The Monte Carlo Method: Versatility Unbounded In A Dynamic Computing World
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RADIOLOGICAL RISK ASSESSMENT OF A STORAGE FACILITY FOR RADIOACTIVE SOURCES

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ABSTRACT

A room with dimensions 4 m x 4 m x 3 m is used as a storage facility for radioactive sources. The sources are stored inside thirteen cylindrical tubes made of standard PVC, dug in the ground with thickness varying from 5 mm to 10 mm. The radioactive sources are stored at the bottom of the cylindrical tubes, at depths varying from 70 cm to 78 cm relative to the ground level of the room. A C-shape concrete barrier with dimensions 38 cm (height) and 11 cm (width) has been built at the ground level surrounding the cylindrical tubes. A cylindrical lead cap with 6 cm thickness closes all the tubes.

The bulk of the study concerned a 530 mCi source of ^{241}Am Be. Considering the radiological hazard of the neutrons from this source, this study was conducted to perform the risk assessment of the facility, which is contiguous to another room with a restricted access but classified as a non-controlled area.

The aim of this computational study consists on assessing the dose rates in the room and compares them with measurements performed in the room using a Bonner-sphere based detector. The state-of-the-art Monte Carlo code MCNPX was used to compute the equivalent doses at different locations above the ground level. The detailed geometry of the setup has been implemented and a standard neutron energy spectrum has been used. The equivalent dose results obtained using different MCNPX tallies have been compared and their agreement has been tested. Considering the long flight path in the soil of neutrons contributing to the point dose in different locations inside the room, the importance of the soil composition has been investigated. The sensitivity of the obtained results to different soil compositions has been checked.

A reasonable agreement between the computed and measured values has been obtained.

Key Words: MCNPX Dose Neutron

1 INTRODUCTION

An underground facility is used to store several types of radioactive sources including a ^{241}Am Be neutron source. The neutrons emitted by this type of radioactive source have an energy ranging from 0,441 eV to 11 MeV.

The room used to store the sources has cubic shape geometry with dimensions 4 m x 4 m x 3 m. The walls are 30 cm width and are made of concrete with a characteristic density of 2,3 g/cm A 10 cm thickness concrete layer covers the floor of the room. The soil below the concrete layer has a characteristic density of 1.6 g cm^{-3}. The geometry of the room is shown in Figure 1

The sources are stored in the bottom of thirteen cylindrical tubes made of PVC dug vertically into the ground. The tubes are arranged in two rows parallel to the wall. There are two sizes of tubes: one with a total length of 80 cm and the other with a total length of 72 cm.

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Enclosing the area occupied by the tubes from the rest of the room there is a C-shape concrete barrier of 38 cm height and 11 cm thickness starting at at ground level

Considering the potential radiological hazard from the stored neutron sources to professional staff working in the area nearby this study tried to assess the dose distribution in the room using the state-of.-the-art computer program MCNPX (ref. [1]). The geometry of the facility setup, including the room and the detailed description of the storage locations has been implemented and is shown in Figure 1. A standard neutron energy spectrum has been used.

The results obtained using different MCNPX tallies have been compared and were found to be in good agreement. In order to validate the computational results, the equivalent dose values obtained using different MCNPX tallies have been compared with measurements performed in the room using a Bonner-sphere based detector. Reasonable agreement has been found.

Considering the long flight path in the soil of neutrons contributing to the point dose in different locations inside the room, the importance of the soil composition has been investigated. The sensitivity of the obtained results to different soil compositions has been checked.

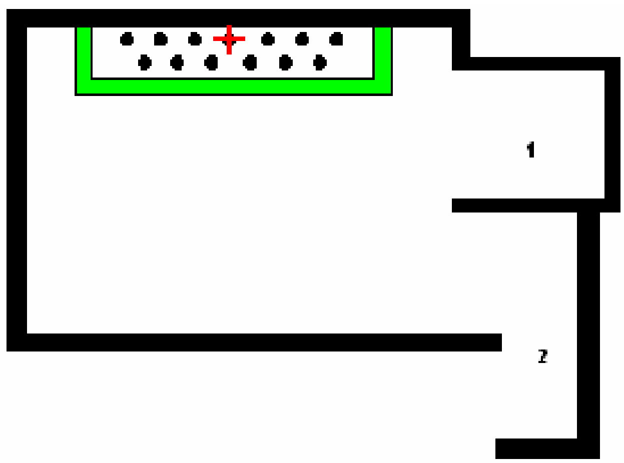

Figure 1: Horizontal layout of the facility The green area corresponds to the C-shape barrier and the black circles correspond to the cylindrical tubes. The cross represents the storage location of the ^{241}AmBe source.

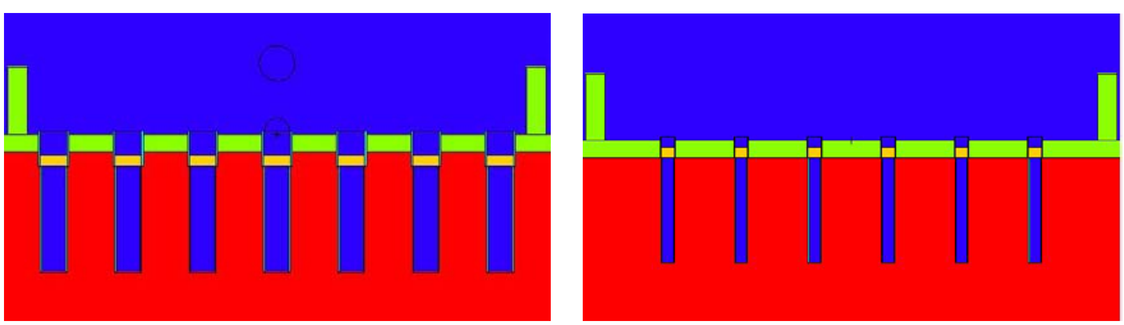

Figure 2: Vertical layout of the cylindrical tubes dug into the ground (viewed behind the wall)

2 DETAILED GEOMETRICAL DESCRIPTION AND COMPOSITION OF THE SOILS

The tubes with larger dimension have a total length of 80 cm (78 cm inside the floor and soil), thickness varying from 10 mm to 7 mm and with inner radius varying from 6,8 cm in the lower section to 7,5 cm in the upper section. The other tubes have a total length of 72 cm (70 cm inside the floor and soil), thickness of 5mm and with inner radius varying from 3,25 cm in the lower section to 3,75 cm in the upper section.

The tubes are made of PVC and have the following composition, in fraction of atomic mass: 4,8% of H; 38,4% of C and 56,8% of Cl and are closed by 6 cm thickness caps made of lead.

Table I: Different soil compositions used during simulations

Elements	H	C	O	Al	Si	K	Ca	Fe	Mg	Na	Ti
Typical Soil	0,021	0,016	0,577	0,050	0,271	0,013	0,041	0,011			
ITN Soil		0,02	0,511	0,046	0,37	0,019	0,007	0,013	0,002	0,009	0,003

2.1 Simplifications made.

The geometry of the facility was simplified by removing the small storage compartment and the baffle plate marked in Figure 1 with the numbers 1 and 2, under the assumption that their contribution to the final result was negligible.

For the sake of sparing computing time, zero-importance was assigned to the region beyond 30 cm thickness inside the walls. This way, all the particles crossing the wall outwards are killed as their contribution to the dose inside the room is unlikely to occur. In the same line of reasoning, particles beyond a soil depth greater than 40 cm below the lower level of the tubes are killed.

2.2 Source description.

The standard ^{241}Am Be source emits neutrons with an Energy distribution ranging from the 0,441eV to 11MeV. The distribution is plotted in Figure 5 as obtained from ref. [2] The corresponding parameters as specified by the manufacturer as displayed in the following Table.

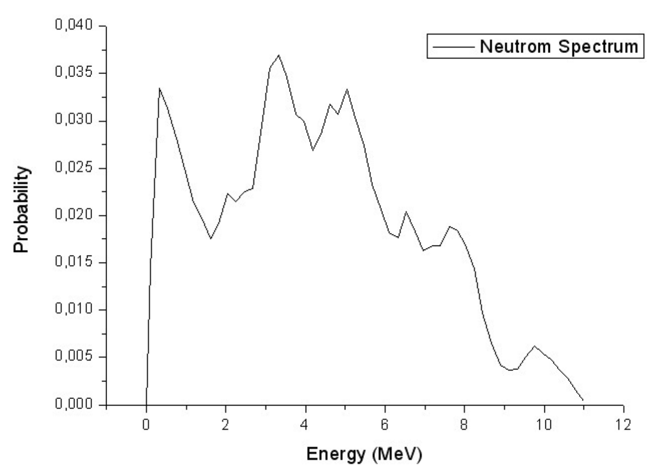

Figure 5: Probability distribution vs. Energy Bin for the neutron source.

Table II: Manufacturer´s data for the 530 mCi neutron source

Source characteristics	Value	Unit
Neutron Emission	2,20E+06	n/sec per Ci
Gamma – Exposure rate	2,50E+00	mR/hr a 1 m per Ci
Dose rate	2,20E+00	mrem/h a 1 m per Ci

2.3 Source Location and Tallies.

Two types of MCNPX tallies were used: flux across a surface (Tally type F2) and point detector tallies (Tally type F5).The tallies were modified by standard dose functions (ICRP-21 1971) and only account for the energy deposited by neutron. The contribution of the photon to the dose was investigated in a first step and was evaluated to be at most ten times smaller than the contribution from the neutrons. Considering this fact and that only the contributions from neutrons could be compared with the experimental data acquired using the Bonner sphere detector (the detection efficiency for photon is negligible), the contributions from neutron-induced photon were ignored.

Using both types of tallies, the dose was assessed in tree points located in the air. The point's position is relative to the ground position marked in Figure 1. For the tally F2, a spherical surface with 10 cm radius filled with air was considered as requested by MCNPX.

For mapping the dose rates in the room, a "mesh tally" centered at 1 m high with 20 cm vertical width, dividing the entire XY (horizontal) plane in squares of 20 cm by 20 cm was computed. Another "mesh tally" centered at y=0 with 20 cm horizontal width and dividing the entire XZ (vertical) plane in squares of 20 cm by 20 cm was also computed.

The computational results obtained using MCNPX as previously explained are displayed in the following Tables. The ^{241}AmBe source is located at the bottom of one of the source containers at a point with coordinates x=0 cm, y=0 cm and z=-70 cm.

3 RESULTS

In order to map the dose rates inside the facility, the "mesh tally" technique of MCNPX was used. The corresponding results in the horizontal and vertical planes previously described are plotted in Figures 3 and 4 respectively.

In order to check the agreement between the results obtained using the two different tallies previously mentioned, the neutron rate at two different locations in air was computed for a standard and for the ITN soil composition. The results are displayed in Table III that shows a good agreement.

The computed doses in three different locations in air, using the ITN soil composition previously described, are displayed in Table IV. A good agreement between the obtained results using the two different tally methodologies can be observed. The same computations were repeated for a typical soil composition and are displayed in Table V. A comparison between the results in the two Tables shows a significant difference and pinpoints the great sensitivity of the computed dose rates to the soil composition.

In order to validate the computational results obtained, several measurements at the same three locations for which the computations have been performed using a Bonner-sphere based detector. The results are displayed in Table VI. The influence of the presence of other types of radioactive sources of smaller activity stored in neighbor tubes has been investigated and found to be small, but measurable, as can be seen in Table VI.

From the analysis of the computed results in Tables IV and V and the measurements performed displayed in Table VI, it can be inferred that for points away from the vertical direction above the source, a better agreement exists when the ITN soil composition is used However, for the two points located vertically above the source location, it seems preferable to use a typical soil composition in order to obtain a better agreement.

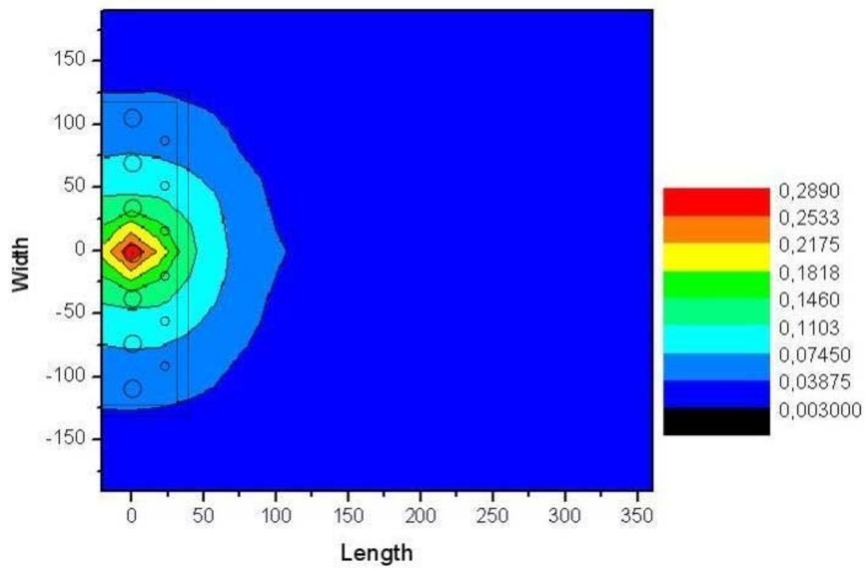

Figure 3: Plot of the dose rates [mRem/h] inside the room viewed from above.

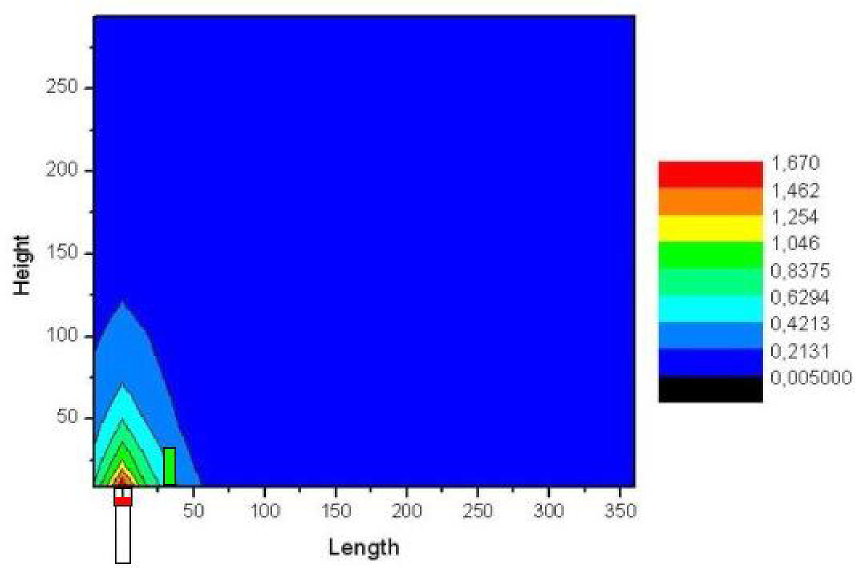

Figure 4: Plot of the dose rates [mRem/h] inside the room viewed from the side.

Table III: Neutron rateat two different locations in air using two different MCNPX tallies for the two soil compositions

Position (cm)	**Neutron rate** (n/sec)		
	Soil	**Tally F2**	**Tally F5**
x=100 y=0 z=100	ITN	3,076E+05	3,326E+05
	Typical	3,004E+04	3,261E+04
x=0 y=0 z=40	ITN	1,870E+06	1,822E+06
	Typical	5,562E+05	5,720E+05

Table IV: Computed dose at three points in air using two different MCNPX tallies for the ITN soil composition

Detector position (cm)	**Dose** (mRem/h)			
	Tally F2	**Uncertainty**	**Tally F5**	**Uncertainty**
x=100 Y=0 z=100	4,95E-02	2,57E-03	4,91E-02	1,18E-04
X=0 Y=0 z=40	8,06E-01	1,24E-02	8,18E-01	1,47E-03
X=0 Y=0 z=0	1,521E+00	1,369E-02	[1]* 2,734E+00	6,836E-03

Table V: Dose at the point in air with coordinates x=100 cm, y=0 cm, z=100 cm using two different MCNPX tallies for the ITN soil composition.

Detector position (cm)	**Dose** (mRem/h)			
	Tally F2	**Uncertainty**	**Tally F5**	**Uncertainty**
x=100 Y=0 z=100	7,91E-03	4,55E-04	8,70E-03	2,70E-05
X=0 Y=0 z=40	5,07E-01	5,12E-03	5,22E-01	5,74E-04
X=0 Y=0 z=0	1,032E+00	9,289E-03	[1]* 1,782E+00	4,455E-03

[1]* Due to the geometric layout of the neighborhood near this point and the proximity of the source, the value of the tally type F5 may be misleading.

Table VI: Measurements performed on the facility

Position	Dose (m Rem/h)	Other sources
x=0, y=0, z=0	0,75	No
x=0, y=0, z=0	1	Cs (48 mCi)
x=0, y=0, z=40	0.4	No
x=0, y=0, z=40	0,5	Cs (48 mCi)
X=100, y=0, z=100	0,1	No

4 CONCLUSIONS

The dose at specific locations in air as well as the overall dose distribution inside an underground facility used for the storage of radioactive sources has been assessed using the state-of-art computer program MCNPX. The computational results obtained using two different types of scoring and tallying methodologies were found to be in a reasonable agreement.

Dose rate measurements were performed at the facility using a standard Bonner sphere detector. Discrepancies between the measured and computed values at specific locations inside the room can be explained by a multiplicity of factors such as:

- Uncertainty on the exact soil composition, underneath the storage room facility
- Uncertainty on the exact composition and geometry of the structural materials (storage tubes, walls, concrete barrier) in the facility
- The detection efficiency and sensitivity of the Bonner sphere, not taken into account in the Monte Carlo simulations performed
- Uncertainty on the real neutron source spectrum (not provided by the manufacturer).
- Uncertainty on the total radiation field existing in the facility, namely the contribution from other radioactive sources (Cs and Co sources of smaller activity) also stored in the facility.

For points away from the vertical position, the computed dose rates results obtained with the ITN soil composition show better agreement with the measurements. . However, when considering points in the vertical direction above the source location, the use of a typical soil composition allows to obtain better agreement. The sensitivity of the computed results to the soil composition is therefore the most important factor determining the variability of the computed dose rate values.

Overall, the ambient dose rate values computed and measured are well below the recommended dose limits for such a facility.

5 ACKNOWLEDGMENTS

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6 REFERENCES

[1] MCNPX version 2.4.0: Monte Carlo N-particle transport code system for multiparticle and high energy applications. RSIC Computer Code Collection CCC-715.

[2] “Reference Neutron Radiations”, International Standard ISO 8529-1:2001(E)