Application of Monte Carlo Modeling based – PHITS code to DSRSs Management in Cameroon

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1. Background and Goal of the present work

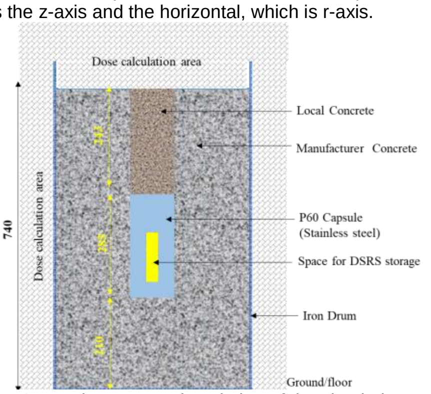
As being non-profitable to the end-users at the end-of-life cycle of a radioactive source, the resulted DSRS is vulnerable. Their management is foremost important to assure that safety and security measures are in place at the management facility. when DSRS becomes waste, the management options in place and internationally recommended ones are made of administrative controls and the implementations of technical measures in terms of "return to the supplier" and/or repatriation, reuse, recycling, long-term storage pending final disposal which could be borehole implementation or geological disposal.

This paper gives an overview of the conditioning of radioactive waste evaluation using Monte Carlo techniques before its experimental implementation. It also discusses the implementation of Monte Carlo simulation in managing the DSRS for the long-term storage option in interim storage facilities. Monte Carlo simulation in this scope is considered as a useful technic to assess the safety and integrity of a waste package.

2. General setting and methodology implementation

2.1. Geometry of the DSRS package

The geometry of the designed DSRS package can be described as an iron or steel drum filled with concrete (Barite concrete or paraffin for neutron and reinforced or ordinary concrete for gamma shielding) with a P60 (Am, Cs or Co model) capsule at the center. The tallies for dose calculation and the decision-making process were set one meter away and at the contact of the capsule in two directions: the vertical which is the z-axis and the horizontal, which is r-axis.

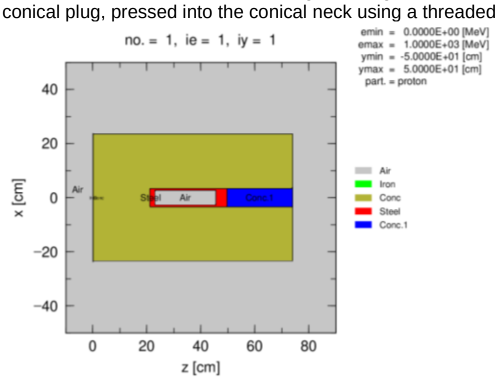


General geometry description of the simulation designed for DSRSs waste management optimization (right) and Pictures of the Drum to contain Am1 P60 or LB 100W container with X. P60 (right)

2.2. Particle and Heavy Ion Transport code System – a Monte Carlo tool

The present study uses Monte Carlo methods to assess the capacity storage of the national interim storage of Cameroon in terms of the available DSRS nationwide in contributing to radioactive waste management nationwide. The principle consists of modeling the real situation by simulating the encasement of DSRSs into an appropriate P60 Capsule, in turn, encased into a concrete-filled drum prepared for long-term storage or disposal purpose.

The Am1 P60 capsule is made of stainless steel with an outer wall thickness of 10 mm, 68 mm diameter, and with a length or height of 285 mm, sealed with a tight conical plug, pressed into the conical neck using a threaded cap.



Geometry Output of the simulation designed for DSRSs waste management optimization generated by PHITS compared to the experimental setup. Different components of the geometry with the materials used and their dimensions.

The following equation was used to compute simulated errors.

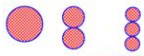
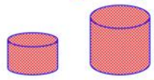
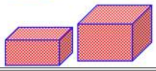
$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}\left(\frac{x_i w_i}{\overline{w}}\right)^2 - N\overline{X}^2}{N(N-1)}}$$

3. Results, discussion and applications

3.1. Output performance of geometrical shapes investigated

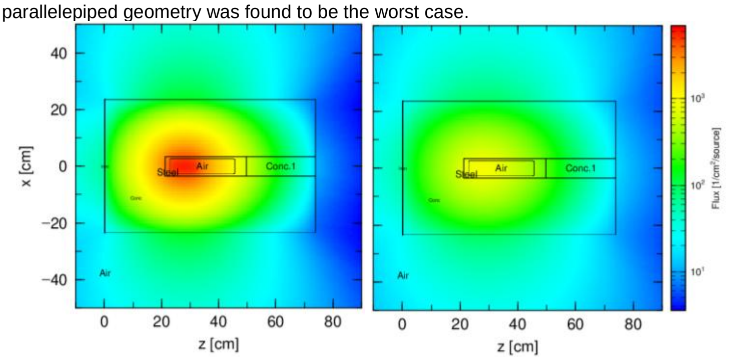
For the sake of conciseness, only the results obtained for the simulation of the ^{241}Am/Be neutron DSRS are described in this section. The shape of the DSRS to be encapsulated in the P60 capsule was investigated before the drum safety evaluation performance around the facility where drums are stored.

Investigation results of DSRS shapes used to encapsulate the sources into the p60 capsule before the housing in the barite concrete-filled drum

Geometry type for waste conditioning	Dimensions	Geometrical form	Volume (cm^3)	External surface (cm^2)
Point-like source (r = ~0)	Point (x_0, y_0, z_0)		~0	~0
Disk source (r = 2.7, h = ~0)	Radius r Center (x_0, y_0)		~0	~πr = (22.9)
Spherical source (r = 2.7) and (n = 1, 2, 3)	Radius r Center (x_0, y_0, z_0)		$4\pi r^3/3$ = (82.45), (164.9), and (247.35)	$4\pi r^2$ = (91.61), (183.22), and (274.83)
Finite cylindrical source (r = 2.7, h = 10) and (r = 2.7, h = 20)	Radius r Height h Center of the bottom face (x_0, y_0, z_0)		$\pi h r^2$ = (229.02) and (458.04)	$2\pi r(h + r)$ = (215.45) and (385.1)
Rectangular or parallelepiped source (x = y, z) = (1.16, 1.16, 10) and (1.16, 1.16, 20)	Thickness X×Y×X x_{min}, x_{max} y_{min}, y_{max} z_{min}, z_{max}		$x \cdot y \cdot z$ = (13.5) and (27)	$2(x \cdot y + x \cdot z + y \cdot z)$ = (49.18) and (95.65)

3.2. Neutron and photon generated fluxes for different geometries

The neutron and photon-generated fluxes for the five investigated DSRS geometry types are presented below. It can be seen that the flux is concentrated at the source position and for volume sources, it is more dispersed than that of the point source of the surface source. This shows that the cylindrical source shape is the most appropriate DSRS geometry to be used while preparing for dismantling, long-term storage, and/or disposal operations. The parallelepiped geometry was found to be the worst case.



Neutron and gamma fluxes from Am-241/Be source in the Cylindrical1 shape geometry

3.3. Exposure assessment based on effective dose calculation and measurement

The 08 neutron DSRSs used for the simulation totaled an effective activity of 450 mCi, which is less than the recommended value of 2 TBq as recommended by the P-60 capsule manufacturer. In addition, the simulation using the source activity limit as recommended by Eckler & Zekler Company demonstrates an agreement with the targeted result of less than 1 mSv/y in the adjacent public area to the interim storage facility. Experimental data were found to be slighter higher than the Monte Carlo simulated values. This could be normally explained by the addition of the background radiation available on site while performing experimental measurement. In addition, the dismantling operation was undertaken for gamma and neutron DSRS at the same time.

Geometry	Effective dose at different positions (µSv/h)		Experimental dose rate (µSv/h)	
	At contact (x-axis)	1 m away	Contact of the drum	1 m away
Point-like	3.04E+01	1.72E+00		
Disk source	3.03E+01	1.70E+00		
Sphere 1	3.24E+01	1.81E+00		
Sphere 2	3.41E+01	1.87E+00		
Sphere 3	3.44E+01	1.88E+00		
Cylindrical 1	3.37E+01	1.84E+00	4.05	2.21
Cylindrical 2	3.42E+01	1.85E+00		
Rectangle 1	3.42E+01	1.86E+00		
Rectangle 2	3.48E+01	1.89E+00		

4. Conclusions and Acknowledgements

The optimum geometry of the DSRS based on PHITS Monte Carlo simulations for the disposal of DSRSs as a waste package was performed. Disk and cylinder were found to be the most optimizing geometries for DSRS long-term storage. Monte Carlo methods are effective computational tools that can be used to enhance the "cradle to grave" management of disused radioactive sources. It is crucial to continuously investigate technical means and ways of safely dispose DSRSs and other rad waste in Cameroon (including the use of Monte Carlo numerical techniques).

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