just the total, but it allows one to apply any kind of flux-to-dose conversions factors.

Table 1: Upper bounds in Mev of the neutron energy mesh (from left to right and top to bottom)

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	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
2.20E+01	2.40E+01	2.60E+01	2.80E+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	7.50E+01	8.00E+01	8.50E+01
9.00E+01	9.50E+01	1.00E+02	1.10E+02	1.20E+02	1.25E+02	1.30E+02	1.40E+02
1.50E+02	1.75E+02	1.80E+02	2.01E+02				

Table 2: Upper bounds in Mev of the gamma energy mesh (from left to right and top to bottom)

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					

6.2 APPLICATION OF A FLUX-TO-DOSE CONVERSIONS FACTORS

The energy mesh presented above enables using any kind of flux-to-dose conversion factors. Those factors can be defined by histograms or values that can be interpolated. This section compares results from a direct calculation and a 'two step' calculation where the flux is calculated first (using the energy mesh defined above) and the flux-to-dose conversion factors are applied in a second step. These calculations are performed using MCNP6.1 for the first bare plutonium system.

6.2.1 COMPARISONS FOR THE NEUTRON DOSES

Flux-to-dose conversion factors from seven references (see Table 3) are used in this section to performed comparisons with the two step calculations. Table 4 presents the ratios of the total neutron dose calculated using the energy mesh with a 'two-step' calculation and a direct calculation. Throughout the rest of the document, the designations presented in Table 3 are used. Responses with an uneven number are used for neutron flux and responses with an even number are used for gamma flux.

Table 3: Designations of the different flux-to-dose conversion factors

Resp 1 / Resp 2	Air kerma – [19][21]
Resp 3 / Resp 4	Tissue kerma in air – [20]
Resp 5 / Resp 6	Henderson absorbed dose – [15]
Resp 7 / Resp 8	ANSI/HPS N13.3 – [18]
Resp 9 / Resp 10	ICRU 57 ambient dose equivalent – [21]
Resp 11 / Resp 12	ICRP 74 ambient dose equivalent – [22]
Resp 13 / Resp 14	ICRU 57 effective dose – [21]
Resp 15 / Resp 16	ICRP 116 effective dose – [23]

Table 4: Ratios and relative errors of the neutron prompt dose calculated using the energy mesh with a 'two-step' calculation and a direct calculation

dist(m)	resp 1		resp 3		resp 5		resp 7		resp 9		resp 11		resp 13		resp 15	
0.3	0.98	0.04%	0.99	0.03%	1.00	0.01%	0.99	0.01%	1.00	0.03%	1.00	0.03%	1.00	0.03%	1.00	0.03%
0.5	0.99	0.06%	0.99	0.06%	1.00	0.01%	0.99	0.01%	1.00	0.06%	1.00	0.06%	1.00	0.06%	1.00	0.06%
1	0.99	0.09%	0.99	0.09%	1.00	0.01%	0.99	0.01%	1.00	0.09%	1.00	0.09%	1.00	0.09%	1.00	0.09%
2	0.99	0.14%	0.99	0.14%	1.00	0.02%	0.99	0.02%	1.00	0.14%	1.00	0.14%	0.99	0.14%	1.00	0.14%
5	0.99	0.22%	0.99	0.21%	1.00	0.03%	0.99	0.03%	1.00	0.21%	1.00	0.21%	1.00	0.21%	1.00	0.21%
10	1.00	0.36%	0.99	0.35%	1.00	0.04%	1.00	0.04%	1.00	0.35%	1.00	0.35%	1.00	0.35%	1.00	0.35%
20	1.00	0.50%	0.99	0.48%	1.00	0.05%	0.99	0.05%	1.00	0.48%	1.00	0.48%	0.99	0.48%	0.99	0.48%
50	1.02	0.98%	1.00	0.92%	1.01	0.08%	1.00	0.08%	1.00	0.92%	1.00	0.92%	1.00	0.92%	1.00	0.92%
100	1.02	1.26%	0.99	1.15%	1.01	0.11%	0.99	0.11%	0.99	1.15%	0.99	1.15%	0.99	1.15%	0.99	1.16%
200	1.02	1.12%	1.00	0.99%	1.02	0.16%	1.00	0.15%	1.00	0.98%	1.00	0.98%	0.99	0.98%	1.00	0.99%
300	1.01	1.25%	1.00	1.12%	1.02	0.21%	1.00	0.20%	1.01	1.11%	1.01	1.11%	0.99	1.12%	1.00	1.12%
500	1.06	1.21%	1.00	1.10%	1.02	0.33%	1.00	0.30%	1.01	1.09%	1.01	1.09%	0.99	1.09%	1.00	1.11%
700	1.04	1.13%	0.99	1.09%	1.02	0.48%	0.99	0.43%	0.99	1.06%	0.99	1.06%	0.99	1.07%	1.00	1.09%
1000	1.05	1.14%	0.97	1.21%	1.00	0.79%	0.98	0.69%	0.98	1.16%	0.98	1.16%	0.97	1.18%	0.97	1.22%
1200	1.03	1.12%	0.96	1.27%	0.99	1.11%	0.97	0.97%	0.97	1.20%	0.97	1.20%	0.96	1.23%	0.97	1.29%

The discrepancies observed for these calculations are low enough to prove that the neutron energy mesh is well defined to performed dose calculations.

6.2.2 COMPARISONS FOR THE GAMMA DOSES

The comparisons performed in the previous section are repeated for gamma doses. Table 5 shows the ratios calculated for the first bare plutonium system.

Table 5: Ratios and relative errors of the gamma prompt dose calculated using the energy mesh with a 'two-step' calculation and a direct calculation

dist(m)	resp 1		resp 3		resp 5		resp 7		resp 9		resp 11		resp 13		resp 15	
0.3	1.00	0.06%	1.00	0.06%	1.02	0.05%	1.00	0.06%	1.00	0.06%	1.00	0.06%	1.00	0.06%	1.00	0.06%
0.5	1.00	0.10%	1.00	0.10%	1.02	0.06%	1.00	0.10%	1.00	0.10%	1.00	0.10%	1.00	0.10%	1.00	0.10%
1	1.00	0.16%	1.00	0.16%	1.02	0.11%	1.01	0.17%	1.00	0.16%	1.00	0.16%	1.00	0.16%	1.00	0.16%
2	1.00	0.24%	1.00	0.24%	1.03	0.16%	1.01	0.25%	1.00	0.24%	1.00	0.24%	1.00	0.24%	1.00	0.24%
5	1.00	0.41%	1.00	0.41%	1.02	0.26%	1.00	0.42%	1.00	0.40%	1.00	0.40%	1.00	0.41%	1.00	0.40%
10	1.00	0.76%	1.00	0.77%	1.02	0.51%	1.01	0.74%	1.00	0.73%	1.00	0.73%	1.00	0.72%	1.00	0.72%
20	1.01	0.84%	1.00	0.85%	1.02	0.56%	1.01	0.85%	0.99	0.85%	0.99	0.85%	0.99	0.87%	0.99	0.86%
50	1.00	1.77%	1.00	1.74%	1.02	1.12%	1.00	1.81%	1.01	1.71%	1.00	1.69%	1.01	1.69%	1.00	1.69%
100	1.02	2.34%	1.00	2.35%	1.04	1.41%	1.02	2.51%	1.00	2.33%	1.01	2.28%	1.00	2.35%	1.01	2.28%
200	0.98	2.79%	0.98	2.80%	1.03	1.84%	1.02	2.89%	1.01	2.72%	1.01	2.72%	1.01	2.73%	1.01	2.78%
300	1.01	3.11%	1.02	3.10%	1.05	1.89%	1.03	3.47%	1.03	3.00%	1.03	3.04%	1.03	3.20%	1.03	3.17%
500	1.02	3.28%	1.01	3.29%	1.04	2.04%	1.01	3.41%	1.04	3.15%	1.04	3.16%	1.04	3.20%	1.04	3.18%
700	1.03	3.80%	1.02	3.88%	1.08	2.30%	1.06	3.94%	1.06	3.78%	1.05	3.60%	1.06	3.60%	1.05	3.58%
1000	1.03	4.33%	1.06	4.62%	1.03	2.74%	0.99	4.81%	1.00	4.25%	1.03	4.23%	1.00	4.48%	1.03	4.33%

The discrepancies observed for these calculations are low enough to prove that the gamma energy mesh is well defined to performed dose calculations.

7 CONCLUSIONS AND PERSPECTIVES

This report presents the calculation performed by AWE, IRSN, LLNL and ORNL to update the Nuclear Criticality Slide Rule for the emergency response to a nuclear criticality accident. This report gives:

- a calculation scheme and its application to the five fissile media considered in the "Slide Rule";
- comparisons between Monte-Carlo codes such as MCNP6.1, SCALE6.1, SCALE6.2 and COG11;
- comparisons between different Flux-to-dose conversion factors;
- an extension of the original "Slide Rule" configurations to plutonium systems.

The next step is to review and update the other sections of the original Slide Rule document and create a Functional document that can be used during emergency response to a criticality accident.

8 APPENDIX

8.1 RESULTS FOR THE INITIAL CONFIGURATIONS (§ 4.2.1 AND 4.2.2)

Table 6: Neutron prompt doses calculated with MCNP and Henderson flux-to-doses factors

Prompt neutron dose (rad)	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Uranyl fluoride (4,95 %)	σ	Damp UO2 (5 %)	σ	Uranyl nitrate solution (93,2 %)	σ	U metal (93,2 %)	σ	Damp U3O8 (93,2 %)	σ
0.3	3.33E+03	0.12%	4.00E+03	0.11%	5.68E+03	0.10%	1.98E+04	0.02%	1.06E+04	0.07%
0.5	1.81E+03	0.14%	2.13E+03	0.13%	2.89E+03	0.07%	8.75E+03	0.04%	4.95E+03	0.09%
1	6.93E+02	0.18%	7.99E+02	0.17%	1.03E+03	0.10%	2.73E+03	0.05%	1.62E+03	0.12%
2	2.35E+02	0.15%	2.67E+02	0.22%	3.35E+02	0.12%	8.26E+02	0.07%	4.99E+02	0.16%
5	4.60E+01	0.34%	5.17E+01	0.32%	6.34E+01	0.19%	1.50E+02	0.11%	9.20E+01	0.16%
10	1.19E+01	0.31%	1.33E+01	0.33%	1.63E+01	0.27%	3.77E+01	0.16%	2.32E+01	0.27%
20	2.99E+00	0.69%	3.37E+00	0.50%	4.10E+00	0.60%	9.33E+00	0.21%	5.79E+00	0.31%
50	4.81E-01	1.07%	5.42E-01	0.79%	6.60E-01	0.92%	1.51E+00	0.56%	9.28E-01	0.57%
100	1.14E-01	0.91%	1.24E-01	2.00%	1.57E-01	0.90%	3.57E-01	0.56%	2.23E-01	0.69%
200	2.23E-02	2.37%	2.47E-02	1.13%	3.02E-02	2.04%	6.74E-02	0.56%	4.23E-02	2.00%
300	6.65E-03	3.29%	7.23E-03	2.24%	9.25E-03	2.84%	1.99E-02	0.92%	1.29E-02	1.53%
500	1.01E-03	0.91%	1.11E-03	0.71%	1.36E-03	0.66%	2.77E-03	1.64%	1.99E-03	2.93%
700	1.95E-04	1.54%	2.11E-04	0.64%	2.57E-04	1.09%	4.84E-04	3.02%	3.35E-04	3.91%
1000	1.95E-05	1.12%	2.14E-05	1.34%	2.68E-05	0.95%	4.76E-05	1.52%	3.63E-05	0.98%
1200	4.63E-06	0.92%	5.04E-06	0.91%	6.27E-06	1.40%	1.12E-05	0.93%	8.10E-06	2.19%

Table 7: Gamma prompt doses calculated with MCNP and Henderson flux-to-doses factors

Prompt Gamma dose (rad)	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Uranyl fluoride (4,95 %)	σ	Damp UO2 (5 %)	σ	Uranyl nitrate solution (93,2 %)	σ	U metal (93,2 %)	σ	Damp U3O8 (93,2 %)	σ
0.3	2.46E+03	0.12%	1.84E+03	0.14%	7.27E+03	0.03%	1.14E+03	0.07%	4.26E+03	0.11%
0.5	1.31E+03	0.14%	9.64E+02	0.17%	3.64E+03	0.05%	5.10E+02	0.12%	1.95E+03	0.13%
1	4.81E+02	0.18%	3.47E+02	0.22%	1.24E+03	0.07%	1.65E+02	0.16%	6.12E+02	0.17%
2	1.54E+02	0.24%	1.11E+02	0.28%	3.78E+02	0.09%	5.17E+01	0.20%	1.79E+02	0.23%
5	2.95E+01	0.35%	2.09E+01	0.42%	7.00E+01	0.14%	8.89E+00	0.31%	3.19E+01	0.35%
10	7.76E+00	0.31%	5.52E+00	0.65%	1.82E+01	0.20%	2.22E+00	0.45%	8.22E+00	0.49%
20	1.95E+00	0.44%	1.38E+00	0.77%	4.51E+00	0.20%	5.77E-01	0.45%	2.02E+00	0.70%
50	2.94E-01	0.72%	2.14E-01	0.93%	6.60E-01	0.46%	1.09E-01	1.66%	3.13E-01	0.70%
100	6.36E-02	1.07%	4.74E-02	1.05%	1.39E-01	0.75%	3.13E-02	1.46%	7.02E-02	1.03%
200	1.14E-02	1.25%	8.55E-03	1.67%	2.39E-02	1.20%	7.46E-03	1.55%	1.31E-02	1.67%
300	3.41E-03	1.88%	2.72E-03	2.06%	6.77E-03	1.32%	2.72E-03	1.87%	4.11E-03	2.47%
500	5.48E-04	3.67%	4.32E-04	3.90%	9.87E-04	2.75%	5.22E-04	1.83%	7.36E-04	4.73%
700	1.25E-04	4.42%	1.08E-04	2.94%	2.26E-04	5.10%	1.29E-04	2.65%	1.59E-04	2.71%
1000	2.05E-05	4.26%	1.72E-05	4.32%	3.24E-05	3.45%	1.98E-05	2.95%	2.51E-05	2.82%
1200	6.64E-06	5.08%	5.13E-06	3.43%	1.15E-05	4.57%	6.56E-06	3.71%	7.87E-06	4.65%

Table 8: Neutron prompt doses calculated with SCALE and Henderson flux-to-doses factors

Prompt neutron dose (rad)	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Uranyl fluoride (4,95 %)	σ	Damp UO2 (5 %)	σ	Uranyl nitrate solution (93,2 %)	σ	U metal (93,2 %)	σ	Damp U3O8 (93,2 %)	σ
0.3	3.34E+03	0.05%	4.01E+03	0.04%	5.69E+03	0.04%	1.99E+04	0.02%	1.07E+04	0.03%
0.5	1.81E+03	0.05%	2.13E+03	0.05%	2.90E+03	0.05%	8.81E+03	0.03%	4.97E+03	0.04%
1	6.94E+02	0.07%	7.98E+02	0.06%	1.04E+03	0.07%	2.75E+03	0.04%	1.62E+03	0.05%
2	2.35E+02	0.09%	2.67E+02	0.08%	3.36E+02	0.09%	8.30E+02	0.05%	5.02E+02	0.07%
5	4.61E+01	0.13%	5.17E+01	0.12%	6.38E+01	0.14%	1.50E+02	0.08%	9.23E+01	0.11%
10	1.20E+01	0.18%	1.33E+01	0.17%	1.64E+01	0.19%	3.78E+01	0.12%	2.34E+01	0.15%
20	3.00E+00	0.26%	3.36E+00	0.24%	4.09E+00	0.27%	9.38E+00	0.17%	5.79E+00	0.22%
50	4.85E-01	0.38%	5.41E-01	0.36%	6.62E-01	0.41%	1.51E+00	0.25%	9.33E-01	0.34%
100	1.15E-01	0.50%	1.28E-01	0.47%	1.57E-01	0.51%	3.58E-01	0.33%	2.22E-01	0.44%
200	2.23E-02	0.66%	2.46E-02	0.61%	3.05E-02	0.66%	6.67E-02	0.45%	4.29E-02	0.59%
300	6.72E-03	0.71%	7.57E-03	0.67%	9.33E-03	0.72%	1.99E-02	0.53%	1.29E-02	0.68%
500	9.95E-04	0.81%	1.10E-03	0.77%	1.36E-03	0.80%	2.80E-03	0.76%	1.87E-03	0.77%
700	1.88E-04	0.76%	2.10E-04	0.75%	2.63E-04	0.74%	5.02E-04	0.71%	3.57E-04	0.75%
1000	1.92E-05	0.77%	2.16E-05	0.85%	2.66E-05	0.75%	4.86E-05	0.81%	3.64E-05	0.78%
1200	4.64E-06	0.91%	5.12E-06	0.92%	6.33E-06	0.88%	1.13E-05	0.97%	8.54E-06	0.93%

Table 9: Gamma prompt doses calculated with SCALE and Henderson flux-to-doses factors

Prompt Gamma dose (rad)	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Uranyl fluoride (4,95 %)	σ	Damp UO2 (5 %)	σ	Uranyl nitrate solution (93,2 %)	σ	U metal (93,2 %)	σ	Damp U3O8 (93,2 %)	σ
0.3	2.43E+03	0.14%	1.81E+03	0.15%	7.19E+03	0.09%	1.13E+03	0.18%	4.19E+03	0.11%
0.5	1.30E+03	0.16%	9.51E+02	0.17%	3.60E+03	0.11%	5.07E+02	0.21%	1.92E+03	0.13%
1	4.75E+02	0.20%	3.42E+02	0.21%	1.23E+03	0.14%	1.65E+02	0.26%	6.04E+02	0.17%
2	1.52E+02	0.26%	1.09E+02	0.27%	3.74E+02	0.19%	5.22E+01	0.31%	1.76E+02	0.23%
5	2.91E+01	0.38%	2.04E+01	0.40%	6.91E+01	0.29%	8.88E+00	0.47%	3.12E+01	0.34%
10	7.71E+00	0.52%	5.39E+00	0.55%	1.80E+01	0.40%	2.21E+00	0.67%	8.03E+00	0.47%
20	1.94E+00	0.70%	1.36E+00	0.74%	4.43E+00	0.55%	5.76E-01	0.89%	1.99E+00	0.65%
50	2.94E-01	1.05%	2.08E-01	1.08%	6.64E-01	0.90%	1.10E-01	1.13%	3.07E-01	0.95%
100	6.32E-02	1.40%	4.72E-02	1.40%	1.38E-01	1.16%	3.18E-02	1.20%	6.98E-02	1.21%
200	1.10E-02	1.85%	8.83E-03	1.78%	2.35E-02	1.53%	7.96E-03	1.24%	1.30E-02	1.50%
300	3.44E-03	2.15%	2.69E-03	1.99%	6.76E-03	1.78%	2.82E-03	1.17%	4.12E-03	1.65%
500	5.39E-04	2.39%	4.45E-04	2.13%	1.03E-03	2.30%	5.43E-04	1.20%	6.73E-04	2.00%
700	1.22E-04	2.84%	1.05E-04	2.40%	2.26E-04	2.71%	1.34E-04	1.20%	1.60E-04	2.03%
1000	1.88E-05	3.53%	1.66E-05	2.91%	3.38E-05	3.55%	2.09E-05	1.39%	2.48E-05	2.46%
1200	6.07E-06	3.66%	5.53E-06	3.22%	1.11E-05	3.98%	7.29E-06	1.57%	8.10E-06	2.83%

Table 10: Neutron prompt doses calculated with COG and Henderson flux-to-doses factors

Prompt neutron dose (rad)	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Uranyl fluoride (4,95 %)	σ	Damp UO2 (5 %)	σ	Uranyl nitrate solution (93,2 %)	σ	U metal (93,2 %)	σ	Damp U3O8 (93,2 %)	σ
0.3	3.31E+03	0.03%	3.98E+03	0.02%	5.64E+03	0.02%	1.98E+04	0.01%	1.06E+04	0.01%
0.5	1.80E+03	0.03%	2.12E+03	0.02%	2.87E+03	0.02%	8.74E+03	0.02%	4.94E+03	0.02%
1	6.89E+02	0.05%	7.91E+02	0.03%	1.03E+03	0.03%	2.73E+03	0.02%	1.61E+03	0.02%
2	2.34E+02	0.06%	2.64E+02	0.04%	3.33E+02	0.04%	8.25E+02	0.03%	4.98E+02	0.03%
5	4.56E+01	0.09%	5.12E+01	0.06%	6.33E+01	0.06%	1.49E+02	0.05%	9.16E+01	0.05%
10	1.19E+01	0.12%	1.32E+01	0.09%	1.62E+01	0.08%	3.76E+01	0.07%	2.32E+01	0.06%
20	2.97E+00	0.19%	3.31E+00	0.13%	4.05E+00	0.12%	9.29E+00	0.10%	5.74E+00	0.10%
50	4.80E-01	0.32%	5.35E-01	0.24%	6.52E-01	0.21%	1.50E+00	0.18%	9.21E-01	0.18%
100	1.14E-01	0.46%	1.28E-01	0.37%	1.55E-01	0.31%	3.55E-01	0.29%	2.19E-01	0.28%
200	2.20E-02	0.82%	2.44E-02	0.57%	2.97E-02	0.59%	6.66E-02	0.51%	4.18E-02	0.46%
300	6.75E-03	1.26%	7.55E-03	0.99%	9.25E-03	0.78%	1.97E-02	0.67%	1.28E-02	0.68%
500	9.89E-04	2.87%	1.10E-03	2.29%	1.32E-03	1.42%	2.83E-03	1.78%	1.82E-03	1.32%
700	1.86E-04	4.26%	2.06E-04	3.08%	2.64E-04	2.78%	5.15E-04	4.26%	3.57E-04	2.66%
1000	1.85E-05	9.31%	1.91E-05	8.88%	2.72E-05	12.71%	5.00E-05	7.42%	3.72E-05	7.63%
1200	4.40E-06	18.67%	4.97E-06	17.17%	8.34E-06	20.90%	1.13E-05	12.55%	8.41E-06	10.50%

Table 11: Gamma prompt doses calculated with COG and Henderson flux-to-doses factors

Prompt Gamma dose (rad)	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Uranyl fluoride (4,95 %)	σ	Damp UO2 (5 %)	σ	Uranyl nitrate solution (93,2 %)	σ	U metal (93,2 %)	σ	Damp U3O8 (93,2 %)	σ
0.3	2.42E+03	0.04%	1.80E+03	0.03%	7.18E+03	0.02%	1.12E+03	0.10%	4.17E+03	0.03%
0.5	1.30E+03	0.04%	9.47E+02	0.04%	3.60E+03	0.02%	5.00E+02	0.12%	1.91E+03	0.03%
1	4.75E+02	0.05%	3.41E+02	0.05%	1.23E+03	0.02%	1.63E+02	0.16%	6.00E+02	0.04%
2	1.53E+02	0.07%	1.09E+02	0.07%	3.75E+02	0.03%	5.17E+01	0.19%	1.76E+02	0.06%
5	2.90E+01	0.11%	2.04E+01	0.10%	6.93E+01	0.05%	8.80E+00	0.29%	3.11E+01	0.09%
10	7.65E+00	0.16%	5.36E+00	0.14%	1.80E+01	0.07%	2.17E+00	0.44%	7.98E+00	0.12%
20	1.92E+00	0.22%	1.36E+00	0.21%	4.45E+00	0.10%	5.72E-01	0.59%	1.99E+00	0.17%
50	2.90E-01	0.35%	2.10E-01	0.33%	6.53E-01	0.17%	1.09E-01	0.96%	3.08E-01	0.32%
100	6.36E-02	0.55%	4.68E-02	0.52%	1.38E-01	0.31%	3.11E-02	1.20%	6.91E-02	0.47%
200	1.11E-02	0.93%	8.63E-03	0.88%	2.30E-02	0.51%	7.53E-03	1.62%	1.27E-02	0.72%
300	3.26E-03	1.33%	2.58E-03	1.16%	6.70E-03	0.71%	2.71E-03	2.10%	3.96E-03	1.04%
500	5.09E-04	2.56%	4.48E-04	2.68%	9.98E-04	1.60%	5.05E-04	3.43%	6.78E-04	2.15%
700	1.21E-04	4.38%	1.04E-04	4.51%	2.10E-04	2.58%	1.28E-04	8.89%	1.60E-04	3.84%
1000	1.60E-05	10.43%	1.62E-05	7.68%	3.08E-05	6.45%	2.06E-05	11.37%	2.41E-05	6.47%
1200	5.97E-06	13.71%	5.03E-06	12.66%	1.38E-05	22.39%	6.65E-06	16.32%	9.36E-06	10.25%

Table 12: Delayed gamma doses calculated with MCNP and Henderson flux-to-doses factors after 1 s

Delayed gamma doses (after 1 s)	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Uranyl fluoride (4,95 %)	σ	Damp UO_2 (5 %)	σ	Uranyl nitrate solution (93,2 %)	σ	U metal (93,2 %)	σ	Damp U_3O_8 (93,2 %)	σ
0.3	3.96E+03	0.17%	3.02E+03	0.22%	1.39E+04	0.08%	2.13E+03	0.29%	8.22E+03	0.15%
0.5	2.10E+03	0.20%	1.57E+03	0.26%	6.93E+03	0.10%	9.26E+02	0.36%	3.75E+03	0.18%
1	7.58E+02	0.25%	5.49E+02	0.47%	2.34E+03	0.19%	2.72E+02	0.50%	1.15E+03	0.24%
2	2.39E+02	0.33%	1.71E+02	0.44%	7.08E+02	0.18%	7.49E+01	0.68%	3.28E+02	0.33%
5	4.56E+01	0.50%	3.23E+01	0.42%	1.31E+02	0.27%	1.31E+01	1.03%	5.85E+01	0.50%
10	1.20E+01	0.70%	8.52E+00	0.59%	3.43E+01	0.38%	3.33E+00	0.65%	1.51E+01	0.70%
20	2.92E+00	1.01%	2.08E+00	0.85%	8.34E+00	0.24%	8.00E-01	0.95%	3.66E+00	1.02%
50	4.22E-01	1.67%	2.99E-01	1.40%	1.20E+00	0.90%	1.15E-01	1.58%	5.22E-01	0.76%
100	8.76E-02	0.66%	6.26E-02	0.88%	2.42E-01	0.36%	2.39E-02	1.39%	1.06E-01	0.68%
200	1.46E-02	1.14%	1.05E-02	1.50%	3.84E-02	0.65%	4.05E-03	2.38%	1.80E-02	2.01%
300	4.16E-03	1.74%	2.96E-03	2.33%	1.07E-02	1.79%	1.17E-03	3.64%	4.99E-03	1.80%
500	5.78E-04	3.65%	4.21E-04	4.71%	1.42E-03	3.98%	1.68E-04	4.01%	7.27E-04	3.74%
700	1.26E-04	2.75%	9.20E-05	3.42%	2.91E-04	4.45%	3.56E-05	4.87%	1.51E-04	2.77%
1000	1.73E-05	4.11%	1.21E-05	3.75%	3.93E-05	2.48%	4.44E-06	5.28%	2.18E-05	3.85%
1200	5.67E-06	4.42%	3.52E-06	4.83%	1.21E-05	3.08%	1.39E-06	6.08%	6.23E-06	4.03%

Table 13: Delayed gamma doses calculated with SCALE and Henderson flux-to-doses factors after 1 s

Delayed gamma doses (after 1 s)	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Uranyl fluoride (4,95 %)	σ	Damp UO_2 (5 %)	σ	Uranyl nitrate solution (93,2 %)	σ	U metal (93,2 %)	σ	Damp U_3O_8 (93,2 %)	σ
0.3	3.83E+03	0.11%	2.92E+03	0.12%	1.34E+04	0.08%	2.15E+03	0.12%	7.92E+03	0.09%
0.5	2.06E+03	0.13%	1.53E+03	0.14%	6.75E+03	0.10%	9.41E+02	0.15%	3.65E+03	0.11%
1	7.49E+02	0.17%	5.45E+02	0.18%	2.30E+03	0.14%	2.77E+02	0.20%	1.13E+03	0.15%
2	2.37E+02	0.23%	1.70E+02	0.25%	6.98E+02	0.18%	7.72E+01	0.27%	3.21E+02	0.21%
5	4.52E+01	0.34%	3.21E+01	0.36%	1.29E+02	0.27%	1.35E+01	0.40%	5.69E+01	0.32%
10	1.20E+01	0.45%	8.48E+00	0.48%	3.36E+01	0.39%	3.46E+00	0.54%	1.47E+01	0.43%
20	2.95E+00	0.66%	2.08E+00	0.68%	8.19E+00	0.52%	8.35E-01	0.76%	3.57E+00	0.60%
50	4.23E-01	1.23%	3.02E-01	1.04%	1.16E+00	0.81%	1.18E-01	1.16%	5.04E-01	0.92%
100	8.54E-02	1.31%	6.18E-02	1.41%	2.35E-01	1.10%	2.38E-02	1.47%	1.03E-01	1.24%
200	1.42E-02	2.33%	1.02E-02	1.72%	3.76E-02	1.39%	3.91E-03	1.83%	1.69E-02	1.53%
300	4.11E-03	1.92%	2.95E-03	1.93%	1.05E-02	1.61%	1.13E-03	2.02%	4.93E-03	1.70%
500	6.05E-04	2.18%	4.41E-04	2.26%	1.44E-03	1.88%	1.65E-04	2.31%	7.64E-04	2.02%
700	1.29E-04	2.46%	9.16E-05	2.59%	2.94E-04	2.12%	3.56E-05	2.58%	1.60E-04	2.26%
1000	1.77E-05	2.87%	1.31E-05	2.94%	3.97E-05	2.48%	4.78E-06	3.03%	2.25E-05	2.70%
1200	5.67E-06	3.19%	3.94E-06	3.24%	1.23E-05	2.66%	1.51E-06	3.46%	6.91E-06	2.98%

Table 14: Delayed gamma doses calculated with COG and Henderson flux-to-doses factors after 1 s

Delayed gamma doses (after 1 s)	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Uranyl fluoride (4,95 %)	σ	Damp UO_2 (5 %)	σ	Uranyl nitrate solution (93,2 %)	σ	U metal (93,2 %)	σ	Damp U_3O_8 (93,2 %)	σ
0.3	3.57E+03	0.04%	2.64E+03	0.05%	1.28E+04	0.02%	1.91E+03	0.07%	6.62E+03	0.03%
0.5	1.90E+03	0.05%	1.37E+03	0.06%	6.41E+03	0.02%	8.28E+02	0.08%	3.02E+03	0.04%
1	6.86E+02	0.06%	4.83E+02	0.07%	2.17E+03	0.03%	2.42E+02	0.11%	9.27E+02	0.05%
2	2.16E+02	0.08%	1.50E+02	0.10%	6.55E+02	0.04%	6.69E+01	0.15%	2.64E+02	0.07%
5	4.13E+01	0.12%	2.82E+01	0.15%	1.21E+02	0.06%	1.18E+01	0.23%	4.68E+01	0.11%
10	1.09E+01	0.16%	7.42E+00	0.20%	3.16E+01	0.09%	3.01E+00	0.33%	1.21E+01	0.16%
20	2.67E+00	0.24%	1.83E+00	0.29%	7.73E+00	0.13%	7.22E-01	0.47%	2.95E+00	0.22%
50	3.83E-01	0.40%	2.60E-01	0.49%	1.09E+00	0.21%	1.04E-01	0.79%	4.15E-01	0.38%
100	7.96E-02	0.61%	5.31E-02	0.77%	2.19E-01	0.34%	2.10E-02	1.24%	8.75E-02	0.60%
200	1.31E-02	1.07%	9.02E-03	1.31%	3.57E-02	0.62%	3.70E-03	2.32%	1.38E-02	1.03%
300	3.70E-03	1.65%	2.68E-03	2.01%	9.63E-03	0.96%	1.02E-03	3.26%	4.17E-03	1.57%
500	4.89E-04	3.51%	3.39E-04	4.44%	1.34E-03	2.12%	1.61E-04	6.54%	6.00E-04	3.24%
700	1.12E-04	6.69%	7.49E-05	7.88%	2.66E-04	4.07%	3.46E-05	11.88%	1.45E-04	5.82%
1000	1.70E-05	15.44%	1.21E-05	16.89%	4.03E-05	9.63%	6.16E-06	26.19%	1.42E-05	15.18%
1200	4.87E-06	27.75%	1.82E-06	35.00%	8.72E-06	18.89%	2.41E-06	35.18%	6.37E-06	23.78%

Table 15: Delayed gamma doses calculated with MCNP and Henderson flux-to-doses factors after 5 s

Delayed gamma doses (after 5 s)	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Uranyl fluoride (4,95 %)	σ	Damp UO_2 (5 %)	σ	Uranyl nitrate solution (93,2 %)	σ	U metal (93,2 %)	σ	Damp U_3O_8 (93,2 %)	σ
0.3	1.35E+03	0.17%	1.04E+03	0.24%	4.82E+03	0.09%	7.33E+02	0.32%	2.85E+03	0.16%
0.5	7.19E+02	0.21%	5.41E+02	0.28%	2.40E+03	0.15%	3.18E+02	0.40%	1.30E+03	0.28%
1	2.59E+02	0.38%	1.90E+02	0.36%	8.13E+02	0.04%	9.27E+01	0.34%	4.00E+02	0.27%
2	8.12E+01	0.50%	5.87E+01	0.48%	2.45E+02	0.26%	2.55E+01	0.47%	1.14E+02	0.36%
5	1.56E+01	0.52%	1.11E+01	0.72%	4.54E+01	0.39%	4.46E+00	0.71%	2.02E+01	0.55%
10	4.10E+00	0.73%	2.89E+00	1.02%	1.18E+01	0.55%	1.14E+00	1.00%	5.25E+00	0.77%
20	9.98E-01	0.67%	7.09E-01	1.47%	2.91E+00	0.56%	2.76E-01	1.45%	1.27E+00	1.11%
50	1.45E-01	1.12%	1.02E-01	2.41%	4.17E-01	0.94%	3.95E-02	2.43%	1.79E-01	1.86%
100	3.02E-02	1.72%	2.15E-02	0.96%	8.50E-02	1.47%	8.19E-03	1.52%	3.67E-02	0.74%
200	5.05E-03	1.21%	3.67E-03	1.63%	1.33E-02	0.68%	1.40E-03	2.61%	6.11E-03	1.28%
300	1.32E-03	4.74%	1.05E-03	2.49%	3.67E-03	1.08%	4.13E-04	3.91%	1.79E-03	1.94%
500	2.05E-04	3.90%	1.56E-04	4.98%	5.02E-04	2.39%	6.03E-05	3.81%	2.57E-04	4.08%
700	4.66E-05	3.04%	3.29E-05	3.96%	1.09E-04	4.52%	1.23E-05	4.90%	5.50E-05	3.23%
1000	6.12E-06	3.58%	4.55E-06	4.91%	1.43E-05	2.78%	1.57E-06	5.80%	7.66E-06	4.95%
1200	2.00E-06	4.65%	1.41E-06	4.47%	4.59E-06	3.25%	4.78E-07	6.12%	2.51E-06	4.81%

Table 16: Delayed gamma doses calculated with SCALE and Henderson flux-to-doses factors after 5 s

Delayed gamma doses (after 5 s)	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Uranyl fluoride (4,95 %)	σ	Damp UO_2 (5 %)	σ	Uranyl nitrate solution (93,2 %)	σ	U metal (93,2 %)	σ	Damp U_3O_8 (93,2 %)	σ
0.3	1.31E+03	0.12%	1.01E+03	0.13%	4.68E+03	0.09%	7.45E+02	0.12%	2.77E+03	0.10%
0.5	7.05E+02	0.13%	5.29E+02	0.15%	2.35E+03	0.10%	3.26E+02	0.15%	1.28E+03	0.12%
1	2.58E+02	0.18%	1.88E+02	0.19%	8.00E+02	0.13%	9.62E+01	0.21%	3.95E+02	0.16%
2	8.17E+01	0.24%	5.89E+01	0.25%	2.42E+02	0.19%	2.67E+01	0.30%	1.13E+02	0.22%
5	1.57E+01	0.35%	1.11E+01	0.38%	4.51E+01	0.28%	4.67E+00	0.42%	1.99E+01	0.32%
10	4.10E+00	0.45%	2.92E+00	0.49%	1.18E+01	0.38%	1.19E+00	0.58%	5.16E+00	0.45%
20	1.01E+00	0.62%	7.24E-01	0.70%	2.86E+00	0.53%	2.91E-01	0.85%	1.25E+00	0.61%
50	1.44E-01	0.99%	1.05E-01	1.27%	4.01E-01	0.81%	4.20E-02	1.51%	1.75E-01	0.94%
100	3.05E-02	1.31%	2.16E-02	1.37%	8.18E-02	1.18%	8.53E-03	1.53%	3.56E-02	1.27%
200	4.94E-03	1.69%	3.56E-03	1.75%	1.30E-02	1.44%	1.43E-03	1.83%	5.99E-03	1.59%
300	1.45E-03	1.89%	1.00E-03	1.96%	3.55E-03	1.57%	4.17E-04	2.05%	1.74E-03	1.99%
500	2.18E-04	2.23%	1.55E-04	2.25%	4.95E-04	1.82%	6.41E-05	2.28%	2.49E-04	2.06%
700	4.59E-05	2.61%	3.48E-05	2.67%	1.01E-04	2.08%	1.32E-05	2.71%	5.48E-05	2.37%
1000	6.82E-06	3.22%	5.09E-06	3.32%	1.38E-05	2.39%	1.84E-06	3.38%	7.69E-06	2.80%
1200	2.16E-06	3.77%	1.64E-06	3.79%	4.28E-06	2.64%	5.86E-07	3.79%	2.39E-06	3.15%

Table 17: Delayed gamma doses calculated with COG and Henderson flux-to-doses factors after 5 s

Delayed gamma doses (after 5 s)	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Uranyl fluoride (4,95 %)	σ	Damp UO_2 (5 %)	σ	Uranyl nitrate solution (93,2 %)	σ	U metal (93,2 %)	σ	Damp U_3O_8 (93,2 %)	σ
0.3	1.24E+03	0.04%	9.10E+02	0.05%	4.53E+03	0.02%	6.48E+02	0.07%	2.30E+03	0.03%
0.5	6.60E+02	0.05%	4.74E+02	0.06%	2.26E+03	0.02%	2.81E+02	0.09%	1.05E+03	0.04%
1	2.38E+02	0.06%	1.67E+02	0.08%	7.65E+02	0.03%	8.21E+01	0.12%	3.22E+02	0.06%
2	7.51E+01	0.08%	5.16E+01	0.10%	2.32E+02	0.04%	2.27E+01	0.16%	9.17E+01	0.08%
5	1.43E+01	0.12%	9.70E+00	0.15%	4.29E+01	0.06%	3.96E+00	0.24%	1.63E+01	0.11%
10	3.79E+00	0.17%	2.54E+00	0.21%	1.11E+01	0.09%	1.01E+00	0.34%	4.20E+00	0.16%
20	9.31E-01	0.24%	6.29E-01	0.30%	2.71E+00	0.13%	2.46E-01	0.48%	1.02E+00	0.23%
50	1.34E-01	0.40%	8.99E-02	0.50%	3.88E-01	0.22%	3.53E-02	0.80%	1.44E-01	0.39%
100	2.75E-02	0.63%	1.87E-02	0.77%	7.82E-02	0.34%	6.98E-03	1.28%	2.99E-02	0.60%
200	4.63E-03	1.10%	2.99E-03	1.35%	1.24E-02	0.62%	1.22E-03	2.49%	5.06E-03	1.38%
300	1.34E-03	1.64%	9.22E-04	2.14%	3.46E-03	0.98%	3.64E-04	3.36%	1.45E-03	1.78%
500	1.88E-04	3.49%	1.40E-04	4.25%	4.93E-04	2.16%	5.13E-05	6.83%	2.19E-04	3.34%
700	4.00E-05	6.31%	3.43E-05	9.38%	9.44E-05	4.35%	1.77E-05	16.84%	4.91E-05	6.22%
1000	4.85E-06	16.20%	5.92E-06	17.21%	1.44E-05	9.58%	1.93E-06	25.71%	7.74E-06	11.85%
1200	2.92E-06	20.04%	1.26E-06	32.40%	4.91E-06	15.66%	4.61E-07	39.69%	1.70E-06	24.19%

Table 18: Delayed gamma doses calculated with MCNP and Henderson flux-to-doses factors after 10 s

Delayed gamma doses (after 10 s)	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Uranyl fluoride (4,95 %)	σ	Damp UO_2 (5 %)	σ	Uranyl nitrate solution (93,2 %)	σ	U metal (93,2 %)	σ	Damp U_3O_8 (93,2 %)	σ
0.3	7.41E+02	0.18%	5.66E+02	0.24%	2.63E+03	0.09%	3.97E+02	0.32%	1.56E+03	0.23%
0.5	3.94E+02	0.21%	2.95E+02	0.28%	1.31E+03	0.15%	1.72E+02	0.40%	7.11E+02	0.28%
1	1.42E+02	0.38%	1.04E+02	0.37%	4.42E+02	0.14%	5.06E+01	0.55%	2.18E+02	0.27%
2	4.45E+01	0.50%	3.20E+01	0.49%	1.33E+02	0.27%	1.39E+01	0.75%	6.21E+01	0.36%
5	8.53E+00	0.33%	6.02E+00	0.73%	2.47E+01	0.40%	2.42E+00	1.14%	1.11E+01	0.55%
10	2.24E+00	0.74%	1.57E+00	1.03%	6.46E+00	0.18%	6.22E-01	0.72%	2.86E+00	0.35%
20	5.47E-01	0.68%	3.89E-01	1.48%	1.58E+00	0.57%	1.50E-01	1.04%	6.96E-01	1.12%
50	7.96E-02	1.12%	5.54E-02	2.45%	2.25E-01	0.43%	2.16E-02	1.74%	9.85E-02	0.84%
100	1.66E-02	0.70%	1.17E-02	0.97%	4.58E-02	0.38%	4.43E-03	1.54%	2.00E-02	1.30%
200	2.75E-03	1.22%	1.95E-03	1.66%	7.37E-03	1.19%	7.44E-04	2.68%	3.29E-03	1.30%
300	7.84E-04	1.87%	5.58E-04	2.53%	2.01E-03	1.09%	2.19E-04	3.99%	9.58E-04	2.03%
500	1.17E-04	3.80%	8.15E-05	5.13%	2.76E-04	2.42%	3.23E-05	4.85%	1.46E-04	4.03%
700	2.50E-05	2.99%	1.69E-05	3.73%	5.99E-05	4.58%	6.45E-06	5.63%	3.01E-05	3.15%
1000	3.34E-06	3.78%	2.40E-06	5.19%	8.09E-06	3.07%	9.28E-07	5.98%	4.18E-06	4.34%
1200	1.11E-06	4.44%	7.91E-07	5.20%	2.48E-06	3.35%	2.99E-07	6.71%	1.27E-06	4.41%

Table 19: Delayed gamma doses calculated with SCALE and Henderson flux-to-doses factors after 10 s

Delayed gamma doses (after 10 s)	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Uranyl fluoride (4,95 %)	σ	Damp UO_2 (5 %)	σ	Uranyl nitrate solution (93,2 %)	σ	U metal (93,2 %)	σ	Damp U_3O_8 (93,2 %)	σ
0.3	7.20E+02	0.12%	5.47E+02	0.12%	2.55E+03	0.08%	4.03E+02	0.13%	1.52E+03	0.10%
0.5	3.87E+02	0.13%	2.88E+02	0.14%	1.28E+03	0.10%	1.76E+02	0.17%	6.97E+02	0.12%
1	1.42E+02	0.18%	1.02E+02	0.19%	4.36E+02	0.14%	5.20E+01	0.24%	2.16E+02	0.16%
2	4.49E+01	0.25%	3.18E+01	0.25%	1.32E+02	0.20%	1.44E+01	0.36%	6.15E+01	0.22%
5	8.60E+00	0.34%	6.05E+00	0.51%	2.44E+01	0.27%	2.51E+00	0.40%	1.10E+01	0.32%
10	2.27E+00	0.45%	1.59E+00	0.49%	6.40E+00	0.38%	6.55E-01	1.36%	2.82E+00	0.44%
20	5.54E-01	0.62%	3.91E-01	0.67%	1.56E+00	0.53%	1.56E-01	0.77%	6.88E-01	0.60%
50	7.92E-02	0.97%	5.61E-02	1.06%	2.22E-01	0.88%	2.22E-02	1.12%	9.71E-02	0.93%
100	1.66E-02	1.30%	1.15E-02	1.56%	4.40E-02	1.10%	4.68E-03	1.69%	1.99E-02	1.23%
200	2.83E-03	1.72%	1.91E-03	1.77%	7.27E-03	1.47%	7.73E-04	1.82%	3.34E-03	1.57%
300	8.20E-04	1.93%	5.56E-04	1.99%	2.00E-03	1.80%	2.21E-04	2.03%	9.59E-04	1.78%
500	1.21E-04	2.42%	8.74E-05	2.28%	2.75E-04	1.86%	3.33E-05	2.44%	1.45E-04	2.02%
700	2.65E-05	2.63%	1.87E-05	2.63%	5.88E-05	2.13%	7.18E-06	2.84%	3.03E-05	2.31%
1000	3.74E-06	3.26%	2.66E-06	3.05%	8.23E-06	2.53%	1.04E-06	3.62%	4.27E-06	2.77%
1200	1.16E-06	3.82%	8.35E-07	3.29%	2.64E-06	2.80%	3.38E-07	4.28%	1.41E-06	3.15%

Table 20: Delayed gamma doses calculated with COG and Henderson flux-to-doses factors after 10 s

Delayed gamma doses (after 10 s)	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Uranyl fluoride (4,95 %)	σ	Damp UO_2 (5 %)	σ	Uranyl nitrate solution (93,2 %)	σ	U metal (93,2 %)	σ	Damp U_3O_8 (93,2 %)	σ
0.3	6.87E+02	0.04%	5.03E+02	0.05%	2.50E+03	0.02%	3.51E+02	0.07%	1.28E+03	0.03%
0.5	3.66E+02	0.05%	2.62E+02	0.06%	1.25E+03	0.02%	1.52E+02	0.09%	5.82E+02	0.04%
1	1.32E+02	0.06%	9.22E+01	0.07%	4.21E+02	0.03%	4.45E+01	0.12%	1.79E+02	0.06%
2	4.15E+01	0.08%	2.86E+01	0.10%	1.27E+02	0.04%	1.24E+01	0.16%	5.09E+01	0.07%
5	7.93E+00	0.12%	5.37E+00	0.15%	2.36E+01	0.06%	2.16E+00	0.24%	9.02E+00	0.11%
10	2.11E+00	0.16%	1.42E+00	0.20%	6.13E+00	0.09%	5.57E-01	0.34%	2.33E+00	0.16%
20	5.17E-01	0.24%	3.50E-01	0.31%	1.50E+00	0.13%	1.34E-01	0.48%	5.68E-01	0.23%
50	7.41E-02	0.41%	5.01E-02	0.49%	2.13E-01	0.22%	1.90E-02	0.82%	8.02E-02	0.38%
100	1.53E-02	0.62%	1.04E-02	0.76%	4.33E-02	0.35%	4.06E-03	1.25%	1.67E-02	0.59%
200	2.56E-03	1.06%	1.70E-03	1.41%	6.92E-03	0.64%	6.26E-04	2.23%	2.78E-03	1.03%
300	7.18E-04	1.66%	4.97E-04	2.08%	1.90E-03	0.99%	1.75E-04	3.45%	7.80E-04	1.59%
500	1.08E-04	3.45%	7.54E-05	4.10%	2.75E-04	2.09%	2.90E-05	7.53%	1.15E-04	3.21%
700	2.17E-05	6.79%	1.87E-05	7.39%	4.50E-05	4.54%	5.27E-06	12.82%	2.45E-05	6.01%
1000	2.61E-06	16.05%	2.82E-06	18.20%	6.24E-06	10.42%	1.82E-06	26.35%	3.02E-06	15.14%
1200	1.24E-06	24.62%	8.66E-07	26.81%	1.78E-06	19.37%	3.28E-08	50.23%	1.19E-06	23.42%

Table 21: Delayed gamma doses calculated with MCNP and Henderson flux-to-doses factors after 1 min

Delayed gamma doses (after 1 min)	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Uranyl fluoride (4,95 %)	σ	Damp UO_2 (5 %)	σ	Uranyl nitrate solution (93,2 %)	σ	U metal (93,2 %)	σ	Damp U_3O_8 (93,2 %)	σ
0.3	1.34E+02	0.17%	1.01E+02	0.23%	4.77E+02	0.08%	7.00E+01	0.31%	2.81E+02	0.15%
0.5	7.15E+01	0.20%	5.26E+01	0.27%	2.38E+02	0.14%	3.04E+01	0.38%	1.28E+02	0.19%
1	2.58E+01	0.26%	1.85E+01	0.35%	8.04E+01	0.13%	8.94E+00	0.52%	3.93E+01	0.16%
2	8.12E+00	0.34%	5.71E+00	0.66%	2.43E+01	0.18%	2.46E+00	0.71%	1.12E+01	0.34%
5	1.55E+00	0.50%	1.08E+00	0.70%	4.51E+00	0.27%	4.29E-01	1.08%	1.99E+00	0.33%
10	4.08E-01	0.70%	2.81E-01	0.98%	1.18E+00	0.38%	1.09E-01	1.52%	5.13E-01	0.46%
20	9.95E-02	1.02%	6.92E-02	1.42%	2.86E-01	0.24%	2.64E-02	0.99%	1.24E-01	0.67%
50	1.44E-02	1.68%	9.87E-03	2.35%	4.10E-02	0.91%	3.77E-03	1.66%	1.76E-02	1.12%
100	2.99E-03	0.67%	2.11E-03	1.13%	8.27E-03	0.37%	7.82E-04	2.54%	3.55E-03	1.73%
200	4.91E-04	1.16%	3.43E-04	1.60%	1.31E-03	0.65%	1.33E-04	2.49%	5.74E-04	2.99%
300	1.38E-04	1.78%	9.69E-05	2.46%	3.60E-04	1.04%	3.85E-05	3.73%	1.70E-04	1.85%
500	2.01E-05	4.50%	1.41E-05	5.07%	4.95E-05	2.26%	5.54E-06	3.54%	2.47E-05	3.89%
700	4.18E-06	2.90%	2.93E-06	3.35%	1.00E-05	4.42%	1.14E-06	3.95%	4.98E-06	3.06%
1000	5.53E-07	3.32%	3.94E-07	4.33%	1.28E-06	3.12%	1.45E-07	5.26%	7.08E-07	3.69%
1200	1.70E-07	3.98%	1.30E-07	6.16%	4.07E-07	2.70%	4.20E-08	5.81%	2.05E-07	4.18%

Table 22: Delayed gamma doses calculated with SCALE and Henderson flux-to-doses factors after 1 min

Delayed gamma doses (after 1 min)	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Uranyl fluoride (4,95 %)	σ	Damp UO_2 (5 %)	σ	Uranyl nitrate solution (93,2 %)	σ	U metal (93,2 %)	σ	Damp U_3O_8 (93,2 %)	σ
0.3	1.31E+02	0.11%	9.82E+01	0.12%	4.63E+02	0.08%	7.16E+01	0.12%	2.74E+02	0.10%
0.5	7.05E+01	0.13%	5.16E+01	0.14%	2.33E+02	0.10%	3.13E+01	0.15%	1.26E+02	0.12%
1	2.57E+01	0.17%	1.84E+01	0.19%	7.92E+01	0.13%	9.23E+00	0.20%	3.90E+01	0.16%
2	8.14E+00	0.23%	5.72E+00	0.25%	2.39E+01	0.18%	2.56E+00	0.28%	1.11E+01	0.22%
5	1.55E+00	0.34%	1.08E+00	0.38%	4.44E+00	0.27%	4.49E-01	0.41%	1.98E+00	0.32%
10	4.10E-01	0.49%	2.84E-01	0.51%	1.15E+00	0.36%	1.16E-01	0.55%	5.11E-01	0.42%
20	1.01E-01	0.64%	6.97E-02	0.70%	2.81E-01	0.50%	2.84E-02	0.75%	1.25E-01	0.61%
50	1.45E-02	1.23%	9.89E-03	1.14%	3.98E-02	0.80%	3.94E-03	1.14%	1.77E-02	0.97%
100	2.94E-03	1.36%	2.03E-03	1.40%	8.20E-03	1.21%	8.26E-04	1.50%	3.59E-03	1.33%
200	4.95E-04	1.66%	3.42E-04	1.85%	1.29E-03	1.49%	1.33E-04	1.82%	5.86E-04	1.65%
300	1.41E-04	1.88%	9.60E-05	1.98%	3.58E-04	1.58%	3.83E-05	2.01%	1.64E-04	1.85%
500	2.12E-05	2.24%	1.43E-05	2.31%	4.95E-05	1.83%	5.72E-06	2.32%	2.43E-05	1.99%
700	4.43E-06	2.43%	2.93E-06	2.55%	9.92E-06	2.05%	1.14E-06	2.67%	5.11E-06	2.31%
1000	6.03E-07	2.92%	4.20E-07	3.02%	1.30E-06	2.45%	1.45E-07	3.10%	6.83E-07	2.77%
1200	1.88E-07	3.29%	1.32E-07	3.46%	4.04E-07	2.70%	4.51E-08	3.50%	2.16E-07	3.18%

Table 23: Delayed gamma doses calculated with COG and Henderson flux-to-doses factors after 1 min

Delayed gamma doses (after 1 min)	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Uranyl fluoride (4,95 %)	σ	Damp UO_2 (5 %)	σ	Uranyl nitrate solution (93,2 %)	σ	U metal (93,2 %)	σ	Damp U_3O_8 (93,2 %)	σ
0.3	1.27E+02	0.04%	9.32E+01	0.05%	4.57E+02	0.02%	6.35E+01	0.07%	2.37E+02	0.03%
0.5	6.79E+01	0.04%	4.84E+01	0.05%	2.29E+02	0.02%	2.75E+01	0.08%	1.08E+02	0.04%
1	2.45E+01	0.06%	1.71E+01	0.07%	7.72E+01	0.03%	8.05E+00	0.11%	3.32E+01	0.05%
2	7.71E+00	0.08%	5.30E+00	0.09%	2.34E+01	0.04%	2.23E+00	0.15%	9.45E+00	0.07%
5	1.47E+00	0.11%	9.94E-01	0.14%	4.32E+00	0.06%	3.90E-01	0.23%	1.68E+00	0.11%
10	3.87E-01	0.16%	2.62E-01	0.19%	1.12E+00	0.09%	1.00E-01	0.32%	4.32E-01	0.15%
20	9.56E-02	0.23%	6.42E-02	0.28%	2.74E-01	0.12%	2.43E-02	0.46%	1.05E-01	0.22%
50	1.36E-02	0.37%	9.13E-03	0.47%	3.88E-02	0.22%	3.42E-03	0.83%	1.49E-02	0.36%
100	2.78E-03	0.59%	1.91E-03	0.72%	7.96E-03	0.33%	7.15E-04	1.23%	3.07E-03	0.57%
200	4.71E-04	1.12%	3.13E-04	1.24%	1.27E-03	0.65%	1.18E-04	2.06%	4.94E-04	0.99%
300	1.29E-04	1.59%	9.06E-05	1.94%	3.40E-04	0.94%	3.42E-05	3.23%	1.46E-04	1.48%
500	1.94E-05	3.29%	1.37E-05	3.78%	4.80E-05	2.03%	5.08E-06	6.52%	2.11E-05	3.10%
700	4.45E-06	5.77%	2.66E-06	7.54%	1.05E-05	3.90%	1.10E-06	11.93%	4.56E-06	5.80%
1000	4.52E-07	15.92%	2.77E-07	19.25%	1.04E-06	10.82%	8.56E-08	26.60%	6.68E-07	13.05%
1200	1.70E-07	22.63%	2.90E-07	21.17%	4.48E-07	15.76%	3.88E-08	43.77%	2.52E-07	21.67%

Table 24: Delayed gamma doses calculated with MCNP and Henderson flux-to-doses factors after 5 min

Delayed gamma doses (after 5 min)	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Uranyl fluoride (4,95 %)	σ	Damp UO_2 (5 %)	σ	Uranyl nitrate solution (93,2 %)	σ	U metal (93,2 %)	σ	Damp U_3O_8 (93,2 %)	σ
0.3	2.15E+01	0.17%	1.61E+01	0.25%	7.94E+01	0.08%	1.12E+01	0.31%	4.51E+01	0.15%
0.5	1.14E+01	0.20%	8.39E+00	0.30%	3.96E+01	0.09%	4.84E+00	0.38%	2.06E+01	0.19%
1	4.13E+00	0.26%	2.95E+00	0.39%	1.34E+01	0.17%	1.42E+00	0.74%	6.29E+00	0.36%
2	1.30E+00	0.48%	9.13E-01	0.51%	4.05E+00	0.16%	3.92E-01	0.71%	1.80E+00	0.34%
5	2.48E-01	0.32%	1.71E-01	0.77%	7.53E-01	0.25%	6.81E-02	1.09%	3.22E-01	0.73%
10	6.52E-02	0.71%	4.45E-02	1.08%	1.96E-01	0.35%	1.73E-02	1.54%	8.35E-02	0.72%
20	1.59E-02	0.65%	1.10E-02	1.56%	4.77E-02	0.50%	4.20E-03	0.99%	2.00E-02	0.47%
50	2.28E-03	1.08%	1.60E-03	2.57%	6.75E-03	0.38%	6.05E-04	3.73%	2.85E-03	0.79%
100	4.74E-04	0.68%	3.26E-04	1.03%	1.36E-03	0.34%	1.22E-04	1.47%	5.81E-04	0.70%
200	7.67E-05	1.18%	5.21E-05	6.93%	2.14E-04	2.34%	2.03E-05	2.56%	9.34E-05	1.22%
300	2.17E-05	1.81%	1.56E-05	2.70%	5.79E-05	3.87%	5.74E-06	3.89%	2.70E-05	1.88%
500	3.00E-06	3.79%	2.08E-06	5.66%	7.74E-06	2.18%	8.18E-07	4.76%	3.87E-06	4.00%
700	6.01E-07	2.75%	4.23E-07	3.99%	1.54E-06	4.34%	1.62E-07	4.80%	7.68E-07	2.93%
1000	8.04E-08	3.95%	5.98E-08	6.66%	1.96E-07	2.86%	2.08E-08	5.91%	1.02E-07	4.16%
1200	2.57E-08	3.85%	1.68E-08	4.86%	5.72E-08	3.00%	6.21E-09	5.69%	3.13E-08	4.89%

Table 25: Delayed gamma doses calculated with SCALE and Henderson flux-to-doses factors after 5 min

Delayed gamma doses (after 5 min)	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Uranyl fluoride (4,95 %)	σ	Damp UO_2 (5 %)	σ	Uranyl nitrate solution (93,2 %)	σ	U metal (93,2 %)	σ	Damp U_3O_8 (93,2 %)	σ
0.3	2.10E+01	0.12%	1.56E+01	0.13%	7.75E+01	0.08%	1.15E+01	0.13%	4.41E+01	0.10%
0.5	1.13E+01	0.14%	8.23E+00	0.15%	3.90E+01	0.10%	5.04E+00	0.15%	2.03E+01	0.12%
1	4.13E+00	0.18%	2.92E+00	0.19%	1.32E+01	0.13%	1.49E+00	0.21%	6.28E+00	0.16%
2	1.31E+00	0.24%	9.11E-01	0.26%	4.02E+00	0.19%	4.13E-01	0.29%	1.80E+00	0.23%
5	2.50E-01	0.35%	1.73E-01	0.40%	7.47E-01	0.28%	7.22E-02	0.45%	3.20E-01	0.34%
10	6.64E-02	0.49%	4.55E-02	0.53%	1.95E-01	0.38%	1.85E-02	0.57%	8.28E-02	0.47%
20	1.61E-02	0.63%	1.12E-02	0.75%	4.71E-02	0.58%	4.46E-03	0.80%	2.00E-02	0.64%
50	2.27E-03	0.98%	1.61E-03	1.17%	6.60E-03	0.86%	6.38E-04	1.34%	2.82E-03	1.01%
100	4.78E-04	1.34%	3.28E-04	1.49%	1.34E-03	1.17%	1.29E-04	1.60%	5.86E-04	1.40%
200	7.86E-05	1.69%	5.46E-05	1.89%	2.14E-04	1.52%	2.12E-05	1.87%	9.33E-05	1.66%
300	2.20E-05	1.85%	1.55E-05	2.04%	5.76E-05	1.59%	5.97E-06	2.00%	2.67E-05	1.79%
500	3.00E-06	2.16%	2.19E-06	2.28%	7.68E-06	1.81%	8.28E-07	2.31%	3.90E-06	2.03%
700	6.15E-07	2.44%	4.49E-07	2.58%	1.49E-06	2.03%	1.64E-07	2.69%	7.86E-07	2.46%
1000	8.24E-08	2.86%	5.95E-08	2.98%	1.92E-07	2.45%	2.21E-08	3.22%	1.08E-07	2.87%
1200	2.50E-08	3.15%	1.81E-08	3.29%	5.74E-08	2.79%	7.04E-09	3.58%	3.15E-08	3.27%

Table 26: Delayed gamma doses calculated with COG and Henderson flux-to-doses factors after 5 min

Delayed gamma doses (after 5 min)	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Uranyl fluoride (4,95 %)	σ	Damp UO_2 (5 %)	σ	Uranyl nitrate solution (93,2 %)	σ	U metal (93,2 %)	σ	Damp U_3O_8 (93,2 %)	σ
0.3	2.41E+01	0.08%	1.75E+01	0.04%	9.02E+01	0.02%	1.20E+01	0.06%	4.52E+01	0.03%
0.5	1.28E+01	0.09%	9.11E+00	0.05%	4.51E+01	0.02%	5.22E+00	0.08%	2.06E+01	0.04%
1	4.63E+00	0.11%	3.21E+00	0.07%	1.52E+01	0.03%	1.53E+00	0.11%	6.31E+00	0.05%
2	1.46E+00	0.14%	9.95E-01	0.09%	4.61E+00	0.04%	4.24E-01	0.14%	1.80E+00	0.07%
5	2.78E-01	0.23%	1.88E-01	0.13%	8.53E-01	0.06%	7.41E-02	0.22%	3.21E-01	0.10%
10	7.32E-02	0.30%	4.95E-02	0.18%	2.22E-01	0.08%	1.90E-02	0.30%	8.27E-02	0.14%
20	1.81E-02	0.41%	1.22E-02	0.00%	5.40E-02	0.12%	4.58E-03	0.44%	2.00E-02	0.20%
50	2.58E-03	0.68%	1.71E-03	0.45%	7.69E-03	0.20%	6.55E-04	0.75%	2.84E-03	0.35%
100	5.19E-04	1.11%	3.58E-04	0.72%	1.55E-03	0.30%	1.32E-04	1.15%	5.84E-04	0.53%
200	8.43E-05	1.85%	5.90E-05	1.18%	2.44E-04	0.55%	2.18E-05	2.03%	9.28E-05	0.94%
300	2.41E-05	2.84%	1.64E-05	1.85%	6.67E-05	0.88%	6.27E-06	3.05%	2.64E-05	1.45%
500	3.56E-06	6.42%	2.11E-06	4.00%	8.91E-06	1.92%	9.11E-07	6.33%	3.92E-06	3.02%
700	5.53E-07	12.58%	4.52E-07	7.52%	1.74E-06	3.90%	1.75E-07	12.64%	7.91E-07	5.80%
1000	9.37E-08	27.99%	5.47E-08	20.98%	1.93E-07	10.05%	6.20E-09	30.47%	8.01E-08	16.04%
1200	4.41E-08	40.42%	5.11E-08	20.77%	6.82E-08	16.09%	1.60E-09	47.59%	1.89E-08	29.56%

Table 27: Delayed gamma doses calculated with MCNP and Henderson flux-to-doses factors after 10 min

Delayed gamma doses (after 10 min)	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Uranyl fluoride (4,95 %)	σ	Damp UO_2 (5 %)	σ	Uranyl nitrate solution (93,2 %)	σ	U metal (93,2 %)	σ	Damp U_3O_8 (93,2 %)	σ
0.3	9.93E+00	0.18%	7.38E+00	0.27%	3.82E+01	0.08%	5.17E+00	0.31%	2.09E+01	0.15%
0.5	5.28E+00	0.21%	3.85E+00	0.32%	1.90E+01	0.13%	2.24E+00	0.39%	9.54E+00	0.19%
1	1.91E+00	0.27%	1.35E+00	0.42%	6.45E+00	0.08%	6.59E-01	0.53%	2.93E+00	0.25%
2	6.01E-01	0.36%	4.18E-01	0.56%	1.95E+00	0.23%	1.81E-01	0.72%	8.36E-01	0.22%
5	1.15E-01	0.53%	7.83E-02	0.84%	3.64E-01	0.24%	3.16E-02	1.10%	1.49E-01	0.33%
10	3.02E-02	0.75%	2.05E-02	1.18%	9.45E-02	0.34%	8.07E-03	1.55%	3.84E-02	0.46%
20	7.34E-03	1.08%	5.05E-03	1.69%	2.30E-02	0.49%	1.97E-03	2.25%	9.24E-03	0.67%
50	1.05E-03	1.80%	7.18E-04	2.80%	3.25E-03	0.83%	2.87E-04	3.74%	1.33E-03	1.76%
100	2.16E-04	0.88%	1.50E-04	1.11%	6.51E-04	0.33%	5.65E-05	1.48%	2.66E-04	0.71%
200	3.50E-05	1.24%	2.44E-05	2.34%	1.01E-04	0.59%	9.23E-06	2.57%	4.21E-05	1.24%
300	9.42E-06	1.94%	6.58E-06	3.02%	2.70E-05	0.95%	2.70E-06	3.84%	1.19E-05	1.91%
500	1.28E-06	4.06%	8.38E-07	6.25%	3.46E-06	2.17%	3.57E-07	3.87%	1.63E-06	4.07%
700	2.43E-07	2.81%	1.71E-07	3.79%	6.22E-07	4.53%	6.46E-08	4.11%	3.01E-07	2.69%
1000	2.91E-08	3.71%	2.05E-08	5.50%	7.25E-08	2.91%	8.30E-09	5.25%	3.76E-08	3.87%
1200	8.84E-09	5.31%	5.45E-09	5.23%	2.05E-08	2.97%	2.32E-09	6.60%	9.93E-09	3.79%

Table 28: Delayed gamma doses calculated with SCALE and Henderson flux-to-doses factors after 10 min

Delayed gamma doses (after 10 min)	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Uranyl fluoride (4,95 %)	σ	Damp UO_2 (5 %)	σ	Uranyl nitrate solution (93,2 %)	σ	U metal (93,2 %)	σ	Damp U_3O_8 (93,2 %)	σ
0.3	9.75E+00	0.12%	7.23E+00	0.13%	3.73E+01	0.08%	5.38E+00	0.13%	2.06E+01	0.10%
0.5	5.24E+00	0.14%	3.81E+00	0.15%	1.88E+01	0.10%	2.36E+00	0.16%	9.47E+00	0.12%
1	1.91E+00	0.18%	1.36E+00	0.20%	6.40E+00	0.14%	6.96E-01	0.22%	2.93E+00	0.16%
2	6.09E-01	0.24%	4.25E-01	0.27%	1.94E+00	0.19%	1.94E-01	0.30%	8.39E-01	0.23%
5	1.17E-01	0.36%	8.01E-02	0.39%	3.62E-01	0.30%	3.37E-02	0.43%	1.50E-01	0.33%
10	3.08E-02	0.49%	2.10E-02	0.50%	9.40E-02	0.37%	8.63E-03	0.61%	3.88E-02	0.45%
20	7.57E-03	0.68%	5.20E-03	0.74%	2.27E-02	0.52%	2.08E-03	0.92%	9.43E-03	0.64%
50	1.08E-03	1.03%	7.33E-04	1.08%	3.20E-03	0.84%	2.91E-04	1.18%	1.31E-03	0.97%
100	2.18E-04	1.38%	1.50E-04	1.45%	6.43E-04	1.23%	5.97E-05	1.52%	2.68E-04	1.55%
200	3.47E-05	1.72%	2.36E-05	1.91%	1.00E-04	1.53%	9.57E-06	1.83%	4.39E-05	1.62%
300	9.53E-06	1.86%	6.59E-06	2.00%	2.67E-05	1.62%	2.60E-06	2.01%	1.20E-05	1.77%
500	1.27E-06	2.14%	9.25E-07	2.26%	3.39E-06	1.77%	3.60E-07	2.21%	1.59E-06	1.99%
700	2.48E-07	2.45%	1.84E-07	2.65%	6.20E-07	2.00%	6.98E-08	2.51%	3.01E-07	2.18%
1000	2.98E-08	2.92%	2.28E-08	3.00%	7.17E-08	2.37%	8.38E-09	2.98%	3.68E-08	2.57%
1200	8.79E-09	3.34%	6.25E-09	3.29%	2.04E-08	2.68%	2.34E-09	3.10%	1.06E-08	2.95%

Table 29: Delayed gamma doses calculated with COG and Henderson flux-to-doses factors after 10 min

Delayed gamma doses (after 10 min)	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Uranyl fluoride (4,95 %)	σ	Damp UO2 (5 %)	σ	Uranyl nitrate solution (93,2 %)	σ	U metal (93,2 %)	σ	Damp U3O8 (93,2 %)	σ
0.3	1.03E+01	0.10%	7.36E+00	0.05%	4.02E+01	0.02%	5.17E+00	0.06%	1.93E+01	0.03%
0.5	5.47E+00	0.11%	3.83E+00	0.05%	2.01E+01	0.02%	2.24E+00	0.08%	8.80E+00	0.04%
1	1.98E+00	0.14%	1.35E+00	0.07%	6.79E+00	0.03%	6.57E-01	0.11%	2.71E+00	0.05%
2	6.23E-01	0.20%	4.19E-01	0.09%	2.06E+00	0.04%	1.83E-01	0.15%	7.71E-01	0.07%
5	1.18E-01	0.24%	7.93E-02	0.13%	3.82E-01	0.06%	3.19E-02	0.22%	1.38E-01	0.10%
10	3.13E-02	0.30%	2.09E-02	0.19%	9.94E-02	0.08%	8.15E-03	0.31%	3.54E-02	0.14%
20	7.67E-03	0.46%	5.09E-03	0.27%	2.42E-02	0.11%	1.97E-03	0.45%	8.58E-03	0.21%
50	1.08E-03	0.73%	7.21E-04	0.45%	3.38E-03	0.19%	2.78E-04	0.75%	1.21E-03	0.35%
100	2.17E-04	1.08%	1.46E-04	0.70%	6.83E-04	0.30%	5.70E-05	1.15%	2.49E-04	0.55%
200	3.51E-05	1.90%	2.41E-05	1.22%	1.06E-04	0.56%	9.04E-06	2.02%	4.05E-05	0.94%
300	1.02E-05	2.87%	6.32E-06	1.94%	2.79E-05	0.89%	2.65E-06	3.17%	1.10E-05	1.52%
500	1.29E-06	6.52%	8.98E-07	4.19%	3.51E-06	2.10%	3.64E-07	6.64%	1.47E-06	3.24%
700	2.87E-07	12.39%	2.00E-07	7.78%	6.04E-07	4.17%	7.99E-08	12.03%	2.79E-07	6.53%
1000	3.54E-08	29.09%	1.82E-08	21.17%	7.66E-08	9.77%	4.35E-09	29.83%	3.69E-08	16.36%
1200	1.18E-08	50.69%	6.43E-09	33.37%	2.44E-08	16.71%	1.53E-09	59.45%	1.69E-08	20.60%

Table 30: Delayed gamma doses calculated with MCNP and Henderson flux-to-doses factors after 50 min

Delayed gamma doses (after 50 min)	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Uranyl fluoride (4,95 %)	σ	Damp UO_2 (5 %)	σ	Uranyl nitrate solution (93,2 %)	σ	U metal (93,2 %)	σ	Damp U_3O_8 (93,2 %)	σ
0.3	2.13E+00	0.12%	1.57E+00	0.28%	8.28E+00	0.05%	1.10E+00	0.30%	4.46E+00	0.09%
0.5	1.13E+00	0.14%	8.20E-01	0.33%	4.14E+00	0.06%	4.78E-01	0.37%	2.03E+00	0.11%
1	4.08E-01	0.39%	2.88E-01	0.43%	1.40E+00	0.07%	1.41E-01	0.50%	6.27E-01	0.15%
2	1.29E-01	0.52%	8.91E-02	0.57%	4.24E-01	0.10%	3.89E-02	0.68%	1.78E-01	0.47%
5	2.48E-02	0.34%	1.67E-02	0.86%	7.90E-02	0.23%	6.76E-03	1.04%	3.20E-02	0.50%
10	6.49E-03	0.76%	4.36E-03	1.21%	2.05E-02	0.15%	1.74E-03	0.65%	8.29E-03	0.70%
20	1.59E-03	0.70%	1.08E-03	1.72%	4.98E-03	0.48%	4.22E-04	2.12%	1.98E-03	0.45%
50	2.24E-04	1.16%	1.52E-04	1.29%	7.02E-04	0.36%	6.09E-05	3.52%	2.80E-04	0.76%
100	4.63E-05	0.73%	3.16E-05	1.13%	1.41E-04	0.32%	1.21E-05	2.43%	5.64E-05	0.67%
200	7.34E-06	1.26%	5.03E-06	2.41%	2.15E-05	0.57%	1.97E-06	2.41%	8.86E-06	1.17%
300	2.05E-06	4.72%	1.34E-06	3.04%	5.71E-06	0.91%	5.32E-07	3.72%	2.45E-06	1.81%
500	2.63E-07	4.22%	1.82E-07	6.38%	6.94E-07	2.10%	6.93E-08	4.03%	3.23E-07	0.09%
700	4.77E-08	2.36%	3.23E-08	3.45%	1.20E-07	4.38%	1.30E-08	4.14%	5.89E-08	2.30%
1000	5.07E-09	2.87%	3.55E-09	3.62%	1.23E-08	1.76%	1.40E-09	3.95%	6.47E-09	2.91%
1200	1.41E-09	2.83%	9.89E-10	4.56%	3.24E-09	2.14%	3.61E-10	4.43%	1.73E-09	3.86%

Table 31: Delayed gamma doses calculated with SCALE and Henderson flux-to-doses factors after 50 min

Delayed gamma doses (after 50 min)	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Uranyl fluoride (4,95 %)	σ	Damp UO_2 (5 %)	σ	Uranyl nitrate solution (93,2 %)	σ	U metal (93,2 %)	σ	Damp U_3O_8 (93,2 %)	σ
0.3	2.11E+00	0.12%	1.55E+00	0.13%	8.16E+00	0.09%	1.14E+00	0.12%	4.40E+00	0.10%
0.5	1.13E+00	0.14%	8.13E-01	0.15%	4.11E+00	0.12%	5.01E-01	0.15%	2.03E+00	0.12%
1	4.15E-01	0.18%	2.90E-01	0.20%	1.40E+00	0.17%	1.48E-01	0.21%	6.27E-01	0.16%
2	1.32E-01	0.24%	9.08E-02	0.26%	4.25E-01	0.19%	4.13E-02	0.27%	1.80E-01	0.23%
5	2.53E-02	0.36%	1.71E-02	0.38%	7.88E-02	0.30%	7.19E-03	0.41%	3.23E-02	0.34%
10	6.67E-03	0.46%	4.50E-03	0.53%	2.06E-02	0.37%	1.84E-03	0.58%	8.27E-03	0.45%
20	1.65E-03	0.65%	1.10E-03	0.76%	4.99E-03	0.53%	4.44E-04	0.80%	2.00E-03	0.62%
50	2.34E-04	0.98%	1.54E-04	1.08%	6.90E-04	0.81%	6.22E-05	1.21%	2.82E-04	0.98%
100	4.74E-05	1.36%	3.12E-05	1.48%	1.41E-04	1.17%	1.24E-05	1.51%	5.89E-05	1.36%
200	7.34E-06	1.67%	5.09E-06	1.85%	2.12E-05	1.49%	1.99E-06	2.13%	9.34E-06	1.65%
300	2.09E-06	2.67%	1.45E-06	1.96%	5.55E-06	1.64%	5.56E-07	2.09%	2.43E-06	1.78%
500	2.71E-07	2.09%	1.88E-07	2.20%	6.97E-07	1.85%	7.18E-08	2.15%	3.23E-07	1.97%
700	4.76E-08	2.33%	3.33E-08	2.36%	1.19E-07	1.98%	1.40E-08	3.56%	5.94E-08	2.18%
1000	5.42E-09	2.61%	3.74E-09	2.66%	1.29E-08	2.35%	1.48E-09	2.67%	6.75E-09	2.51%
1200	1.41E-09	2.92%	9.71E-10	2.90%	3.34E-09	2.57%	3.79E-10	2.84%	1.83E-09	2.75%

Table 32: Delayed gamma doses calculated with COG and Henderson flux-to-doses factors after 50 min

Delayed gamma doses (after 50 min)	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Uranyl fluoride (4,95 %)	σ	Damp UO_2 (5 %)	σ	Uranyl nitrate solution (93,2 %)	σ	U metal (93,2 %)	σ	Damp U_3O_8 (93,2 %)	σ
0.3	2.23E+00	0.39%	1.52E+00	0.04%	8.38E+00	0.02%	1.07E+00	0.06%	3.99E+00	0.03%
0.5	1.19E+00	0.51%	7.88E-01	0.05%	4.19E+00	0.02%	4.62E-01	0.08%	1.82E+00	0.04%
1	4.27E-01	0.61%	2.78E-01	0.07%	1.42E+00	0.03%	1.36E-01	0.10%	5.60E-01	0.05%
2	1.33E-01	0.61%	8.66E-02	0.09%	4.30E-01	0.04%	3.78E-02	0.14%	1.60E-01	0.07%
5	2.56E-02	1.48%	1.64E-02	0.13%	7.98E-02	0.05%	6.64E-03	0.21%	2.85E-02	0.10%
10	6.40E-03	0.32%	4.29E-03	0.18%	2.07E-02	0.08%	1.69E-03	0.30%	7.34E-03	0.14%
20	1.58E-03	0.48%	1.05E-03	0.26%	5.04E-03	0.11%	4.09E-04	0.45%	1.77E-03	0.20%
50	2.24E-04	0.89%	1.46E-04	0.45%	7.05E-04	0.19%	5.76E-05	0.74%	2.52E-04	0.34%
100	4.48E-05	1.05%	3.02E-05	0.69%	1.41E-04	0.29%	1.16E-05	1.16%	5.04E-05	0.54%
200	7.27E-06	1.94%	4.65E-06	1.22%	2.19E-05	0.54%	1.96E-06	1.94%	7.92E-06	0.94%
300	2.05E-06	2.86%	1.35E-06	1.99%	5.72E-06	0.87%	5.14E-07	3.14%	2.11E-06	1.47%
500	2.58E-07	6.29%	1.82E-07	7.94%	6.83E-07	1.98%	7.15E-08	6.42%	2.79E-07	3.43%
700	5.10E-08	12.31%	3.02E-08	8.99%	1.27E-07	4.05%	1.07E-08	13.33%	5.35E-08	6.41%
1000	8.26E-09	28.16%	2.58E-09	19.14%	1.53E-08	10.39%	1.20E-09	42.65%	5.39E-09	16.55%
1200	1.12E-09	55.93%	1.28E-09	28.23%	4.07E-09	19.39%	1.81E-10	61.42%	1.00E-09	35.49%

Table 33: Delayed gamma doses calculated with MCNP and Henderson flux-to-doses factors after 100 min

Delayed gamma doses (after 100 min)	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Uranyl fluoride (4,95 %)	σ	Damp UO_2 (5 %)	σ	Uranyl nitrate solution (93,2 %)	σ	U metal (93,2 %)	σ	Damp U_3O_8 (93,2 %)	σ
0.3	9.51E-01	0.17%	6.96E-01	0.25%	3.70E+00	0.07%	4.85E-01	0.29%	1.99E+00	0.09%
0.5	5.05E-01	0.28%	3.63E-01	0.30%	1.85E+00	0.09%	2.11E-01	0.51%	9.07E-01	0.11%
1	1.82E-01	0.36%	1.27E-01	0.39%	6.26E-01	0.07%	6.18E-02	0.49%	2.79E-01	0.12%
2	5.75E-02	0.47%	3.94E-02	0.51%	1.89E-01	0.15%	1.71E-02	0.67%	7.93E-02	0.45%
5	1.10E-02	0.50%	7.39E-03	0.77%	3.53E-02	0.23%	2.97E-03	1.02%	1.43E-02	0.48%
10	2.89E-03	0.70%	1.94E-03	1.07%	9.18E-03	0.32%	7.64E-04	1.43%	3.66E-03	0.43%
20	7.08E-04	1.01%	4.74E-04	1.55%	2.22E-03	0.47%	1.87E-04	2.06%	8.85E-04	0.98%
50	1.00E-04	1.68%	6.71E-05	2.56%	3.14E-04	0.78%	2.68E-05	3.42%	1.26E-04	1.03%
100	2.17E-05	2.53%	1.39E-05	1.02%	6.32E-05	1.20%	5.23E-06	1.37%	2.51E-05	0.65%
200	3.24E-06	4.48%	2.21E-06	1.77%	9.59E-06	0.55%	8.77E-07	2.31%	3.95E-06	1.13%
300	8.86E-07	1.80%	6.07E-07	2.73%	2.51E-06	0.89%	2.45E-07	3.54%	1.08E-06	1.75%
500	1.11E-07	3.95%	7.53E-08	6.01%	3.02E-07	2.06%	3.08E-08	3.49%	1.48E-07	3.73%
700	2.05E-08	2.32%	1.38E-08	3.22%	5.09E-08	4.34%	5.81E-09	4.26%	2.61E-08	2.21%
1000	2.29E-09	3.11%	1.61E-09	3.84%	5.47E-09	1.76%	6.08E-10	4.10%	2.89E-09	2.97%
1200	5.94E-10	3.23%	4.18E-10	3.99%	1.42E-09	2.09%	1.69E-10	5.21%	7.25E-10	2.72%

Table 34: Delayed gamma doses calculated with SCALE and Henderson flux-to-doses factors after 100 min

Delayed gamma doses (after 100 min)	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Uranyl fluoride (4,95 %)	σ	Damp UO_2 (5 %)	σ	Uranyl nitrate solution (93,2 %)	σ	U metal (93,2 %)	σ	Damp U_3O_8 (93,2 %)	σ
0.3	9.48E-01	0.12%	6.89E-01	0.13%	3.66E+00	0.08%	5.08E-01	0.14%	1.98E+00	0.10%
0.5	5.10E-01	0.14%	3.63E-01	0.15%	1.84E+00	0.10%	2.23E-01	0.18%	9.09E-01	0.12%
1	1.86E-01	0.18%	1.29E-01	0.20%	6.27E-01	0.13%	6.59E-02	0.27%	2.83E-01	0.16%
2	5.94E-02	0.24%	4.04E-02	0.26%	1.91E-01	0.19%	1.84E-02	0.43%	8.09E-02	0.23%
5	1.14E-02	0.35%	7.73E-03	0.38%	3.57E-02	0.28%	3.20E-03	0.41%	1.44E-02	0.34%
10	3.02E-03	0.46%	2.02E-03	0.51%	9.25E-03	0.37%	8.24E-04	0.56%	3.69E-03	0.45%
20	7.37E-04	0.63%	4.99E-04	0.69%	2.26E-03	0.52%	1.99E-04	0.83%	8.93E-04	0.64%
50	1.05E-04	1.07%	7.04E-05	1.12%	3.18E-04	0.85%	2.76E-05	1.21%	1.24E-04	0.98%
100	2.14E-05	1.41%	1.44E-05	1.47%	6.28E-05	1.17%	5.58E-06	1.53%	2.56E-05	1.42%
200	3.27E-06	1.71%	2.33E-06	2.35%	9.52E-06	1.49%	9.01E-07	1.93%	3.99E-06	1.71%
300	9.11E-07	1.90%	6.56E-07	2.01%	2.53E-06	1.69%	2.47E-07	1.98%	1.11E-06	1.78%
500	1.15E-07	2.04%	8.27E-08	2.18%	3.01E-07	1.90%	3.28E-08	2.22%	1.44E-07	1.97%
700	2.07E-08	2.25%	1.51E-08	2.37%	5.07E-08	1.93%	5.97E-09	2.44%	2.58E-08	2.11%
1000	2.21E-09	2.56%	1.64E-09	3.01%	5.38E-09	2.27%	6.70E-10	2.78%	2.81E-09	2.55%
1200	6.12E-10	2.77%	4.26E-10	3.21%	1.38E-09	2.52%	1.75E-10	3.19%	7.47E-10	2.81%

Table 35: Delayed gamma doses calculated with COG and Henderson flux-to-doses factors after 100 min

Delayed gamma doses (after 100 min)	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Uranyl fluoride (4,95 %)	σ	Damp UO_2 (5 %)	σ	Uranyl nitrate solution (93,2 %)	σ	U metal (93,2 %)	σ	Damp U_3O_8 (93,2 %)	σ
0.3	1.05E+00	0.77%	6.69E-01	0.04%	3.70E+00	0.02%	4.66E-01	0.06%	1.76E+00	0.03%
0.5	5.60E-01	0.96%	3.48E-01	0.05%	1.85E+00	0.02%	2.01E-01	0.07%	8.04E-01	0.04%
1	2.00E-01	1.08%	1.23E-01	0.06%	6.26E-01	0.03%	5.93E-02	0.10%	2.47E-01	0.05%
2	6.33E-02	1.56%	3.81E-02	0.09%	1.90E-01	0.04%	1.65E-02	0.14%	7.06E-02	0.06%
5	1.15E-02	2.07%	7.19E-03	0.13%	3.52E-02	0.05%	2.88E-03	0.21%	1.26E-02	0.10%
10	3.03E-03	3.01%	1.89E-03	0.18%	9.13E-03	0.07%	7.35E-04	0.29%	3.24E-03	0.14%
20	7.40E-04	3.07%	4.66E-04	0.26%	2.22E-03	0.11%	1.76E-04	0.43%	7.82E-04	0.20%
50	9.85E-05	0.65%	6.56E-05	0.43%	3.14E-04	0.18%	2.52E-05	0.71%	1.10E-04	0.33%
100	2.03E-05	1.16%	1.32E-05	0.67%	6.23E-05	0.29%	5.07E-06	1.12%	2.23E-05	0.55%
200	3.20E-06	1.78%	2.13E-06	1.20%	9.77E-06	0.54%	8.07E-07	1.93%	3.50E-06	0.93%
300	8.30E-07	2.84%	5.77E-07	1.85%	2.53E-06	0.99%	2.20E-07	3.01%	1.00E-06	1.44%
500	1.15E-07	5.98%	8.16E-08	3.85%	3.25E-07	1.91%	2.16E-08	7.36%	1.28E-07	3.14%
700	1.89E-08	13.17%	1.37E-08	7.66%	5.14E-08	3.96%	7.56E-09	12.46%	2.24E-08	6.21%
1000	2.59E-09	28.50%	9.97E-10	20.36%	6.11E-09	9.81%	2.73E-10	29.87%	1.99E-09	17.63%
1200	1.05E-09	46.28%	6.39E-10	27.39%	1.49E-09	20.31%	2.45E-10	65.35%	5.29E-10	31.62%

Table 36: Delayed gamma doses calculated with MCNP and Henderson flux-to-doses factors after 500 min

Delayed gamma doses (after 500 min)	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Uranyl fluoride (4,95 %)	σ	Damp UO_2 (5 %)	σ	Uranyl nitrate solution (93,2 %)	σ	U metal (93,2 %)	σ	Damp U_3O_8 (93,2 %)	σ
0.3	8.16E-02	0.28%	5.98E-02	0.30%	3.32E-01	0.07%	4.28E-02	0.33%	1.73E-01	0.10%
0.5	4.33E-02	0.32%	3.12E-02	0.36%	1.66E-01	0.09%	1.86E-02	0.41%	7.90E-02	0.12%
1	1.57E-02	0.30%	1.10E-02	0.46%	5.62E-02	0.07%	5.47E-03	0.55%	2.43E-02	0.27%
2	4.93E-03	0.55%	3.41E-03	0.61%	1.70E-02	0.10%	1.51E-03	0.75%	6.94E-03	0.36%
5	9.49E-04	0.37%	6.40E-04	0.91%	3.17E-03	0.23%	2.64E-04	1.15%	1.25E-03	0.34%
10	2.48E-04	0.81%	1.69E-04	0.57%	8.24E-04	0.47%	6.59E-05	1.64%	3.20E-04	0.48%
20	6.08E-05	0.74%	4.16E-05	0.82%	2.00E-04	0.68%	1.62E-05	2.35%	7.71E-05	0.50%
50	8.57E-06	1.24%	5.76E-06	3.10%	2.81E-05	1.13%	2.27E-06	1.75%	1.08E-05	0.83%
100	1.75E-06	0.78%	1.19E-06	1.22%	5.64E-06	0.32%	4.39E-07	6.16%	2.18E-06	0.73%
200	2.75E-07	1.35%	1.96E-07	3.60%	8.51E-07	0.57%	7.55E-08	2.67%	3.42E-07	1.27%
300	7.29E-08	2.10%	5.06E-08	3.26%	2.19E-07	0.92%	2.13E-08	4.08%	8.74E-08	5.02%
500	9.07E-09	4.54%	5.97E-09	3.02%	2.55E-08	2.14%	2.46E-09	4.15%	1.20E-08	4.30%
700	1.57E-09	2.45%	1.08E-09	3.83%	4.16E-09	4.63%	4.59E-10	3.92%	2.06E-09	2.45%
1000	1.63E-10	3.68%	1.13E-10	3.81%	4.15E-10	1.77%	5.06E-11	4.73%	2.11E-10	3.14%
1200	4.44E-11	3.27%	2.95E-11	4.14%	1.02E-10	2.17%	1.05E-11	3.77%	5.36E-11	3.12%

Table 37: Delayed gamma doses calculated with SCALE and Henderson flux-to-doses factors after 500 min

Delayed gamma doses (after 500 min)	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Uranyl fluoride (4,95 %)	σ	Damp UO_2 (5 %)	σ	Uranyl nitrate solution (93,2 %)	σ	U metal (93,2 %)	σ	Damp U_3O_8 (93,2 %)	σ
0.3	8.09E-02	0.12%	5.91E-02	0.13%	3.26E-01	0.08%	4.48E-02	0.13%	1.71E-01	0.10%
0.5	4.35E-02	0.14%	3.11E-02	0.16%	1.64E-01	0.10%	1.96E-02	0.16%	7.90E-02	0.12%
1	1.60E-02	0.19%	1.11E-02	0.20%	5.60E-02	0.14%	5.82E-03	0.22%	2.45E-02	0.17%
2	5.09E-03	0.25%	3.50E-03	0.28%	1.70E-02	0.19%	1.63E-03	0.30%	7.02E-03	0.23%
5	9.76E-04	0.37%	6.63E-04	0.40%	3.17E-03	0.29%	2.86E-04	0.46%	1.26E-03	0.34%
10	2.59E-04	0.49%	1.74E-04	0.52%	8.25E-04	0.39%	7.32E-05	0.64%	3.24E-04	0.46%
20	6.35E-05	0.82%	4.24E-05	0.76%	1.99E-04	0.52%	1.77E-05	0.81%	7.75E-05	0.66%
50	9.00E-06	1.10%	5.98E-06	1.16%	2.83E-05	0.90%	2.48E-06	1.24%	1.10E-05	1.19%
100	1.82E-06	1.52%	1.19E-06	1.47%	5.56E-06	1.19%	5.03E-07	1.60%	2.22E-06	1.28%
200	2.79E-07	1.78%	1.85E-07	1.87%	8.45E-07	1.45%	7.90E-08	2.27%	3.51E-07	1.63%
300	7.38E-08	1.93%	5.07E-08	2.07%	2.20E-07	1.72%	2.09E-08	2.01%	9.58E-08	1.98%
500	9.12E-09	2.04%	6.40E-09	2.21%	2.54E-08	1.85%	2.74E-09	2.24%	1.20E-08	1.99%
700	1.62E-09	2.23%	1.12E-09	2.35%	4.25E-09	1.99%	4.66E-10	2.44%	2.08E-09	2.20%
1000	1.69E-10	2.63%	1.15E-10	2.70%	4.11E-10	2.36%	4.86E-11	2.60%	2.19E-10	2.61%
1200	4.48E-11	2.94%	2.94E-11	3.03%	1.02E-10	2.54%	1.23E-11	2.89%	5.73E-11	2.87%

Table 38: Delayed gamma doses calculated with COG and Henderson flux-to-doses factors after 500 min

Delayed gamma doses (after 500 min)	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Uranyl fluoride (4,95 %)	σ	Damp UO2 (5 %)	σ	Uranyl nitrate solution (93,2 %)	σ	U metal (93,2 %)	σ	Damp U3O8 (93,2 %)	σ
0.3	8.00E-02	0.04%	5.66E-02	0.04%	3.32E-01	0.02%	4.11E-02	0.06%	1.52E-01	0.03%
0.5	4.26E-02	0.04%	2.95E-02	0.05%	1.66E-01	0.02%	1.78E-02	0.08%	6.93E-02	0.04%
1	1.54E-02	0.05%	1.04E-02	0.07%	5.63E-02	0.03%	5.22E-03	0.11%	2.13E-02	0.05%
2	4.87E-03	0.07%	3.23E-03	0.09%	1.71E-02	0.04%	1.46E-03	0.14%	6.10E-03	0.07%
5	9.34E-04	0.11%	6.11E-04	0.13%	3.18E-03	0.05%	2.54E-04	0.22%	1.09E-03	0.10%
10	2.45E-04	0.15%	1.60E-04	0.18%	8.25E-04	0.07%	6.50E-05	0.30%	2.80E-04	0.14%
20	6.01E-05	0.21%	3.93E-05	0.27%	2.00E-04	0.11%	1.58E-05	0.44%	6.74E-05	0.20%
50	8.50E-06	0.35%	5.56E-06	0.44%	2.81E-05	0.18%	2.19E-06	0.76%	9.48E-06	0.34%
100	1.71E-06	0.55%	1.12E-06	0.70%	5.60E-06	0.29%	4.45E-07	1.19%	1.92E-06	0.53%
200	2.70E-07	0.98%	1.76E-07	1.22%	8.54E-07	0.52%	7.25E-08	1.97%	3.05E-07	0.94%
300	7.22E-08	1.60%	4.69E-08	1.94%	2.17E-07	0.86%	2.18E-08	4.20%	8.35E-08	1.49%
500	8.54E-09	3.41%	6.21E-09	4.14%	2.48E-08	2.00%	2.54E-09	7.15%	1.02E-08	3.51%
700	1.49E-09	7.20%	1.06E-09	8.17%	4.05E-09	4.24%	4.32E-10	13.15%	1.83E-09	6.46%
1000	1.23E-10	19.67%	1.65E-10	21.07%	3.14E-10	12.64%	2.25E-11	36.92%	2.16E-10	17.09%
1200	4.50E-11	30.81%	7.60E-11	43.92%	1.15E-10	20.86%	1.63E-12	49.05%	2.00E-11	41.99%

Table 39: Delayed gamma doses calculated with MCNP and Henderson flux-to-doses factors after 1000 min

Delayed gamma doses (after 1000 min)	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Uranyl fluoride (4,95 %)	σ	Damp UO_2 (5 %)	σ	Uranyl nitrate solution (93,2 %)	σ	U metal (93,2 %)	σ	Damp U_3O_8 (93,2 %)	σ
0.3	2.73E-02	0.36%	1.93E-02	0.25%	1.30E-01	0.08%	1.39E-02	0.37%	5.76E-02	0.18%
0.5	1.45E-02	0.19%	1.01E-02	0.46%	6.51E-02	0.09%	6.05E-03	0.46%	2.63E-02	0.22%
1	5.28E-03	0.38%	3.54E-03	0.38%	2.21E-02	0.12%	1.78E-03	0.39%	8.07E-03	0.42%
2	1.67E-03	0.41%	1.10E-03	0.50%	6.75E-03	0.16%	4.98E-04	0.84%	2.32E-03	0.40%
5	3.20E-04	0.47%	2.09E-04	0.74%	1.26E-03	0.24%	8.62E-05	0.81%	4.12E-04	0.85%
10	8.35E-05	1.48%	5.46E-05	1.04%	3.26E-04	0.15%	2.19E-05	1.15%	1.06E-04	0.85%
20	2.04E-05	0.95%	1.31E-05	1.51%	7.85E-05	0.22%	5.22E-06	1.67%	2.56E-05	1.23%
50	2.82E-06	1.60%	1.77E-06	2.55%	1.10E-05	0.37%	7.50E-07	2.78%	3.64E-06	2.02%
100	5.61E-07	2.46%	3.78E-07	1.57%	2.22E-06	1.27%	1.50E-07	4.24%	7.19E-07	0.81%
200	8.96E-08	1.74%	5.96E-08	2.71%	3.21E-07	0.59%	2.43E-08	2.99%	1.10E-07	1.42%
300	2.32E-08	2.69%	1.43E-08	4.35%	7.81E-08	0.98%	6.07E-09	4.78%	2.88E-08	2.22%
500	2.54E-09	6.24%	1.59E-09	4.39%	8.03E-09	2.47%	7.06E-10	3.93%	3.35E-09	5.14%
700	3.84E-10	2.83%	2.48E-10	4.27%	1.28E-09	5.61%	1.16E-10	4.19%	5.32E-10	2.66%
1000	3.43E-11	3.95%	2.16E-11	3.68%	9.89E-11	2.68%	9.39E-12	5.12%	4.59E-11	3.04%
1200	7.59E-12	3.48%	5.22E-12	5.74%	2.11E-11	3.07%	2.31E-12	5.43%	9.94E-12	3.97%

Table 40: Delayed gamma doses calculated with SCALE and Henderson flux-to-doses factors after 1000 min

Delayed gamma doses (after 1000 min)	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Uranyl fluoride (4,95 %)	σ	Damp UO_2 (5 %)	σ	Uranyl nitrate solution (93,2 %)	σ	U metal (93,2 %)	σ	Damp U_3O_8 (93,2 %)	σ
0.3	2.71E-02	0.13%	1.91E-02	0.14%	1.28E-01	0.09%	1.48E-02	0.15%	5.68E-02	0.11%
0.5	1.46E-02	0.15%	1.01E-02	0.17%	6.44E-02	0.11%	6.47E-03	0.18%	2.62E-02	0.13%
1	5.36E-03	0.20%	3.61E-03	0.22%	2.20E-02	0.15%	1.92E-03	0.25%	8.13E-03	0.18%
2	1.71E-03	0.27%	1.14E-03	0.29%	6.71E-03	0.19%	5.36E-04	0.31%	2.34E-03	0.28%
5	3.32E-04	0.42%	2.16E-04	0.44%	1.25E-03	0.29%	9.41E-05	0.44%	4.19E-04	0.36%
10	8.65E-05	0.53%	5.66E-05	0.57%	3.25E-04	0.45%	2.40E-05	0.60%	1.08E-04	0.51%
20	2.12E-05	0.78%	1.38E-05	0.75%	7.79E-05	0.56%	5.80E-06	0.86%	2.57E-05	0.69%
50	2.96E-06	1.69%	1.94E-06	1.16%	1.09E-05	0.90%	8.07E-07	1.39%	3.60E-06	1.04%
100	5.80E-07	1.50%	3.91E-07	1.52%	2.14E-06	1.25%	1.61E-07	1.63%	7.24E-07	1.41%
200	8.89E-08	1.89%	6.00E-08	1.82%	3.23E-07	1.56%	2.36E-08	1.86%	1.11E-07	1.70%
300	2.26E-08	1.85%	1.49E-08	1.97%	7.72E-08	1.65%	6.31E-09	1.97%	2.81E-08	1.80%
500	2.66E-09	2.04%	1.75E-09	2.07%	8.07E-09	1.78%	7.56E-10	2.14%	3.33E-09	2.01%
700	4.17E-10	2.25%	2.85E-10	2.26%	1.13E-09	1.91%	1.19E-10	2.30%	5.12E-10	2.12%
1000	3.69E-11	2.49%	2.45E-11	2.55%	9.09E-11	2.58%	1.05E-11	2.73%	4.57E-11	2.39%
1200	8.25E-12	2.80%	5.43E-12	2.53%	1.99E-11	2.48%	2.43E-12	3.17%	1.03E-11	2.76%

Table 41: Delayed gamma doses calculated with COG and Henderson flux-to-doses factors after 1000 min

Delayed gamma doses (after 1000 min)	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Uranyl fluoride (4,95 %)	σ	Damp UO_2 (5 %)	σ	Uranyl nitrate solution (93,2 %)	σ	U metal (93,2 %)	σ	Damp U_3O_8 (93,2 %)	σ
0.3	2.65E-02	0.04%	1.82E-02	0.05%	1.31E-01	0.02%	1.34E-02	0.08%	5.05E-02	0.03%
0.5	1.41E-02	0.05%	9.45E-03	0.06%	6.53E-02	0.02%	5.81E-03	0.10%	2.31E-02	0.04%
1	5.13E-03	0.06%	3.34E-03	0.08%	2.22E-02	0.03%	1.71E-03	0.13%	7.10E-03	0.06%
2	1.62E-03	0.08%	1.04E-03	0.10%	6.77E-03	0.04%	4.75E-04	0.18%	2.04E-03	0.08%
5	3.12E-04	0.12%	1.99E-04	0.15%	1.26E-03	0.05%	8.35E-05	0.26%	3.65E-04	0.11%
10	8.18E-05	0.17%	5.17E-05	0.21%	3.26E-04	0.08%	2.13E-05	0.37%	9.34E-05	0.16%
20	2.00E-05	0.24%	1.26E-05	0.31%	7.86E-05	0.11%	5.09E-06	0.54%	2.25E-05	0.23%
50	2.81E-06	0.41%	1.75E-06	0.52%	1.10E-05	0.19%	7.21E-07	0.90%	3.13E-06	0.39%
100	5.66E-07	0.68%	3.57E-07	0.89%	2.18E-06	0.33%	1.48E-07	1.43%	6.30E-07	0.61%
200	8.38E-08	1.19%	5.58E-08	2.15%	3.16E-07	0.56%	2.19E-08	2.74%	9.72E-08	1.13%
300	2.17E-08	1.87%	1.34E-08	2.33%	7.51E-08	0.92%	6.06E-09	3.85%	2.63E-08	1.71%
500	2.60E-09	4.45%	1.52E-09	5.34%	7.75E-09	2.32%	7.08E-10	8.86%	2.89E-09	3.98%
700	4.16E-10	9.40%	2.99E-10	10.81%	1.14E-09	5.46%	1.29E-10	16.72%	3.80E-10	9.42%
1000	2.14E-11	32.34%	3.15E-11	26.81%	8.57E-11	16.85%	1.77E-11	40.07%	2.70E-11	25.28%
1200	2.24E-12	31.66%	1.05E-11	52.74%	2.89E-11	27.98%	8.17E-12	55.27%	6.01E-12	42.62%

8.2 RESULTS FOR THE ADDITIONAL SYSTEMS (§ 5.2.1, 5.2.2 AND 5.2.3)

Table 42: Prompt neutron doses for bare plutonium configuration, calculated with MCNP and ANSI/HPS N13.3 flux-to-dose conversion factors

Prompt neutron dose in Gy	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Pu (H/Pu = 0)	σ	Pu (H/Pu = 10)	σ	Pu (H/Pu = 100)	σ	Pu (H/Pu = 900)	σ	Pu (H/Pu = 2000)	σ
0.3	4.64E+02	0.03%	1.81E+02	0.04%	1.33E+02	0.05%	8.56E+01	0.06%	3.61E+01	0.08%
0.5	1.92E+02	0.05%	8.53E+01	0.08%	6.49E+01	0.07%	4.40E+01	0.07%	2.03E+01	0.11%
1	5.67E+01	0.06%	2.84E+01	0.08%	2.24E+01	0.09%	1.60E+01	0.10%	8.13E+00	0.14%
2	1.67E+01	0.09%	8.89E+00	0.12%	7.20E+00	0.13%	5.28E+00	0.15%	2.84E+00	0.17%
5	2.97E+00	0.15%	1.65E+00	0.20%	1.35E+00	0.21%	1.01E+00	0.24%	5.70E-01	0.25%
10	7.44E-01	0.22%	4.20E-01	0.28%	3.48E-01	0.30%	2.63E-01	0.34%	1.52E-01	0.53%
20	1.85E-01	0.40%	1.07E-01	0.40%	8.86E-02	0.48%	6.77E-02	0.51%	3.94E-02	0.52%
50	3.13E-02	0.61%	1.79E-02	0.69%	1.54E-02	1.79%	1.16E-02	1.04%	6.69E-03	0.98%
100	7.65E-03	0.85%	4.42E-03	0.93%	3.70E-03	0.93%	2.76E-03	1.00%	1.59E-03	1.32%
200	1.56E-03	0.86%	8.58E-04	1.32%	7.09E-04	1.14%	5.43E-04	1.29%	3.05E-04	1.16%
300	4.87E-04	1.14%	2.74E-04	1.41%	2.27E-04	1.60%	1.67E-04	1.55%	9.55E-05	1.69%
500	7.59E-05	1.08%	4.29E-05	1.82%	3.35E-05	1.43%	2.55E-05	1.58%	1.47E-05	1.56%
700	1.44E-05	1.17%	7.88E-06	2.26%	6.62E-06	1.66%	5.03E-06	1.95%	2.90E-06	1.58%
1000	1.46E-06	1.14%	8.46E-07	1.53%	6.86E-07	1.48%	5.20E-07	1.64%	3.10E-07	1.68%
1200	3.38E-07	1.23%	2.03E-07	1.55%	1.67E-07	1.76%	1.26E-07	1.74%	7.58E-08	1.73%

Table 43: Prompt gamma doses for bare plutonium configuration, calculated with MCNP and ANSI/HPS N13.3 flux-to-dose conversion factors

Prompt gamma dose in Gy	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Pu (H/Pu = 0)	σ	Pu (H/Pu = 10)	σ	Pu (H/Pu = 100)	σ	Pu (H/Pu = 900)	σ	Pu (H/Pu = 2000)	σ
0.3	2.59E+01	0.03%	5.63E+01	0.02%	1.04E+02	0.02%	9.76E+01	0.02%	6.13E+01	0.03%
0.5	1.08E+01	0.05%	2.61E+01	0.03%	4.99E+01	0.03%	4.93E+01	0.03%	3.38E+01	0.04%
1	3.28E+00	0.09%	8.30E+00	0.06%	1.63E+01	0.04%	1.69E+01	0.04%	1.28E+01	0.06%
2	9.94E-01	0.13%	2.45E+00	0.09%	4.87E+00	0.06%	5.22E+00	0.06%	4.21E+00	0.09%
5	1.67E-01	0.22%	4.36E-01	0.15%	8.83E-01	0.10%	9.72E-01	0.10%	8.19E-01	0.15%
10	4.10E-02	0.32%	1.12E-01	0.22%	2.28E-01	0.14%	2.53E-01	0.14%	2.17E-01	0.21%
20	1.05E-02	0.45%	2.80E-02	0.30%	5.65E-02	0.20%	6.27E-02	0.21%	5.40E-02	0.40%
50	1.93E-03	1.03%	4.37E-03	0.68%	8.35E-03	0.41%	9.21E-03	0.39%	8.05E-03	0.62%
100	5.26E-04	1.42%	9.96E-04	0.87%	1.82E-03	0.56%	1.97E-03	0.57%	1.69E-03	0.66%
200	1.25E-04	1.52%	1.91E-04	1.43%	3.21E-04	0.83%	3.31E-04	0.75%	2.80E-04	0.97%
300	4.42E-05	2.03%	5.93E-05	1.44%	9.57E-05	1.24%	9.50E-05	1.16%	8.02E-05	1.19%
500	8.98E-06	1.90%	1.02E-05	1.91%	1.57E-05	1.51%	1.49E-05	1.63%	1.22E-05	1.83%
700	2.15E-06	2.27%	2.42E-06	2.18%	3.49E-06	1.93%	3.32E-06	1.92%	2.65E-06	2.66%
1000	3.56E-07	3.03%	3.99E-07	3.44%	5.19E-07	2.89%	5.03E-07	2.98%	3.97E-07	4.12%
1200	1.15E-07	3.41%	1.29E-07	4.12%	1.85E-07	3.52%	1.65E-07	3.64%	1.31E-07	5.03%

Table 44: Prompt neutron doses for bare plutonium configuration, calculated with COG and ANSI/HPS N13.3 flux-to-dose conversion factors

Prompt neutron dose in Gy	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Pu (H/Pu = 0)	σ	Pu (H/Pu = 10)	σ	Pu (H/Pu = 100)	σ	Pu (H/Pu = 900)	σ	Pu (H/Pu = 2000)	σ
0.3	4.65E+02	0.00%	1.81E+02	0.01%	1.32E+02	0.01%	8.52E+01	0.01%	3.56E+01	0.01%
0.5	1.93E+02	0.01%	8.53E+01	0.01%	6.48E+01	0.01%	4.39E+01	0.01%	2.01E+01	0.01%
1	5.70E+01	0.01%	2.84E+01	0.01%	2.24E+01	0.01%	1.59E+01	0.01%	8.05E+00	0.02%
2	1.68E+01	0.01%	8.89E+00	0.01%	7.16E+00	0.01%	5.26E+00	0.02%	2.82E+00	0.02%
5	2.98E+00	0.01%	1.65E+00	0.02%	1.35E+00	0.02%	1.01E+00	0.02%	5.63E-01	0.03%
10	7.48E-01	0.02%	4.22E-01	0.03%	3.47E-01	0.03%	2.62E-01	0.03%	1.49E-01	0.04%
20	1.87E-01	0.03%	1.07E-01	0.04%	8.86E-02	0.04%	6.73E-02	0.05%	3.87E-02	0.06%
50	3.11E-02	0.05%	1.81E-02	0.06%	1.50E-02	0.07%	1.14E-02	0.08%	6.53E-03	0.11%
100	7.74E-03	0.08%	4.45E-03	0.10%	3.67E-03	0.11%	2.75E-03	0.12%	1.57E-03	0.17%
200	1.57E-03	0.13%	8.76E-04	0.17%	7.16E-04	0.18%	5.32E-04	0.21%	3.04E-04	0.28%
300	4.95E-04	0.20%	2.73E-04	0.25%	2.23E-04	0.26%	1.66E-04	0.34%	9.40E-05	0.42%
500	7.54E-05	0.39%	4.13E-05	0.52%	3.35E-05	0.52%	2.54E-05	0.65%	1.46E-05	0.96%
700	1.44E-05	0.73%	8.01E-06	0.94%	6.57E-06	0.88%	4.99E-06	1.47%	2.75E-06	1.37%
1000	1.52E-06	2.36%	8.39E-07	1.94%	6.88E-07	2.46%	5.25E-07	4.25%	3.16E-07	3.30%
1200	3.29E-07	2.77%	1.96E-07	3.86%	1.53E-07	4.15%	1.24E-07	5.03%	7.03E-08	6.35%

Table 45: Prompt gamma doses for bare plutonium configuration, calculated with COG and ANSI/HPS N13.3 flux-to-dose conversion factors

Prompt gamma dose in Gy	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Pu (H/Pu = 0)	σ	Pu (H/Pu = 10)	σ	Pu (H/Pu = 100)	σ	Pu (H/Pu = 900)	σ	Pu (H/Pu = 2000)	σ
0.3	2.52E+01	0.03%	5.50E+01	0.01%	1.03E+02	0.01%	9.72E+01	0.01%	6.11E+01	0.01%
0.5	1.06E+01	0.04%	2.55E+01	0.02%	4.95E+01	0.01%	4.91E+01	0.01%	3.38E+01	0.01%
1	3.23E+00	0.05%	8.13E+00	0.02%	1.62E+01	0.01%	1.69E+01	0.01%	1.28E+01	0.01%
2	9.87E-01	0.06%	2.41E+00	0.03%	4.84E+00	0.02%	5.21E+00	0.01%	4.20E+00	0.01%
5	1.65E-01	0.10%	4.28E-01	0.04%	8.77E-01	0.02%	9.68E-01	0.02%	8.18E-01	0.02%
10	4.04E-02	0.14%	1.10E-01	0.06%	2.27E-01	0.33%	2.52E-01	0.03%	2.17E-01	0.03%
20	1.03E-02	0.20%	2.74E-02	0.08%	5.60E-02	0.05%	6.23E-02	0.04%	5.40E-02	0.04%
50	1.87E-03	0.29%	4.26E-03	0.13%	8.33E-03	0.08%	9.21E-03	0.07%	7.96E-03	0.07%
100	5.22E-04	0.39%	9.61E-04	0.22%	1.80E-03	0.13%	1.96E-03	0.12%	1.67E-03	0.11%
200	1.25E-04	0.67%	1.86E-04	0.36%	3.16E-04	0.23%	3.30E-04	0.20%	2.77E-04	0.20%
300	4.47E-05	0.75%	5.87E-05	0.49%	9.39E-05	0.33%	9.52E-05	0.31%	7.94E-05	0.32%
500	8.73E-06	1.40%	1.01E-05	0.93%	1.49E-05	0.92%	1.44E-05	0.62%	1.18E-05	0.67%
700	2.22E-06	2.28%	2.33E-06	1.69%	3.39E-06	1.20%	3.19E-06	1.20%	2.63E-06	1.32%
1000	3.54E-07	4.72%	3.54E-07	3.04%	5.13E-07	2.42%	4.75E-07	2.52%	3.75E-07	2.60%
1200	1.11E-07	5.27%	1.26E-07	4.84%	1.65E-07	3.64%	1.71E-07	6.52%	1.32E-07	4.04%

Table 46: Prompt neutron doses for bare plutonium configuration, calculated with SCALE and ANSI/HPS N13.3 flux-to-dose conversion factors

Prompt neutron dose in Gy	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Pu (H/Pu = 0)	σ	Pu (H/Pu = 10)	σ	Pu (H/Pu = 100)	σ	Pu (H/Pu = 900)	σ	Pu (H/Pu = 2000)	σ
0.3	4.67E+02	0.004%	1.82E+02	0.01%	1.33E+02	0.01%	8.57E+01	0.01%	3.59E+01	0.01%
0.5	1.93E+02	0.01%	8.56E+01	0.01%	6.50E+01	0.01%	4.41E+01	0.01%	2.02E+01	0.01%
1	5.71E+01	0.01%	2.84E+01	0.01%	2.24E+01	0.01%	1.60E+01	0.01%	8.10E+00	0.01%
2	1.68E+01	0.01%	8.91E+00	0.01%	7.19E+00	0.01%	5.28E+00	0.02%	2.84E+00	0.02%
5	2.99E+00	0.01%	1.65E+00	0.02%	1.35E+00	0.02%	1.01E+00	0.02%	5.67E-01	0.02%
10	7.50E-01	0.02%	4.22E-01	0.02%	3.48E-01	0.03%	2.63E-01	0.03%	1.50E-01	0.03%
20	1.87E-01	0.03%	1.07E-01	0.03%	8.88E-02	0.04%	6.76E-02	0.05%	3.90E-02	0.05%
50	3.12E-02	0.04%	1.81E-02	0.05%	1.51E-02	0.06%	1.14E-02	0.07%	6.57E-03	0.08%
100	7.77E-03	0.06%	4.47E-03	0.08%	3.68E-03	0.08%	2.77E-03	0.09%	1.58E-03	0.09%
200	1.57E-03	0.07%	8.80E-04	0.09%	7.19E-04	0.09%	5.36E-04	0.11%	3.06E-04	0.11%
300	4.96E-04	0.09%	2.74E-04	0.10%	2.23E-04	0.10%	1.66E-04	0.12%	9.53E-05	0.11%
500	7.54E-05	0.14%	4.16E-05	0.15%	3.40E-05	0.15%	2.54E-05	0.16%	1.46E-05	0.15%
700	1.45E-05	0.19%	8.09E-06	0.20%	6.65E-06	0.20%	4.98E-06	0.21%	2.87E-06	0.20%
1000	1.49E-06	0.30%	8.44E-07	0.32%	7.01E-07	0.33%	5.26E-07	0.35%	3.07E-07	0.33%
1200	3.52E-07	0.41%	2.01E-07	0.46%	1.68E-07	0.46%	1.27E-07	0.48%	7.41E-08	0.46%

Table 47: Prompt gamma doses for bare plutonium configuration, calculated with SCALE and ANSI/HPS N13.3 flux-to-dose conversion factors

Prompt gamma dose in Gy	Case 1		Case 2		Case 3		Case 4		Case 5	
Distance (m)	Pu (H/Pu = 0)	σ	Pu (H/Pu = 10)	σ	Pu (H/Pu = 100)	σ	Pu (H/Pu = 900)	σ	Pu (H/Pu = 2000)	σ
0.3	2.55E+01	0.09%	5.53E+01	0.18%	1.03E+02	0.14%	9.65E+01	0.14%	6.08E+01	0.13%
0.5	1.06E+01	0.11%	2.57E+01	0.21%	4.94E+01	0.16%	4.88E+01	0.16%	3.36E+01	0.15%
1	3.26E+00	0.14%	8.20E+00	0.28%	1.62E+01	0.22%	1.68E+01	0.21%	1.27E+01	0.19%
2	9.95E-01	0.17%	2.43E+00	0.37%	4.81E+00	0.29%	5.20E+00	0.28%	4.17E+00	0.25%
5	1.66E-01	0.26%	4.32E-01	0.56%	8.77E-01	0.44%	9.59E-01	0.42%	8.09E-01	0.37%
10	4.06E-02	0.37%	1.09E-01	0.79%	2.26E-01	0.60%	2.49E-01	0.58%	2.16E-01	0.51%
20	1.03E-02	0.50%	2.75E-02	1.08%	5.59E-02	0.84%	6.14E-02	0.82%	5.36E-02	0.71%
50	1.87E-03	0.67%	4.27E-03	1.60%	8.34E-03	1.30%	9.09E-03	1.26%	7.93E-03	1.11%
100	5.21E-04	0.82%	1.00E-03	2.10%	1.81E-03	1.78%	1.94E-03	1.72%	1.65E-03	1.49%
200	1.26E-04	0.84%	1.85E-04	2.38%	3.22E-04	2.23%	3.34E-04	2.46%	2.72E-04	2.09%
300	4.53E-05	0.87%	5.72E-05	2.60%	9.33E-05	2.53%	9.54E-05	2.80%	7.59E-05	2.38%
500	8.84E-06	0.93%	9.86E-06	2.84%	1.50E-05	3.13%	1.42E-05	3.44%	1.18E-05	3.17%
700	2.15E-06	0.93%	2.22E-06	3.02%	3.64E-06	3.53%	3.03E-06	4.01%	2.57E-06	3.58%
1000	3.36E-07	1.08%	3.67E-07	3.41%	5.18E-07	4.11%	4.71E-07	4.58%	3.89E-07	4.35%
1200	1.13E-07	1.26%	1.19E-07	4.22%	1.63E-07	4.54%	1.68E-07	5.15%	1.19E-07	5.89%

Table 48: Prompt neutron doses for cylinder cases, calculated with MCNP and ANSI/HPS N13.3 flux-to-dose conversion factors

Prompt neutron dose in Gy	Cylinder 1				Cylinder 2				Cylinder 3			
Distance (m)	Pu (H/Pu = 0)	σ	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 0)	σ	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 0)	σ	Pu (H/Pu = 2000)	σ
0.3	4.89E+02	0.03%	4.66E+01	0.07%	3.67E+02	0.03%	2.65E+01	0.08%	5.58E+02	0.03%	5.07E+01	0.07%
0.5	1.98E+02	0.04%	2.47E+01	0.08%	1.53E+02	0.04%	1.45E+01	0.10%	2.24E+02	0.04%	2.85E+01	0.08%
1	5.76E+01	0.06%	9.09E+00	0.11%	4.63E+01	0.07%	5.73E+00	0.14%	6.41E+01	0.06%	1.08E+01	0.10%
2	1.68E+01	0.09%	3.00E+00	0.15%	1.39E+01	0.10%	1.98E+00	0.20%	1.85E+01	0.09%	3.59E+00	0.15%
5	2.99E+00	0.15%	5.83E-01	0.24%	2.47E+00	0.17%	3.87E-01	0.33%	3.29E+00	0.14%	6.98E-01	0.24%
10	7.48E-01	0.21%	1.53E-01	0.33%	6.16E-01	0.24%	1.02E-01	0.45%	8.25E-01	0.20%	1.81E-01	0.33%
20	1.86E-01	0.31%	3.93E-02	0.55%	1.56E-01	0.35%	2.75E-02	0.67%	2.04E-01	0.29%	4.59E-02	0.49%
50	3.10E-02	0.53%	6.56E-03	0.85%	2.71E-02	0.62%	4.98E-03	1.19%	3.32E-02	0.49%	7.37E-03	0.82%
100	7.69E-03	0.66%	1.61E-03	1.19%	7.01E-03	0.77%	1.31E-03	1.41%	8.16E-03	0.65%	1.73E-03	1.19%
200	1.56E-03	0.90%	3.09E-04	1.11%	1.47E-03	0.95%	2.63E-04	1.36%	1.63E-03	0.85%	3.28E-04	1.24%
300	4.89E-04	1.03%	9.31E-05	1.36%	4.66E-04	1.06%	8.37E-05	1.50%	5.12E-04	1.03%	1.02E-04	1.53%
500	7.41E-05	1.14%	1.47E-05	1.38%	7.11E-05	1.11%	1.30E-05	1.69%	7.59E-05	1.09%	1.51E-05	1.60%
700	1.44E-05	1.13%	2.82E-06	1.45%	1.38E-05	1.18%	2.56E-06	1.74%	1.46E-05	1.16%	2.97E-06	1.64%
1000	1.48E-06	1.23%	3.07E-07	1.41%	1.41E-06	1.26%	2.71E-07	1.73%	1.47E-06	1.18%	3.21E-07	1.75%
1200	3.37E-07	1.23%	7.24E-08	1.47%	3.29E-07	1.26%	6.57E-08	1.72%	3.50E-07	1.21%	7.66E-08	1.93%

Table 49: Prompt gamma doses for cylinder cases, calculated with MCNP and ANSI/HPS N13.3 flux-to-dose conversion factors

Prompt gamma dose in Gy	Cylinder 1				Cylinder 2				Cylinder 3			
Distance (m)	Pu (H/Pu = 0)	σ	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 0)	σ	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 0)	σ	Pu (H/Pu = 2000)	σ
0.3	2.80E+01	0.03%	7.19E+01	0.03%	1.85E+01	0.04%	4.59E+01	0.04%	3.46E+01	0.02%	7.68E+01	0.03%
0.5	1.13E+01	0.05%	3.85E+01	0.04%	7.72E+00	0.06%	2.53E+01	0.05%	1.38E+01	0.04%	4.25E+01	0.04%
1	3.34E+00	0.08%	1.40E+01	0.06%	2.47E+00	0.10%	9.68E+00	0.06%	3.98E+00	0.06%	1.57E+01	0.05%
2	1.01E+00	0.12%	4.43E+00	0.08%	7.86E-01	0.15%	3.21E+00	0.10%	1.17E+00	0.09%	4.99E+00	0.08%
5	1.69E-01	0.21%	8.40E-01	0.14%	1.28E-01	0.25%	6.24E-01	0.15%	1.98E-01	0.15%	9.46E-01	0.13%
10	4.12E-02	0.30%	2.21E-01	0.20%	3.07E-02	0.37%	1.66E-01	0.22%	4.84E-02	0.22%	2.48E-01	0.18%
20	1.05E-02	0.43%	5.47E-02	0.28%	8.11E-03	0.52%	4.16E-02	0.31%	1.24E-02	0.33%	6.12E-02	0.33%
50	1.94E-03	0.92%	8.12E-03	0.62%	1.58E-03	1.27%	6.37E-03	0.56%	2.15E-03	0.72%	9.02E-03	0.56%
100	5.41E-04	1.22%	1.69E-03	0.63%	4.66E-04	1.36%	1.38E-03	0.83%	5.94E-04	0.93%	1.86E-03	0.62%
200	1.31E-04	1.43%	2.81E-04	0.87%	1.15E-04	1.53%	2.31E-04	0.97%	1.35E-04	1.05%	3.02E-04	0.86%
300	4.84E-05	3.70%	8.33E-05	1.28%	4.31E-05	1.83%	7.28E-05	5.73%	5.02E-05	3.30%	8.76E-05	1.22%
500	9.06E-06	1.70%	1.23E-05	1.84%	8.68E-06	1.76%	9.94E-06	1.94%	9.46E-06	1.45%	1.33E-05	1.82%
700	2.29E-06	2.41%	2.64E-06	2.73%	2.20E-06	2.59%	2.30E-06	2.69%	2.30E-06	1.70%	2.78E-06	2.53%
1000	3.61E-07	2.64%	4.38E-07	4.32%	3.50E-07	2.87%	3.39E-07	3.96%	3.77E-07	2.30%	4.39E-07	4.10%
1200	1.24E-07	3.25%	1.27E-07	4.86%	1.13E-07	3.31%	1.07E-07	4.68%	1.24E-07	2.70%	1.48E-07	4.99%

Table 50: Prompt neutron doses for cylinder cases, calculated with SCALE and ANSI/HPS N13.3 flux-to-dose conversion factors

Prompt neutron dose in Gy	Cylinder 1				Cylinder 2				Cylinder 3			
Distance (m)	Pu (H/Pu = 0)	σ	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 0)	σ	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 0)	σ	Pu (H/Pu = 2000)	σ
0.3	4.93E+02	0.004%	4.67E+01	0.01%	3.71E+02	0.004%	2.67E+01	0.01%	5.62E+02	0.004%	5.09E+01	0.01%
0.5	2.00E+02	0.01%	2.48E+01	0.01%	1.54E+02	0.01%	1.46E+01	0.01%	2.26E+02	0.01%	2.86E+01	0.01%
1	5.80E+01	0.01%	9.11E+00	0.01%	4.67E+01	0.01%	5.77E+00	0.01%	6.45E+01	0.01%	1.08E+01	0.01%
2	1.69E+01	0.01%	3.01E+00	0.02%	1.41E+01	0.01%	2.00E+00	0.02%	1.86E+01	0.01%	3.59E+00	0.02%
5	3.00E+00	0.01%	5.82E-01	0.02%	2.48E+00	0.01%	3.88E-01	0.02%	3.32E+00	0.01%	7.00E-01	0.03%
10	7.53E-01	0.02%	1.52E-01	0.03%	6.21E-01	0.02%	1.03E-01	0.04%	8.30E-01	0.02%	1.82E-01	0.04%
20	1.88E-01	0.03%	3.90E-02	0.05%	1.57E-01	0.03%	2.76E-02	0.05%	2.06E-01	0.03%	4.60E-02	0.05%
50	3.12E-02	0.04%	6.55E-03	0.08%	2.73E-02	0.04%	5.08E-03	0.07%	3.36E-02	0.04%	7.44E-03	0.08%
100	7.78E-03	0.06%	1.57E-03	0.08%	7.07E-03	0.06%	1.30E-03	0.08%	8.21E-03	0.05%	1.74E-03	0.10%
200	1.57E-03	0.07%	3.03E-04	0.10%	1.48E-03	0.08%	2.63E-04	0.11%	1.64E-03	0.07%	3.27E-04	0.12%
300	4.96E-04	0.09%	9.40E-05	0.11%	4.72E-04	0.09%	8.35E-05	0.11%	5.13E-04	0.09%	1.00E-04	0.12%
500	7.56E-05	0.14%	1.44E-05	0.15%	7.25E-05	0.14%	1.30E-05	0.15%	7.74E-05	0.13%	1.52E-05	0.16%
700	1.45E-05	0.19%	2.83E-06	0.21%	1.40E-05	0.19%	2.57E-06	0.21%	1.48E-05	0.19%	2.97E-06	0.21%
1000	1.49E-06	0.30%	3.01E-07	0.34%	1.43E-06	0.30%	2.72E-07	0.33%	1.52E-06	0.29%	3.15E-07	0.34%
1200	3.53E-07	0.40%	7.21E-08	0.46%	3.37E-07	0.41%	6.52E-08	0.44%	3.63E-07	0.40%	7.62E-08	0.46%

Table 51: Prompt gamma doses for cylinder cases, calculated with SCALE and ANSI/HPS N13.3 flux-to-dose conversion factors

Prompt gamma dose in Gy	Cylinder 1				Cylinder 2				Cylinder 3			
Distance (m)	Pu (H/Pu = 0)	σ	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 0)	σ	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 0)	σ	Pu (H/Pu = 2000)	σ
0.3	2.75E+01	0.09%	7.13E+01	0.12%	1.82E+01	0.11%	4.57E+01	0.09%	3.41E+01	0.07%	7.63E+01	0.18%
0.5	1.11E+01	0.11%	3.83E+01	0.14%	7.60E+00	0.13%	2.52E+01	0.11%	1.36E+01	0.09%	4.24E+01	0.20%
1	3.29E+00	0.14%	1.38E+01	0.19%	2.43E+00	0.17%	9.63E+00	0.13%	3.92E+00	0.12%	1.56E+01	0.26%
2	9.96E-01	0.17%	4.41E+00	0.24%	7.76E-01	0.20%	3.19E+00	0.18%	1.16E+00	0.15%	4.98E+00	0.34%
5	1.66E-01	0.26%	8.32E-01	0.37%	1.26E-01	0.31%	6.20E-01	0.26%	1.96E-01	0.22%	9.39E-01	0.50%
10	4.03E-02	0.37%	2.19E-01	0.50%	3.04E-02	0.44%	1.65E-01	0.36%	4.81E-02	0.32%	2.46E-01	0.69%
20	1.03E-02	0.50%	5.42E-02	0.70%	8.00E-03	0.59%	4.15E-02	0.50%	1.22E-02	0.44%	6.10E-02	0.96%
50	1.87E-03	0.67%	7.93E-03	1.08%	1.56E-03	0.77%	6.22E-03	0.76%	2.12E-03	0.59%	8.73E-03	1.52%
100	5.30E-04	0.84%	1.64E-03	1.49%	4.61E-04	0.90%	1.34E-03	1.00%	5.79E-04	0.73%	1.80E-03	2.07%
200	1.25E-04	0.84%	2.77E-04	2.04%	1.15E-04	0.89%	2.29E-04	1.36%	1.34E-04	0.81%	2.99E-04	2.96%
300	4.53E-05	0.85%	8.16E-05	2.42%	4.23E-05	0.91%	6.55E-05	1.55%	4.75E-05	0.80%	8.31E-05	3.55%
500	8.79E-06	0.90%	1.21E-05	3.06%	8.32E-06	0.95%	1.02E-05	2.09%	9.25E-06	0.85%	1.43E-05	4.82%
700	2.15E-06	0.93%	2.73E-06	4.27%	2.06E-06	0.96%	2.18E-06	2.52%	2.23E-06	0.88%	2.79E-06	6.04%
1000	3.43E-07	1.06%	4.08E-07	4.28%	3.24E-07	1.09%	3.36E-07	3.19%	3.54E-07	1.06%	4.13E-07	6.22%
1200	1.12E-07	1.23%	1.23E-07	4.77%	1.09E-07	1.25%	1.10E-07	4.01%	1.17E-07	1.26%	1.36E-07	6.34%

Table 52: Prompt neutron doses for cylinder cases, calculated with COG and ANSI/HPS N13.3 flux-to-dose conversion factors

Prompt neutron dose in Gy	Cylinder 1				Cylinder 2				Cylinder 3			
Distance (m)	Pu (H/Pu = 0)	σ	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 0)	σ	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 0)	σ	Pu (H/Pu = 2000)	σ
0.3	4.91E+02	0.00%	4.64E+01	0.01%	3.70E+02	0.00%	2.65E+01	0.01%	5.60E+02	0.00%	5.05E+01	0.01%
0.5	1.99E+02	0.00%	2.46E+01	0.01%	1.54E+02	0.01%	1.45E+01	0.02%	2.25E+02	0.00%	2.84E+01	0.01%
1	5.79E+01	0.01%	9.06E+00	0.02%	4.66E+01	0.01%	5.74E+00	0.02%	6.43E+01	0.01%	1.08E+01	0.01%
2	1.69E+01	0.01%	2.99E+00	0.02%	1.40E+01	0.01%	1.99E+00	0.03%	1.86E+01	0.01%	3.57E+00	0.02%
5	3.00E+00	0.01%	5.78E-01	0.03%	2.48E+00	0.02%	3.86E-01	0.37%	3.31E+00	0.01%	6.96E-01	0.03%
10	7.51E-01	0.02%	1.51E-01	0.04%	6.19E-01	0.02%	1.02E-01	0.05%	8.29E-01	0.02%	1.81E-01	0.04%
20	1.87E-01	0.03%	3.88E-02	0.06%	1.57E-01	0.03%	2.75E-02	0.08%	2.05E-01	0.03%	4.57E-02	0.06%
50	3.12E-02	0.05%	6.51E-03	0.10%	2.73E-02	0.06%	5.05E-03	0.13%	3.35E-02	0.05%	7.39E-03	0.10%
100	7.75E-03	0.08%	1.56E-03	0.16%	7.05E-03	0.09%	1.29E-03	0.19%	8.18E-03	0.08%	1.72E-03	0.16%
200	1.57E-03	0.14%	3.00E-04	0.29%	1.47E-03	0.14%	2.60E-04	0.28%	1.63E-03	0.14%	3.23E-04	0.27%
300	4.93E-04	0.20%	9.30E-05	0.39%	4.72E-04	0.21%	8.26E-05	0.47%	5.10E-04	0.20%	1.00E-04	0.50%
500	7.51E-05	0.37%	1.42E-05	0.79%	7.27E-05	0.41%	1.29E-05	0.85%	7.77E-05	0.41%	1.49E-05	0.78%
700	1.43E-05	0.62%	2.86E-06	1.60%	1.41E-05	0.94%	2.53E-06	1.61%	1.49E-05	0.73%	3.09E-06	2.00%
1000	1.47E-06	1.69%	2.95E-07	3.16%	1.47E-06	2.55%	2.88E-07	7.82%	1.49E-06	1.56%	3.23E-07	3.32%
1200	3.45E-07	3.39%	6.68E-08	6.12%	3.46E-07	4.29%	6.55E-08	6.44%	3.56E-07	2.94%	7.25E-08	5.38%

Table 53: Prompt gamma doses for cylinder cases, calculated with COG and ANSI/HPS N13.3 flux-to-dose conversion factors

Prompt gamma dose in Gy	Cylinder 1				Cylinder 2				Cylinder 3			
Distance (m)	Pu (H/Pu = 0)	σ	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 0)	σ	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 0)	σ	Pu (H/Pu = 2000)	σ
0.3	2.72E+01	0.03%	7.19E+01	0.01%	1.80E+01	0.04%	4.60E+01	0.01%	3.38E+01	0.28%	7.68E+01	0.01%
0.5	1.10E+01	0.04%	3.85E+01	0.01%	7.56E+00	0.05%	2.54E+01	0.01%	1.35E+01	0.04%	4.25E+01	0.01%
1	3.27E+00	0.05%	1.39E+01	0.01%	2.42E+00	0.06%	9.69E+00	0.01%	3.90E+00	0.05%	1.57E+01	0.01%
2	9.90E-01	0.06%	4.42E+00	0.01%	7.73E-01	0.07%	3.21E+00	0.02%	1.15E+00	0.06%	4.99E+00	0.01%
5	1.66E-01	0.10%	8.40E-01	0.02%	1.25E-01	0.11%	6.25E-01	0.02%	1.95E-01	0.09%	9.46E-01	0.02%
10	4.02E-02	0.14%	2.20E-01	0.03%	3.01E-02	0.16%	1.66E-01	0.03%	4.77E-02	0.13%	2.47E-01	0.03%
20	1.03E-02	0.20%	5.47E-02	0.04%	7.88E-03	0.23%	4.16E-02	0.05%	1.21E-02	0.19%	6.10E-02	0.04%
50	1.87E-03	0.30%	8.03E-03	0.07%	1.54E-03	0.31%	6.28E-03	0.08%	2.11E-03	0.27%	8.87E-03	0.07%
100	5.19E-04	0.39%	1.69E-03	0.11%	4.54E-04	0.43%	1.36E-03	0.13%	5.69E-04	0.39%	1.84E-03	0.11%
200	1.26E-04	0.53%	2.79E-04	0.21%	1.14E-04	0.66%	2.30E-04	0.25%	1.33E-04	0.51%	3.02E-04	0.20%
300	4.56E-05	0.78%	7.98E-05	0.31%	4.22E-05	0.84%	6.63E-05	0.36%	4.78E-05	0.70%	8.55E-05	0.31%
500	8.89E-06	1.39%	1.18E-05	0.63%	8.29E-06	1.13%	9.83E-06	0.70%	9.15E-06	1.21%	1.28E-05	0.64%
700	2.11E-06	1.75%	2.66E-06	1.23%	2.05E-06	1.83%	2.23E-06	1.35%	2.25E-06	1.78%	2.78E-06	1.13%
1000	3.15E-07	3.58%	3.73E-07	2.61%	3.32E-07	3.70%	3.32E-07	3.04%	3.45E-07	4.41%	4.26E-07	3.07%
1200	1.11E-07	5.36%	1.20E-07	4.79%	1.10E-07	4.90%	1.02E-07	4.49%	1.13E-07	5.44%	1.41E-07	3.94%

Table 54: Prompt neutron doses for reflected sphere cases at a H/Pu ratio of 0, calculated with MCNP and ANSI/HPS N13.3 flux-to-dose conversion factors

Prompt neutron dose in Gy	R_steel = 0.1 cm		R_steel = 0.3 cm		R_steel = 1 cm		R_steel = 5 cm		R_steel = 10 cm		R_steel = 20 cm	
Distance (m)	Pu (H/Pu = 0)	σ	Pu (H/Pu = 0)	σ	Pu (H/Pu = 0)	σ	Pu (H/Pu = 0)	σ	Pu (H/Pu = 0)	σ	Pu (H/Pu = 0)	σ
0.3	4.61E+02	0.04%	4.54E+02	0.03%	4.32E+02	0.03%	3.12E+02	0.13%	2.13E+02	0.04%	1.07E+02	0.05%
0.5	1.91E+02	0.04%	1.89E+02	0.04%	1.81E+02	0.04%	1.40E+02	0.05%	1.03E+02	0.05%	5.78E+01	0.06%
1	5.65E+01	0.08%	5.60E+01	0.08%	5.43E+01	0.06%	4.46E+01	0.07%	3.51E+01	0.00%	2.22E+01	0.09%
2	1.66E+01	0.11%	1.65E+01	0.11%	1.61E+01	0.13%	1.36E+01	0.10%	1.12E+01	0.12%	7.57E+00	0.13%
5	2.96E+00	0.15%	2.94E+00	0.16%	2.87E+00	0.15%	2.48E+00	0.17%	2.08E+00	0.18%	1.48E+00	0.21%
10	7.41E-01	0.22%	7.36E-01	0.22%	7.20E-01	0.22%	6.29E-01	0.24%	5.34E-01	0.27%	3.90E-01	0.33%
20	1.85E-01	0.32%	1.84E-01	0.32%	1.80E-01	0.37%	1.59E-01	0.34%	1.37E-01	0.38%	1.02E-01	0.42%
50	3.13E-02	0.74%	3.10E-02	0.59%	3.04E-02	0.64%	2.73E-02	0.63%	2.37E-02	0.66%	1.82E-02	0.73%
100	7.73E-03	1.07%	7.72E-03	1.08%	7.62E-03	1.00%	6.76E-03	0.78%	5.87E-03	0.79%	4.59E-03	1.00%
200	1.56E-03	0.90%	1.54E-03	0.88%	1.52E-03	0.84%	1.36E-03	1.07%	1.14E-03	1.01%	8.18E-04	1.12%
300	4.92E-04	1.07%	4.90E-04	1.09%	4.76E-04	1.10%	4.05E-04	1.20%	3.37E-04	1.45%	2.28E-04	1.79%
500	7.62E-05	1.13%	7.50E-05	1.11%	7.08E-05	1.12%	5.77E-05	1.30%	4.40E-05	1.77%	2.54E-05	2.43%
700	1.45E-05	1.46%	1.42E-05	1.45%	1.35E-05	1.17%	1.01E-05	1.62%	7.21E-06	1.92%	3.35E-06	2.84%
1000	1.49E-06	1.19%	1.42E-06	1.23%	1.36E-06	1.30%	9.25E-07	1.42%	6.04E-07	1.81%	2.23E-07	2.33%
1200	3.41E-07	1.32%	3.37E-07	1.24%	3.14E-07	1.35%	2.07E-07	1.51%	1.25E-07	2.13%	4.58E-08	3.95%

Table 55: Prompt gamma doses for reflected sphere cases at a H/Pu ratio of 0, calculated with MCNP and ANSI/HPS N13.3 flux-to-dose conversion factors

Prompt gamma dose in Gy	R_steel = 0.1 cm		R_steel = 0.3 cm		R_steel = 1 cm		R_steel = 5 cm		R_steel = 10 cm		R_steel = 20 cm	
Distance (m)	Pu (H/Pu = 0)	σ	Pu (H/Pu = 0)	σ	Pu (H/Pu = 0)	σ	Pu (H/Pu = 0)	σ	Pu (H/Pu = 0)	σ	Pu (H/Pu = 0)	σ
0.3	2.60E+01	0.03%	2.60E+01	0.03%	2.51E+01	0.03%	1.41E+01	0.03%	6.02E+00	0.10%	1.80E+00	0.23%
0.5	1.09E+01	0.05%	1.09E+01	0.05%	1.06E+01	0.05%	6.47E+00	0.06%	3.09E+00	0.15%	1.14E+00	0.28%
1	3.32E+00	0.08%	3.33E+00	0.08%	3.29E+00	0.08%	2.19E+00	0.09%	1.21E+00	0.20%	5.83E-01	0.35%
2	1.01E+00	0.12%	1.02E+00	0.12%	1.01E+00	0.12%	7.09E-01	0.16%	4.31E-01	0.27%	2.43E-01	0.44%
5	1.70E-01	0.21%	1.70E-01	0.20%	1.69E-01	0.20%	1.20E-01	0.24%	7.35E-02	0.45%	4.11E-02	0.71%
10	4.16E-02	0.30%	4.16E-02	0.30%	4.13E-02	0.30%	2.96E-02	0.35%	1.82E-02	0.73%	1.06E-02	1.09%
20	1.06E-02	0.49%	1.07E-02	0.44%	1.06E-02	0.43%	7.87E-03	0.49%	5.28E-03	0.93%	3.73E-03	1.33%
50	1.89E-03	1.05%	1.91E-03	1.05%	1.91E-03	0.96%	1.56E-03	1.12%	1.20E-03	1.49%	1.03E-03	1.85%
100	5.28E-04	1.19%	5.31E-04	1.26%	5.26E-04	1.19%	4.66E-04	1.39%	4.14E-04	1.78%	3.82E-04	1.90%
200	1.28E-04	1.35%	1.27E-04	1.37%	1.28E-04	1.39%	1.16E-04	1.48%	1.09E-04	2.00%	9.93E-05	2.09%
300	4.59E-05	1.81%	4.65E-05	1.80%	4.54E-05	1.82%	4.20E-05	1.72%	3.73E-05	1.88%	3.45E-05	2.36%
500	9.51E-06	1.80%	9.03E-06	1.76%	9.05E-06	1.77%	8.11E-06	2.04%	7.00E-06	2.01%	5.60E-06	2.48%
700	2.27E-06	2.14%	2.21E-06	2.11%	2.24E-06	2.18%	1.89E-06	2.08%	1.66E-06	2.38%	1.28E-06	2.88%
1000	3.71E-07	2.74%	3.61E-07	2.76%	3.43E-07	2.69%	3.07E-07	3.13%	2.45E-07	3.14%	2.07E-07	4.13%
1200	1.20E-07	3.29%	1.17E-07	3.29%	1.11E-07	3.64%	9.90E-08	3.60%	8.53E-08	3.77%	7.49E-08	5.20%

Table 56: Prompt neutron doses for reflected sphere cases at a H/Pu ratio of 2000, calculated with MCNP and ANSI/HPS N13.3 flux-to-dose conversion factors

Prompt neutron dose in Gy	R_steel = 0.1 cm		R_steel = 0.3 cm		R_steel = 1 cm		R_steel = 5 cm		R_steel = 10 cm		R_steel = 20 cm	
Distance (m)	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 2000)	σ
0.3	3.57E+01	0.09%	3.52E+01	0.08%	3.44E+01	0.08%	2.57E+01	0.08%	1.73E+01	0.10%	8.70E+00	0.11%
0.5	2.01E+01	0.09%	1.98E+01	0.09%	1.94E+01	0.09%	1.47E+01	0.10%	1.02E+01	0.11%	5.44E+00	0.14%
1	8.03E+00	0.12%	7.94E+00	0.12%	7.77E+00	0.12%	6.02E+00	0.13%	4.33E+00	0.15%	2.45E+00	0.18%
2	2.82E+00	0.17%	2.79E+00	0.16%	2.73E+00	0.16%	2.14E+00	0.18%	1.56E+00	0.20%	9.33E-01	0.24%
5	5.63E-01	0.27%	5.58E-01	0.25%	5.45E-01	0.25%	4.30E-01	0.28%	3.20E-01	0.30%	1.99E-01	0.38%
10	1.49E-01	0.37%	1.48E-01	0.37%	1.44E-01	0.36%	1.15E-01	0.39%	8.57E-02	0.43%	5.45E-02	0.58%
20	3.86E-02	0.51%	3.83E-02	0.52%	3.74E-02	0.52%	2.97E-02	0.58%	2.27E-02	0.62%	1.47E-02	0.79%
50	6.64E-03	0.97%	6.50E-03	0.90%	6.31E-03	0.82%	5.13E-03	0.91%	3.99E-03	1.04%	2.66E-03	1.24%
100	1.57E-03	1.28%	1.54E-03	1.02%	1.54E-03	1.14%	1.27E-03	1.10%	1.01E-03	1.36%	6.57E-04	1.69%
200	3.06E-04	1.19%	3.02E-04	1.19%	2.95E-04	1.24%	2.45E-04	1.34%	1.86E-04	1.57%	1.21E-04	2.62%
300	9.36E-05	1.49%	9.29E-05	1.50%	9.13E-05	1.69%	7.26E-05	1.64%	5.52E-05	2.00%	3.29E-05	2.64%
500	1.42E-05	1.46%	1.43E-05	1.51%	1.39E-05	1.55%	1.09E-05	1.86%	7.22E-06	2.15%	3.76E-06	3.07%
700	2.88E-06	1.87%	2.86E-06	1.57%	2.80E-06	1.68%	1.97E-06	1.94%	1.21E-06	2.59%	5.00E-07	3.39%
1000	3.01E-07	1.54%	2.91E-07	1.54%	2.83E-07	1.56%	1.85E-07	1.85%	9.95E-08	2.38%	3.19E-08	3.93%
1200	7.46E-08	1.78%	7.28E-08	1.65%	6.86E-08	1.64%	4.52E-08	2.10%	2.34E-08	2.74%	6.74E-09	5.16%

Table 57: Prompt gamma doses for reflected sphere cases at a H/Pu ratio of 2000, calculated with MCNP and ANSI/HPS N13.3 flux-to-dose conversion factors

Prompt gamma dose in Gy	R_steel = 0.1 cm		R_steel = 0.3 cm		R_steel = 1 cm		R_steel = 5 cm		R_steel = 10 cm		R_steel = 20 cm	
Distance (m)	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 2000)	σ
0.3	5.94E+01	0.03%	5.59E+01	0.04%	4.64E+01	0.06%	1.56E+01	0.07%	4.09E+00	0.14%	4.91E-01	0.34%
0.5	3.28E+01	0.06%	3.09E+01	0.04%	2.56E+01	0.05%	8.78E+00	0.09%	2.40E+00	0.19%	3.18E-01	0.40%
1	1.24E+01	0.06%	1.17E+01	0.09%	9.72E+00	0.07%	3.41E+00	0.11%	9.84E-01	0.26%	1.53E-01	0.53%
2	4.08E+00	0.09%	3.84E+00	0.09%	3.19E+00	0.10%	1.14E+00	0.16%	3.42E-01	0.31%	5.91E-02	0.69%
5	7.93E-01	0.16%	7.49E-01	0.15%	6.20E-01	0.16%	2.23E-01	0.25%	6.76E-02	0.48%	1.18E-02	1.11%
10	2.10E-01	0.21%	1.98E-01	0.21%	1.64E-01	0.23%	5.91E-02	0.36%	1.78E-02	0.68%	3.23E-03	1.60%
20	5.22E-02	0.29%	4.93E-02	0.30%	4.09E-02	0.32%	1.48E-02	0.51%	4.73E-03	0.94%	9.58E-04	2.14%
50	7.67E-03	0.47%	7.29E-03	0.51%	6.07E-03	0.50%	2.30E-03	0.82%	7.76E-04	1.48%	2.17E-04	3.33%
100	1.64E-03	0.73%	1.55E-03	0.67%	1.30E-03	0.70%	5.03E-04	1.30%	1.93E-04	2.08%	6.90E-05	3.41%
200	2.71E-04	0.95%	2.58E-04	0.89%	2.22E-04	0.95%	9.10E-05	1.54%	3.95E-05	2.40%	1.70E-05	3.70%
300	7.87E-05	1.20%	7.46E-05	1.23%	6.53E-05	1.92%	2.79E-05	1.95%	1.20E-05	2.97%	5.61E-06	4.31%
500	1.18E-05	1.82%	1.15E-05	2.08%	1.01E-05	2.02%	4.52E-06	2.83%	2.07E-06	3.82%	8.86E-07	4.38%
700	2.58E-06	2.52%	2.48E-06	2.70%	2.14E-06	2.78%	1.14E-06	3.89%	4.84E-07	3.62%	2.16E-07	3.69%
1000	3.86E-07	4.23%	3.74E-07	4.31%	3.69E-07	4.87%	1.71E-07	3.93%	9.15E-08	4.85%	3.26E-08	7.93%
1200	1.28E-07	5.17%	1.29E-07	5.29%	1.25E-07	6.18%	6.78E-08	4.66%	3.21E-08	5.57%	1.37E-08	6.52%

Table 58: Prompt neutron doses for reflected sphere cases at a H/Pu ratio of 0, calculated with SCALE and ANSI/HPS N13.3 flux-to-dose conversion factors

Prompt neutron dose in Gy	R_steel = 0.1 cm		R_steel = 0.3 cm		R_steel = 1 cm		R_steel = 5 cm		R_steel = 10 cm		R_steel = 20 cm	
Distance (m)	Pu (H/Pu = 0)	σ	Pu (H/Pu = 0)	σ	Pu (H/Pu = 0)	σ	Pu (H/Pu = 0)	σ	Pu (H/Pu = 0)	σ	Pu (H/Pu = 0)	σ
0.3	4.64E+02	0.004%	4.57E+02	0.004%	4.34E+02	0.004%	3.14E+02	0.004%	2.13E+02	0.004%	1.07E+02	0.004%
0.5	1.92E+02	0.01%	1.90E+02	0.01%	1.82E+02	0.01%	1.41E+02	0.01%	1.03E+02	0.01%	5.79E+01	0.004%
1	5.68E+01	0.01%	5.63E+01	0.01%	5.46E+01	0.01%	4.48E+01	0.01%	3.52E+01	0.01%	2.22E+01	0.01%
2	1.67E+01	0.01%	1.66E+01	0.01%	1.62E+01	0.01%	1.37E+01	0.01%	1.12E+01	0.01%	7.59E+00	0.01%
5	2.98E+00	0.01%	2.96E+00	0.01%	2.89E+00	0.01%	2.50E+00	0.01%	2.09E+00	0.01%	1.49E+00	0.01%
10	7.47E-01	0.02%	7.42E-01	0.02%	7.26E-01	0.02%	6.33E-01	0.02%	5.36E-01	0.02%	3.91E-01	0.02%
20	1.87E-01	0.03%	1.85E-01	0.03%	1.82E-01	0.03%	1.60E-01	0.03%	1.37E-01	0.02%	1.03E-01	0.02%
50	3.11E-02	0.04%	3.09E-02	0.04%	3.03E-02	0.04%	2.72E-02	0.04%	2.38E-02	0.03%	1.84E-02	0.03%
100	7.74E-03	0.06%	7.70E-03	0.06%	7.57E-03	0.06%	6.81E-03	0.05%	5.98E-03	0.05%	4.61E-03	0.04%
200	1.56E-03	0.07%	1.56E-03	0.07%	1.53E-03	0.07%	1.35E-03	0.07%	1.15E-03	0.06%	8.37E-04	0.05%
300	4.94E-04	0.09%	4.91E-04	0.09%	4.79E-04	0.09%	4.13E-04	0.09%	3.39E-04	0.08%	2.28E-04	0.07%
500	7.50E-05	0.14%	7.43E-05	0.14%	7.21E-05	0.14%	5.84E-05	0.13%	4.42E-05	0.12%	2.51E-05	0.11%
700	1.44E-05	0.19%	1.43E-05	0.19%	1.37E-05	0.19%	1.04E-05	0.18%	7.26E-06	0.17%	3.45E-06	0.17%
1000	1.47E-06	0.30%	1.45E-06	0.30%	1.37E-06	0.30%	9.73E-07	0.27%	6.09E-07	0.27%	2.27E-07	0.31%
1200	3.48E-07	0.41%	3.38E-07	0.41%	3.20E-07	0.42%	2.18E-07	0.38%	1.29E-07	0.37%	4.16E-08	0.45%

Table 59: Prompt gamma doses for reflected sphere cases at a H/Pu ratio of 0, calculated with SCALE and ANSI/HPS N13.3 flux-to-dose conversion factors

Prompt gamma dose in Gy	R_steel = 0.1 cm		R_steel = 0.3 cm		R_steel = 1 cm		R_steel = 5 cm		R_steel = 10 cm		R_steel = 20 cm	
Distance (m)	Pu (H/Pu = 0)	σ	Pu (H/Pu = 0)	σ	Pu (H/Pu = 0)	σ	Pu (H/Pu = 0)	σ	Pu (H/Pu = 0)	σ	Pu (H/Pu = 0)	σ
0.3	2.55E+01	0.09%	2.56E+01	0.08%	2.48E+01	0.08%	1.41E+01	0.04%	6.06E+00	0.04%	1.78E+00	0.05%
0.5	1.07E+01	0.11%	1.07E+01	0.10%	1.05E+01	0.10%	6.47E+00	0.05%	3.10E+00	0.05%	1.12E+00	0.06%
1	3.27E+00	0.14%	3.29E+00	0.13%	3.24E+00	0.12%	2.19E+00	0.06%	1.21E+00	0.06%	5.77E-01	0.06%
2	9.97E-01	0.17%	1.00E+00	0.17%	9.93E-01	0.15%	7.09E-01	0.08%	4.33E-01	0.07%	2.40E-01	0.07%
5	1.67E-01	0.26%	1.68E-01	0.25%	1.67E-01	0.23%	1.20E-01	0.11%	7.33E-02	0.10%	4.10E-02	0.10%
10	4.11E-02	0.36%	4.11E-02	0.35%	4.08E-02	0.33%	2.95E-02	0.16%	1.82E-02	0.15%	1.06E-02	0.14%
20	1.06E-02	0.49%	1.05E-02	0.48%	1.05E-02	0.46%	7.85E-03	0.22%	5.26E-03	0.19%	3.58E-03	0.17%
50	1.91E-03	0.66%	1.91E-03	0.65%	1.90E-03	0.61%	1.55E-03	0.29%	1.22E-03	0.24%	1.03E-03	0.18%
100	5.27E-04	0.79%	5.30E-04	0.79%	5.34E-04	0.75%	4.62E-04	0.36%	3.98E-04	0.28%	3.64E-04	0.21%
200	1.25E-04	0.85%	1.26E-04	0.83%	1.25E-04	0.80%	1.13E-04	0.38%	1.03E-04	0.29%	9.42E-05	0.21%
300	4.50E-05	0.87%	4.51E-05	0.86%	4.49E-05	0.82%	4.10E-05	0.40%	3.70E-05	0.31%	3.24E-05	0.23%
500	8.88E-06	0.89%	8.58E-06	0.90%	8.48E-06	0.84%	7.69E-06	0.44%	6.72E-06	0.35%	5.47E-06	0.28%
700	2.15E-06	0.94%	2.13E-06	0.92%	2.10E-06	0.87%	1.84E-06	0.48%	1.56E-06	0.41%	1.22E-06	0.35%
1000	3.39E-07	1.11%	3.33E-07	1.09%	3.28E-07	1.00%	2.82E-07	0.59%	2.38E-07	0.54%	1.88E-07	0.48%
1200	1.11E-07	1.30%	1.10E-07	1.26%	1.09E-07	1.15%	9.48E-08	0.71%	8.17E-08	0.65%	6.66E-08	0.57%

Table 60: Prompt neutron doses for reflected sphere cases at a H/Pu ratio of 2000, calculated with SCALE and ANSI/HPS N13.3 flux-to-dose conversion factors

Prompt neutron dose in Gy	R_steel = 0.1 cm		R_steel = 0.3 cm		R_steel = 1 cm		R_steel = 5 cm		R_steel = 10 cm		R_steel = 20 cm	
Distance (m)	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 2000)	σ
0.3	3.58E+01	0.01%	3.53E+01	0.01%	3.45E+01	0.01%	2.58E+01	0.01%	1.74E+01	0.01%	8.70E+00	0.01%
0.5	2.02E+01	0.01%	1.99E+01	0.01%	1.95E+01	0.01%	1.48E+01	0.01%	1.02E+01	0.01%	5.43E+00	0.01%
1	8.07E+00	0.01%	7.98E+00	0.01%	7.80E+00	0.01%	6.03E+00	0.01%	4.33E+00	0.01%	2.46E+00	0.01%
2	2.83E+00	0.02%	2.79E+00	0.02%	2.73E+00	0.01%	2.13E+00	0.01%	1.57E+00	0.01%	9.34E-01	0.01%
5	5.65E-01	0.02%	5.59E-01	0.02%	5.46E-01	0.02%	4.30E-01	0.02%	3.22E-01	0.01%	1.99E-01	0.01%
10	1.50E-01	0.03%	1.48E-01	0.03%	1.44E-01	0.03%	1.14E-01	0.02%	8.60E-02	0.02%	5.43E-02	0.02%
20	3.88E-02	0.05%	3.84E-02	0.05%	3.74E-02	0.04%	2.97E-02	0.03%	2.27E-02	0.03%	1.47E-02	0.02%
50	6.55E-03	0.07%	6.48E-03	0.07%	6.34E-03	0.06%	5.13E-03	0.04%	3.99E-03	0.04%	2.66E-03	0.03%
100	1.58E-03	0.08%	1.56E-03	0.08%	1.54E-03	0.07%	1.27E-03	0.06%	9.93E-04	0.05%	6.61E-04	0.04%
200	3.05E-04	0.10%	3.03E-04	0.10%	2.99E-04	0.09%	2.46E-04	0.08%	1.88E-04	0.07%	1.19E-04	0.06%
300	9.49E-05	0.11%	9.41E-05	0.11%	9.26E-05	0.11%	7.45E-05	0.10%	5.48E-05	0.09%	3.21E-05	0.08%
500	1.46E-05	0.15%	1.44E-05	0.16%	1.40E-05	0.15%	1.07E-05	0.14%	7.20E-06	0.13%	3.51E-06	0.13%
700	2.84E-06	0.21%	2.83E-06	0.21%	2.73E-06	0.21%	1.95E-06	0.19%	1.21E-06	0.19%	4.92E-07	0.20%
1000	3.02E-07	0.34%	2.99E-07	0.34%	2.87E-07	0.32%	1.90E-07	0.29%	1.06E-07	0.28%	3.37E-08	0.34%
1200	7.31E-08	0.47%	7.23E-08	0.47%	6.80E-08	0.43%	4.35E-08	0.38%	2.31E-08	0.37%	6.43E-09	0.48%

Table 61: Prompt gamma doses for reflected sphere cases at a H/Pu ratio of 2000, calculated with SCALE and ANSI/HPS N13.3 flux-to-dose conversion factors

Prompt gamma dose in Gy	R_steel = 0.1 cm		R_steel = 0.3 cm		R_steel = 1 cm		R_steel = 5 cm		R_steel = 10 cm		R_steel = 20 cm	
Distance (m)	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 2000)	σ
0.3	5.89E+01	0.13%	5.55E+01	0.13%	4.61E+01	0.09%	1.53E+01	0.04%	3.98E+00	0.03%	4.70E-01	0.05%
0.5	3.26E+01	0.15%	3.06E+01	0.15%	2.55E+01	0.10%	8.63E+00	0.04%	2.34E+00	0.04%	3.09E-01	0.05%
1	1.24E+01	0.19%	1.16E+01	0.19%	9.67E+00	0.13%	3.36E+00	0.06%	9.59E-01	0.04%	1.51E-01	0.06%
2	4.06E+00	0.25%	3.82E+00	0.24%	3.17E+00	0.16%	1.12E+00	0.07%	3.33E-01	0.06%	5.98E-02	0.07%
5	7.86E-01	0.37%	7.39E-01	0.36%	6.18E-01	0.24%	2.18E-01	0.10%	6.55E-02	0.08%	1.16E-02	0.10%
10	2.08E-01	0.50%	1.97E-01	0.49%	1.64E-01	0.33%	5.79E-02	0.14%	1.75E-02	0.11%	3.17E-03	0.13%
20	5.18E-02	0.70%	4.91E-02	0.69%	4.10E-02	0.46%	1.46E-02	0.20%	4.56E-03	0.15%	9.60E-04	0.17%
50	7.72E-03	1.10%	7.16E-03	1.06%	6.06E-03	0.70%	2.25E-03	0.29%	7.62E-04	0.22%	2.22E-04	0.20%
100	1.61E-03	1.47%	1.51E-03	1.50%	1.31E-03	0.93%	4.99E-04	0.38%	1.86E-04	0.27%	6.88E-05	0.22%
200	2.77E-04	2.00%	2.53E-04	1.87%	2.24E-04	1.25%	9.03E-05	0.48%	3.73E-05	0.33%	1.63E-05	0.26%
300	7.52E-05	2.32%	7.24E-05	2.21%	6.42E-05	1.45%	2.80E-05	0.54%	1.21E-05	0.37%	5.45E-06	0.28%
500	1.19E-05	3.14%	1.10E-05	2.87%	1.02E-05	1.91%	4.63E-06	0.67%	2.09E-06	0.46%	9.16E-07	0.37%
700	2.44E-06	3.83%	2.46E-06	3.08%	2.35E-06	2.19%	1.11E-06	0.81%	5.06E-07	0.58%	2.12E-07	0.47%
1000	3.85E-07	5.46%	3.86E-07	4.40%	3.63E-07	2.94%	1.82E-07	0.98%	8.50E-08	0.74%	3.50E-08	0.65%
1200	1.32E-07	6.15%	1.24E-07	5.56%	1.22E-07	3.47%	6.37E-08	1.14%	3.02E-08	0.88%	1.27E-08	0.77%

Table 62: Prompt neutron doses for reflected sphere cases at a H/Pu ratio of 0, calculated with COG and ANSI/HPS N13.3 flux-to-dose conversion factors

Prompt neutron dose in Gy	R_steel = 0.1 cm		R_steel = 0.3 cm		R_steel = 1 cm		R_steel = 5 cm		R_steel = 10 cm		R_steel = 20 cm	
Distance (m)	Pu (H/Pu = 0)	σ	Pu (H/Pu = 0)	σ	Pu (H/Pu = 0)	σ	Pu (H/Pu = 0)	σ	Pu (H/Pu = 0)	σ	Pu (H/Pu = 0)	σ
0.3	4.62E+02	0.00%	4.55E+02	0.00%	4.33E+02	0.00%	3.13E+02	0.00%	2.13E+02	0.00%	1.07E+02	0.01%
0.5	1.91E+02	0.01%	1.89E+02	0.01%	1.82E+02	0.01%	1.41E+02	0.01%	1.03E+02	0.01%	5.78E+01	0.00%
1	5.67E+01	0.01%	5.62E+01	0.01%	5.45E+01	0.01%	4.47E+01	0.01%	3.51E+01	0.01%	2.22E+01	0.01%
2	1.67E+01	0.01%	1.66E+01	0.01%	1.61E+01	0.01%	1.37E+01	0.01%	1.12E+01	0.01%	7.56E+00	0.01%
5	2.97E+00	0.01%	2.95E+00	0.01%	2.88E+00	0.02%	2.49E+00	0.02%	2.09E+00	0.02%	1.48E+00	0.02%
10	7.46E-01	0.02%	7.40E-01	0.02%	7.24E-01	0.02%	6.31E-01	0.02%	5.34E-01	0.02%	3.90E-01	0.02%
20	1.86E-01	0.03%	1.85E-01	0.03%	1.81E-01	0.03%	1.60E-01	0.03%	1.37E-01	0.03%	1.03E-01	0.03%
50	3.10E-02	0.05%	3.08E-02	0.05%	3.03E-02	0.05%	2.71E-02	0.05%	2.37E-02	0.05%	1.84E-02	0.05%
100	7.72E-03	0.08%	7.68E-03	0.08%	7.56E-03	0.08%	6.79E-03	0.08%	5.95E-03	0.08%	4.59E-03	0.08%
200	1.56E-03	0.13%	1.55E-03	0.13%	1.52E-03	0.13%	1.35E-03	0.14%	1.15E-03	0.14%	8.34E-04	0.15%
300	4.91E-04	0.19%	4.88E-04	0.20%	4.79E-04	0.20%	4.13E-04	0.21%	3.38E-04	0.20%	2.27E-04	0.21%
500	7.41E-05	0.35%	7.45E-05	0.41%	7.17E-05	0.40%	5.85E-05	0.48%	4.38E-05	0.46%	2.48E-05	0.52%
700	1.44E-05	0.75%	1.44E-05	0.83%	1.36E-05	0.64%	1.04E-05	0.75%	7.26E-06	0.89%	3.40E-06	1.38%
1000	1.44E-06	1.52%	1.47E-06	2.18%	1.36E-06	1.71%	9.61E-07	2.30%	6.17E-07	2.38%	2.18E-07	3.00%
1200	3.54E-07	3.32%	3.36E-07	2.88%	3.13E-07	2.94%	2.25E-07	3.16%	1.26E-07	3.93%	4.08E-08	18.03%

Table 63: Prompt gamma doses for reflected sphere cases at a H/Pu ratio of 0, calculated with COG and ANSI/HPS N13.3 flux-to-dose conversion factors

Prompt gamma dose in Gy	R_steel = 0.1 cm		R_steel = 0.3 cm		R_steel = 1 cm		R_steel = 5 cm		R_steel = 10 cm		R_steel = 20 cm	
Distance (m)	Pu (H/Pu = 0)	σ	Pu (H/Pu = 0)	σ	Pu (H/Pu = 0)	σ	Pu (H/Pu = 0)	σ	Pu (H/Pu = 0)	σ	Pu (H/Pu = 0)	σ
0.3	2.53E+01	0.03%	2.53E+01	0.03%	2.46E+01	0.03%	1.40E+01	0.03%	6.01E+00	0.04%	1.77E+00	0.07%
0.5	1.06E+01	0.04%	1.06E+01	0.04%	1.04E+01	0.04%	6.42E+00	0.04%	3.07E+00	0.05%	1.11E+00	0.08%
1	3.25E+00	0.05%	3.26E+00	0.05%	3.23E+00	0.05%	2.17E+00	0.05%	1.20E+00	0.06%	5.74E-01	0.09%
2	9.91E-01	0.06%	9.97E-01	0.06%	9.88E-01	0.06%	7.05E-01	0.06%	4.29E-01	0.07%	2.39E-01	0.09%
5	1.66E-01	0.10%	1.67E-01	0.09%	1.66E-01	0.09%	1.19E-01	0.09%	7.28E-02	0.10%	4.07E-02	0.13%
10	4.06E-02	0.14%	4.09E-02	0.14%	4.07E-02	0.13%	2.94E-02	0.12%	1.80E-02	0.15%	1.05E-02	0.23%
20	1.04E-02	0.20%	1.04E-02	0.19%	1.04E-02	0.18%	7.81E-03	0.18%	5.22E-03	0.23%	3.55E-03	0.34%
50	1.87E-03	0.30%	1.90E-03	0.30%	1.89E-03	0.29%	1.55E-03	0.28%	1.21E-03	0.32%	1.03E-03	0.40%
100	5.23E-04	0.41%	5.22E-04	0.38%	5.25E-04	0.40%	4.58E-04	0.39%	3.95E-04	0.41%	3.62E-04	0.43%
200	1.25E-04	0.60%	1.24E-04	0.51%	1.24E-04	0.56%	1.13E-04	0.48%	1.04E-04	0.74%	9.38E-05	0.66%
300	4.50E-05	0.69%	4.47E-05	0.68%	4.44E-05	0.70%	4.05E-05	0.76%	3.67E-05	0.69%	3.22E-05	0.74%
500	8.53E-06	1.13%	8.63E-06	1.13%	8.67E-06	1.47%	7.61E-06	1.38%	6.72E-06	1.25%	5.34E-06	1.25%
700	2.13E-06	1.70%	2.13E-06	1.95%	2.11E-06	2.66%	1.82E-06	1.82%	1.53E-06	1.91%	1.22E-06	2.16%
1000	3.11E-07	4.14%	3.45E-07	3.98%	3.23E-07	3.32%	2.71E-07	3.07%	2.37E-07	3.30%	1.84E-07	3.23%
1200	1.07E-07	5.77%	1.02E-07	5.44%	1.10E-07	5.52%	9.00E-08	5.14%	7.33E-08	4.50%	6.97E-08	4.84%

Table 64: Prompt neutron doses for reflected sphere cases at a H/Pu ratio of 2000, calculated with COG and ANSI/HPS N13.3 flux-to-dose conversion factors

Prompt neutron dose in Gy	R_steel = 0.1 cm		R_steel = 0.3 cm		R_steel = 1 cm		R_steel = 5 cm		R_steel = 10 cm		R_steel = 20 cm	
Distance (m)	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 2000)	σ
0.3	3.55E+01	0.01%	3.50E+01	0.01%	3.43E+01	0.01%	2.56E+01	0.01%	1.73E+01	0.01%	8.65E+00	0.02%
0.5	2.00E+01	0.01%	1.98E+01	0.01%	1.93E+01	0.00%	1.47E+01	0.01%	1.02E+01	0.02%	5.40E+00	0.02%
1	8.02E+00	0.02%	7.93E+00	0.02%	7.75E+00	0.02%	6.00E+00	0.02%	4.31E+00	0.02%	2.44E+00	0.02%
2	2.81E+00	0.02%	2.78E+00	0.02%	2.71E+00	0.02%	2.12E+00	0.02%	1.56E+00	0.03%	9.29E-01	0.03%
5	5.61E-01	0.03%	5.56E-01	0.03%	5.42E-01	0.03%	4.28E-01	0.03%	3.20E-01	0.04%	1.98E-01	0.04%
10	1.49E-01	0.04%	1.47E-01	0.04%	1.43E-01	0.04%	1.14E-01	0.05%	8.56E-02	0.05%	5.40E-02	0.06%
20	3.86E-02	0.06%	3.81E-02	0.06%	3.71E-02	0.06%	2.96E-02	0.07%	2.26E-02	0.08%	1.46E-02	0.08%
50	6.51E-03	0.11%	6.44E-03	0.11%	6.31E-03	0.11%	5.10E-03	0.12%	3.96E-03	0.12%	2.64E-03	0.13%
100	1.57E-03	0.16%	1.55E-03	0.17%	1.53E-03	0.17%	1.26E-03	0.18%	9.88E-04	0.19%	6.58E-04	0.21%
200	3.02E-04	0.29%	3.00E-04	0.27%	2.97E-04	0.27%	2.43E-04	0.28%	1.87E-04	0.33%	1.17E-04	0.31%
300	9.37E-05	0.40%	9.37E-05	0.43%	9.20E-05	0.52%	7.39E-05	0.51%	5.44E-05	0.48%	3.17E-05	0.50%
500	1.43E-05	0.74%	1.41E-05	0.93%	1.39E-05	0.73%	1.06E-05	1.08%	7.05E-06	1.30%	3.53E-06	1.36%
700	2.83E-06	1.53%	2.86E-06	1.77%	2.77E-06	1.66%	1.99E-06	1.82%	1.21E-06	1.89%	4.67E-07	2.38%
1000	2.93E-07	4.12%	2.96E-07	4.22%	2.79E-07	3.67%	1.87E-07	3.74%	1.07E-07	4.84%	3.37E-08	7.05%
1200	8.02E-08	8.29%	7.16E-08	6.79%	6.65E-08	5.34%	4.02E-08	8.61%	2.15E-08	8.82%	5.58E-09	14.08%

Table 65: Prompt gamma doses for reflected sphere cases at a H/Pu ratio of 2000, calculated with COG and ANSI/HPS N13.3 flux-to-dose conversion factors

Prompt gamma dose in Gy	R_steel = 0.1 cm		R_steel = 0.3 cm		R_steel = 1 cm		R_steel = 5 cm		R_steel = 10 cm		R_steel = 20 cm	
Distance (m)	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 2000)	σ	Pu (H/Pu = 2000)	σ
0.3	5.91E+01	0.01%	5.55E+01	0.01%	4.60E+01	0.01%	1.52E+01	0.01%	3.96E+00	0.03%	4.69E-01	0.09%
0.5	3.26E+01	0.01%	3.07E+01	0.01%	2.54E+01	0.01%	8.59E+00	0.02%	2.32E+00	0.03%	3.07E-01	0.11%
1	1.24E+01	0.01%	1.16E+01	0.01%	9.64E+00	0.01%	3.34E+00	0.02%	9.54E-01	0.04%	1.50E-01	0.12%
2	4.06E+00	0.01%	3.82E+00	0.02%	3.16E+00	0.02%	1.11E+00	0.03%	3.32E-01	0.05%	5.94E-02	0.14%
5	7.91E-01	0.02%	7.44E-01	0.02%	6.15E-01	0.02%	2.17E-01	0.04%	6.52E-02	0.08%	1.15E-02	0.20%
10	2.09E-01	0.03%	1.97E-01	0.03%	1.63E-01	0.03%	5.77E-02	0.06%	1.74E-02	0.11%	3.17E-03	0.32%
20	5.22E-02	0.04%	4.91E-02	0.05%	4.07E-02	0.05%	1.46E-02	0.08%	4.54E-03	0.18%	9.55E-04	0.42%
50	7.70E-03	0.07%	7.25E-03	0.08%	6.02E-03	0.09%	2.23E-03	0.14%	7.57E-04	0.27%	2.22E-04	0.69%
100	1.62E-03	0.12%	1.53E-03	0.12%	1.29E-03	0.14%	4.96E-04	0.22%	1.85E-04	0.46%	6.86E-05	1.05%
200	2.71E-04	0.20%	2.58E-04	0.21%	2.19E-04	0.25%	8.98E-05	0.41%	3.71E-05	0.68%	1.63E-05	1.53%
300	7.77E-05	0.33%	7.42E-05	0.32%	6.42E-05	0.35%	2.76E-05	0.57%	1.20E-05	0.91%	5.45E-06	1.76%
500	1.17E-05	0.68%	1.12E-05	0.70%	1.00E-05	0.69%	4.67E-06	1.36%	2.08E-06	1.91%	9.05E-07	3.53%
700	2.54E-06	1.16%	2.45E-06	1.28%	2.25E-06	1.26%	1.11E-06	1.85%	4.91E-07	2.63%	2.14E-07	4.04%
1000	3.74E-07	2.81%	3.72E-07	2.65%	3.41E-07	2.71%	1.87E-07	6.31%	8.22E-08	4.83%	3.30E-08	7.80%
1200	1.24E-07	4.13%	1.32E-07	4.36%	1.21E-07	4.13%	6.64E-08	10.37%	2.55E-08	7.59%	1.03E-08	11.34%

8.3 SLIDE RULE SPECIFICATIONS - STEP 2

UPDATE OF THE NUCLEAR CRITICALITY SLIDE RULE CALCULATIONS

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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.

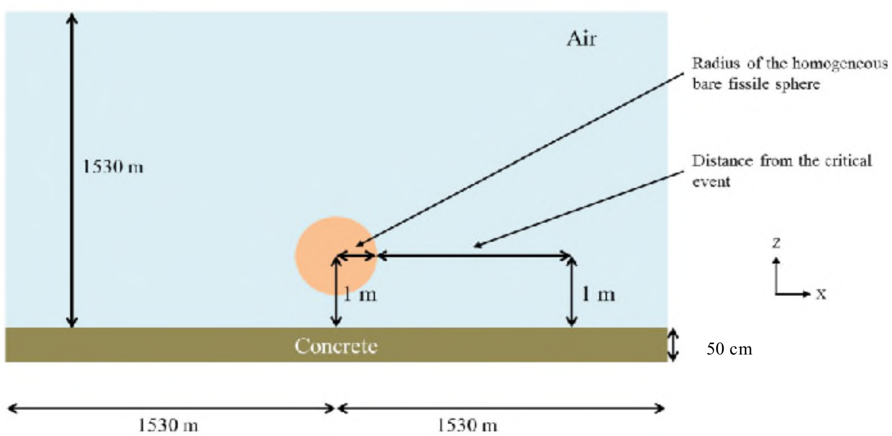

Figure 1: X-Z Plan view of the configuration

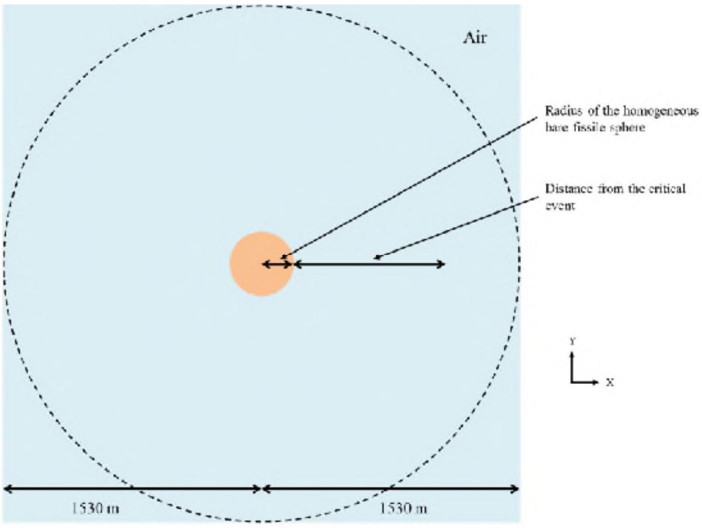

Figure 2: X-Y Plan view of the configuration

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

	H/Pu = 0	H/Pu = 10	H/Pu = 100	H/Pu = 900	H/Pu = 2000
	Number density (atom/barn-cm)				
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

	H/Pu = 0	H/Pu = 10	H/Pu = 100	H/Pu = 900	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	H/Pu = 0	H/Pu = 10	H/Pu = 100	H/Pu = 900	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[2] 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

Steel 304 PNNL	Number density (atom/barn-cm)
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
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

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

Steel 304 PNNL	Number density (atom/barn-cm)
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)				
		H/Pu = 0	H/Pu = 10	H/Pu = 100	H/Pu = 900	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.

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

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

Concrete	Number density (atom/barn-cm)
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[3]:

- 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 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[4],
  - S: sphere[5]
  - UN: unreflected (no shielding)[6],
  - G1: first case with a ground[7],
  - C1: first case with the plutonium system (H/Pu = 0)[8],
  - d03: distance 0.3 m,
  - N: prompt neutron[9].

[3] 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.

[4] Pu is for Plutonium

[5] CYL1, CYL2 or CYL3 stands for cylinders

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

[7] G1 is for concrete ground.

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

[9] « G » stands for prompt gamma.

8.4 SLIDE RULE SPECIFICATIONS - STEP 3

UPDATE OF THE NUCLEAR CRITICALITY SLIDE RULE CALCULATIONS

–

SENSITIVITY STUDIES

IDENTIFICATION NUMBER: SR-U-UNREFLECTED-GROUND-002

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. Additional configurations were performed to include plutonium systems.

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

2 DESCRIPTION OF THE CONFIGURATIONS

2.1 GEOMETRY

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

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.

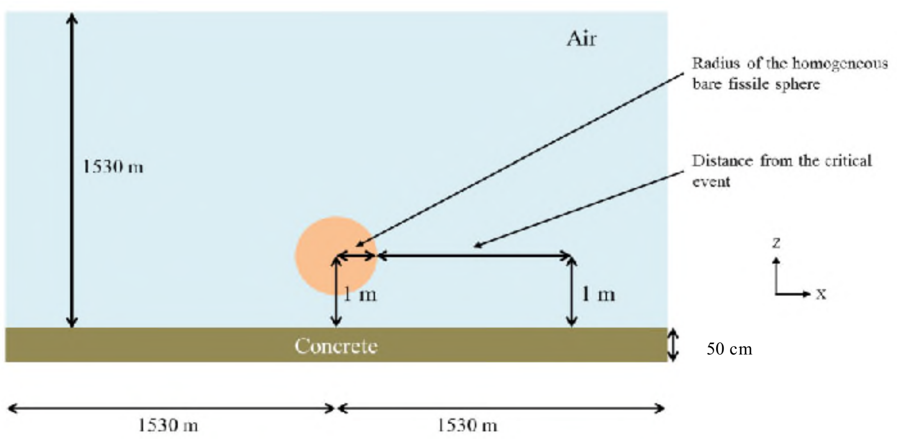

Figure 2-1: X-Z Plan view of the configuration

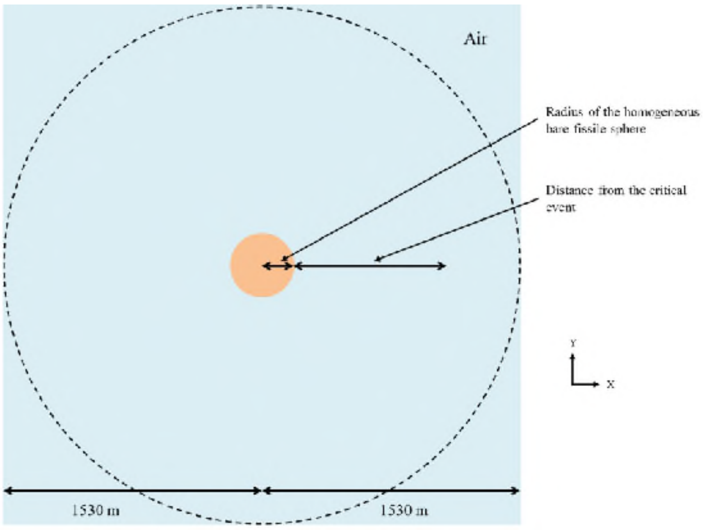

Figure 2-2: X-Y Plan view of the configuration

2.2 SOURCE

The critical uranium systems are as follows:

- unreflected sphere of 4.95 wt % enriched aqueous uranyl fluoride, $U(4.95)O_2F_2$ and 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, $U(93.2)O_2(NO_3)_2$ and H_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).

2.2.1 DIMENSIONS

The 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[10]

[10] This radius, calculated with the first Slide Rule, does not guarantee a critical system. A radius of 12.22 cm should be considered instead.

2.2.2 MATERIAL AND TEMPERATURE DATA

The atomic compositions for the source are given in Table 2-2.

Table 2-2: Composition 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%)
	Number density (atom/barn-cm)				
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

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

3 DESCRIPTION OF THE SENSITIVITY STUDIES

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

3.1 MOISTURE IN AIR

Initial slide rule configurations were calculated with a humidity of 0 %. Neutron and gamma prompt dose calculations will be performed with a humidity of 10 % and 100 %, at the room temperature, for the case 1 (UO_2F_2) and case 4 (U metal). The air composition to be used is given in the following table:

Table 3-1: Composition of air – humidity of 0 %, 10 % and 100 %

	Air Humidity 0 %	Air Humidity 10 %	Air Humidity 100 %
	Number density (atom/barn-cm)		
N-14	3.9305E-05	3.9214E-05	3.8397E-05
O-16	1.0765E-05	1.0798E-05	1.1094E-05
H-1	0	1.1559E-07	1.1559E-06

3.2 GROUND COMPOSITION AND DIMENSIONS

Calculations will be performed with the regulatory concrete composition, cf. Table 3-2. Nevertheless, a dry soil composition (without hydrogen) will be also tested for the case 1 and case 4, cf. Table 3-3. In each case, neutron and gamma prompt dose calculations should be performed. Moreover, the dimension for the ground was changed from 30.48 cm (initial configurations) to **50 cm**. The following tables give atomic concentration of the concrete and the soil[11].

[11] 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 3-2: Composition of concrete (REGULAR-CONCRETE-NRC)

Concrete	Number density (atom/barn-cm)
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 3-3: Composition of soil (EARTH US average - PNNL)

Soil	Number density (atom/barn-cm)
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

Soil	Number density (atom/barn-cm)
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

Skyshine will be determined for height superior to 10 m in each configuration. The calculations will be performed for heights of 1530 m and 10 m for the case 1 and case 4. The variations of the dose between these two configurations will provide the impact of the skyshine effect.

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 dimensions of the screen are infinite in the Y and Z directions. The calculations will be performed for heights of 1530 m and 10 m for the case 1 and case 4.

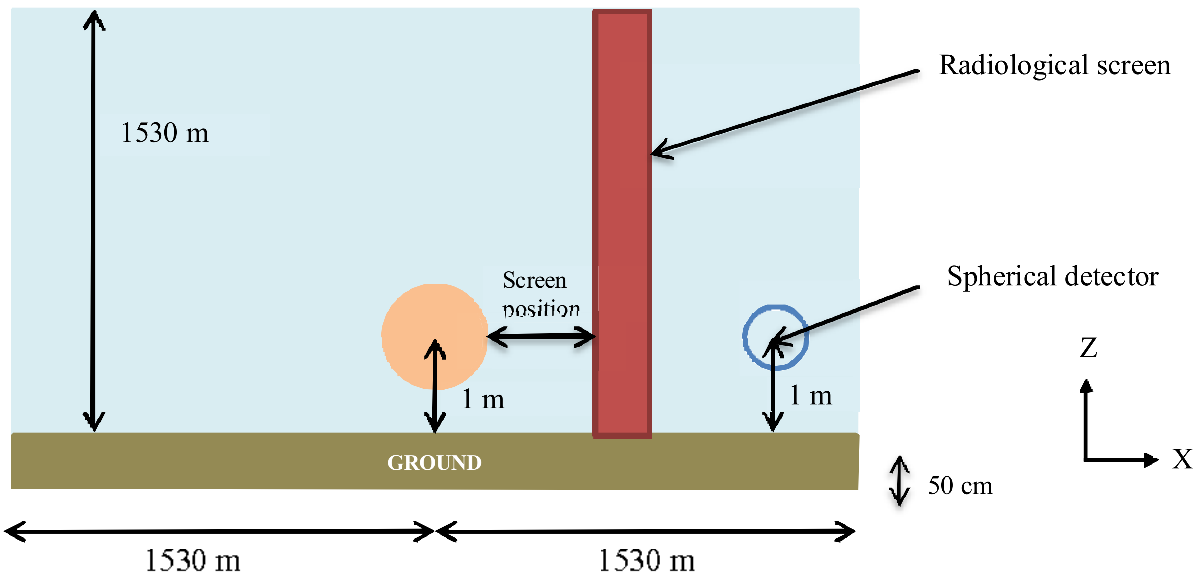

Figure 3-1: X-Z Plan view of the configuration with a radiological screen

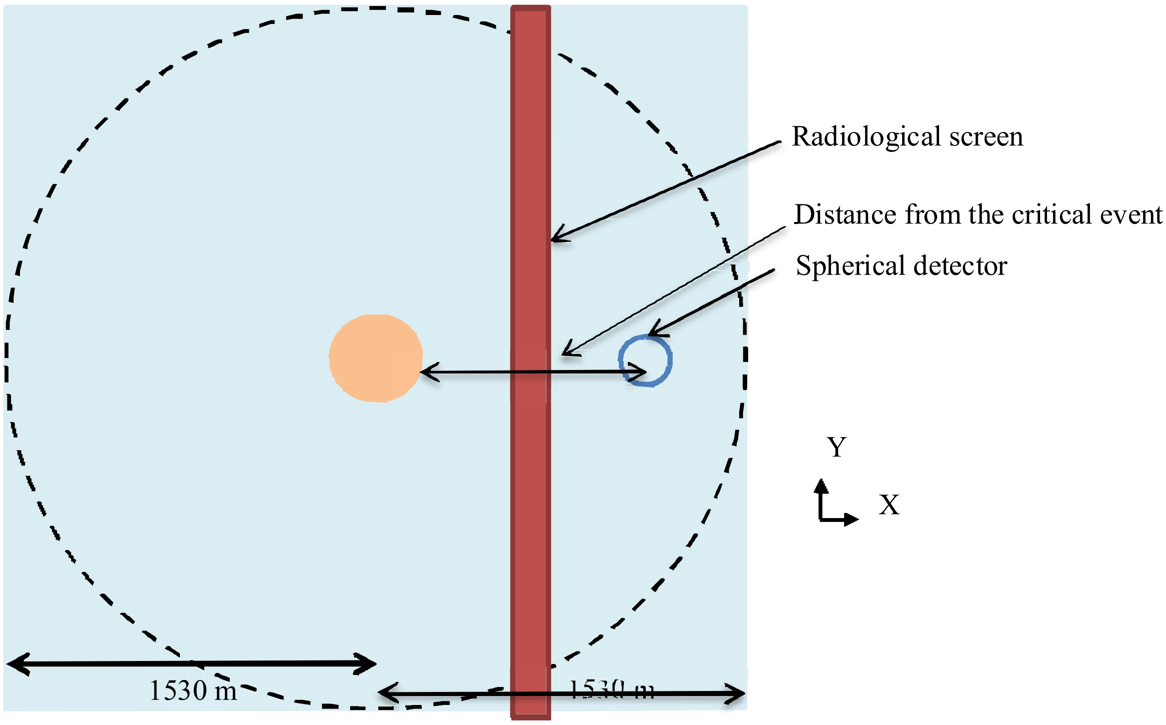

Figure 3-2: X-Y Plan view of the configuration with a radiological screen

The following table presents screen positions for each detector distance.

Table 3-4: 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[12] for the radiological screen are presented in the following table.

Table 3-5: Compositions for the radiological screen

Steel 304 PNNL	Number density (atom/barn-cm)	Water PNNL	Number density (atom/barn-cm)	Lead PNNL	Number density (atom/barn-cm)	Concrete	Number density (atom/barn-cm)
C-6	1.6000E-04	H-1	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	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-16	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						

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

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

Table 3-6: 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. 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 3-7 and Table 3-8 (only a measurement of the flux with these factors). Theses group structures were created using the energy bins used in references [A1] to [A8].

Table 3-7: 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

Upper bounds in MeV						
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
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 3-8: 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			

4 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.

For configurations with a radiological screen, the detector has a spherical shape with a default radius of 20 cm for detector positions from 0.3 cm to 100 m. Then, the radius of the detector may increase to 40 cm for higher distances.

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.

Neutron and gamma doses will be calculated for the following distances: 0.3 m, 0.5 m, 1 m, 2 m, 5 m, 10 m, 20 m, 50 m, 100 m, 200 m, 300 m, 500 m, 700 m, 1000 m and 1200 m.

5 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.

6 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-U-UN-G1-C1-d03-DG10s.inp stands for:
  - SR: slide rule,
  - U: uranium[13],
  - UN: unreflected (no shielding)[14],
  - G1: first case with a ground[15],
  - C1: first case with the uranium system (Uranyl fluoride (4.95%))[16],
  - d03: distance 0.3 m,
  - DG10s: delayed gamma (after 10 seconds)[17].

At the end, 1290 results may be obtained from all the calculations regarding the neutron and gamma prompt doses.

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[A8] American National Standards Institute (ANSI) standard (1977)

[13] Pu is for Plutonium

[14] R stand for reflected configurations.

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

[16] 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.

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

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