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Gamma radiation dose to different organs of a standard human phantom due to exposure from a road paved with oil sludge containing Naturally Occurring Radioactive Materials

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ABSTRACT

Oil extraction and processing is a major industry that is present in almost all countries. Large amount of crude oil sludge is left over in oil wells sites. These contain naturally occurring radioactive materials (NORM). This research investigated the gamma radiation dose to a number of organs of a standard human phantom presumably standing on a road paved with oil sludge. The sludge was assumed to have similar NORM contents to sludge from specific oil well. Monte Carlo neutral particles (MCNP) code was used to tally gamma radiation dose to the phantom organs from three circular areas of road of 10, 50, and 100 m radii, paved with 6 cm layer of oil sludge. Effective gamma radiation dose to a number of organs was calculated and compared with the safe limits to workers or public, of 50 mSv/year. All gamma doses to the studied organs were far below the reference dose limits. This suggests that using oil well sludge in paving roads is a safe sustainable environmental solution.

Key words: Dose limit, Gamma dose, NORM, Oil well sludge, Pavement, Public, Worker.

1. Introduction

Oil industry is one of the largest industries in the world. However, it produces huge amounts of wastes some of them are radioactive. These wastes include oil sludge, scales, drilling well-cores and water generated during processing crude oil. Sludge contains elevated levels of naturally occurring radioactive materials (NORM). The presence of radioactive elements in the oily sludge is well documented (Karen et al., 1999, Canoba et al., 2007; IOGP, 2008). Radioactive waste contains NORM, mainly from ^{238}U, ^{235}U, ^{232}Th, ^{226}Ra, ^{228}Ra, and ^{40}K (Pillay et al., 2010; Chukwuocha and Enyinna, 2010; Pitta and Rao, 2011). Hence, oil sludge should be disposed of in controlled manner to avoid environmental pollution and radiation exposure to public. This presents a major problem to oil producers and refineries. Some companies proposed using oil sludge to pave roads in uninhibited areas (EPA, 1996). However, there have always been fears of the radiation dose from NORM contents to any user of these roads. Oil sludge is oily sediment produced during cleaning oil storage tanks and other surface equipment. It is a mixture of sand and heavy hydrocarbons residues left in the process of oil refining. Using this sludge to pave roads was considered, but fear of high radiation dose was a concern. However, the thinness of the paving layer may reduce the gamma dose to road users to below reference dose limits. This study aimed to evaluate the radiation safety of using oil sludge for paving roads.

2. Materials and Methods

Monte Carlo neutral particles (MCNP) code was used to calculate the gamma radiation dose to several organs of an average human male, represented by a standard MCNP phantom presumably standing on a road that was paved by oil sludge (LANL, 2003). Phantom is a specially designed object that is scanned or imaged in the field of medical imaging to evaluate, analyze, and tune the performance of various imaging devices. A phantom is more readily available and provides more consistent results than the use of a living subject and likewise avoids subjecting a living subject to direct risk The human phantom was for an average male.

It was prepared by Oak Ridge National Laboratory (ORNL) in 2007. The height of the phantom was 180 cm (Figure 1), assuming average body built of 70 kg, and average size of its organs (Krstic and Nikezic, 2007). Three different circular areas of road 10, 50, 100 m in radius were assumed to be the ground under the feet of the human phantom standing at its center. The road was made of 6 cm thick layer of oil sludge containing the radioisotopes (Table 1).

The gamma radioactivity of the sludge was 67078 Bq/kg (Al-Futaisi et al., 2007; Subber et al., 2014). The phantom was assumed to be standing at the center of the circular road area. Using MCNP code, gamma radiation dose was tallied in the following organs of the phantom; skin, right lung, left lung, liver, urinary bladder, the two testes, brain, and thyroid, assuming the previous radioisotopes contents in the sludge pavement of the road. In MCNP code, all doses were tallied per becquerel radioactivity of the sludge.

These doses per becquerel were used to calculate the expected annual cumulative dose to the studied organs at exposure to gamma radiation from the road pavement, assuming continuous 24 hours daily exposure. Thus, cumulative annual gamma dose to the studied organs were calculated. These were compared with the maximum dose limit to public and to occupational exposure.

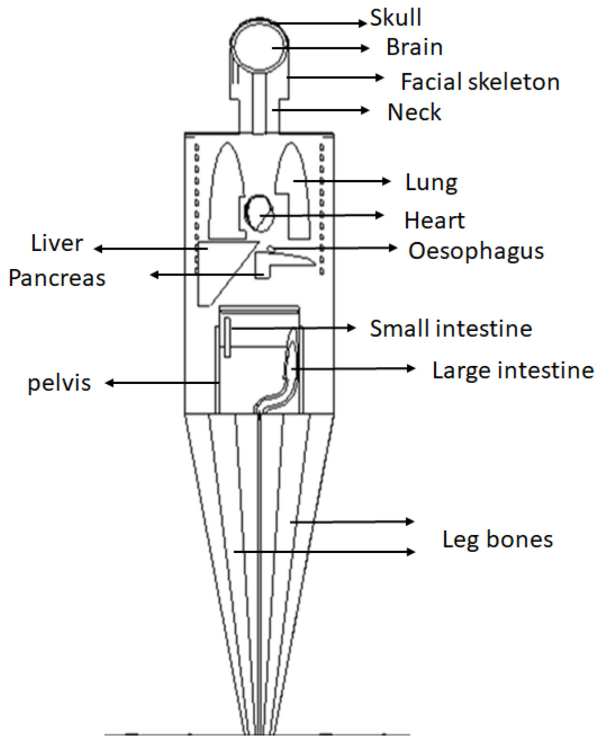

Fig. 1. The adult human phantom by ORNL

The most recent release of MCNP allows an unstructured mesh generated from Abaqus /CAE to be imported as an alternative geometry to the traditional constructive solid geometry (CSG). This capability can provide improved geometry and computational run time compared to mathematical and voxelized models. It also provides improved visualization capabilities, isolation by parts (for visualization and source specification flux and dose information for each element, multi-physics finite element analysis (FEA) of the mesh, and the potential for patient specific models. This report demonstrates these new capabilities of MCNP, specifically the use of unstructured mesh human phantoms for health physics and medical applications

3. Results

Table (1) showed that the emitted gamma rays lies in range between 49 keV and 1460.83 keV. About 26.844% of gamma was 54 keV from Ra-226, other 40% gamma were less than 350 keV also from Ra-226. Exactly, 13% of gamma was 1460.83 keV from K-40. Gamma contribution from U-238 was much less than 1% of total gamma. The maximum energy gamma was 2614 keV from Th-232, which was only 3.73% of total gamma. Therefore, it can be seen that gamma from the studied oil sludge were generally low energy.

Table. 1. Radioisotopes in oil sludge sample, and their relative activity.

Isotope	Gamma energy/keV	Relative activity in sludge sample
U-238	49.55	$1.12249E^{-5}$
	63.30	$6.03923E^{-4}$
	92.38	$3.5108E^{-4}$
	92.80	$3.46249E^{-4}$
	112.81	$3.46249E^{-5}$
	766.361	$5.20179E^{-5}$
	1001.026	$1.36406E^{-4}$
Ra-226	54	0.26844
	170	0.09499
	229	0.09499
	287	0.10738
	345	0.1239
	611	0.04749
	770	0.01239
	942	0.00826
	1131	0.01032
	1249	0.00619
	1398	0.00516
	1761	0.00413
	2158	$5.16235E^{-4}$
Th-232	277	0.00237
	510	0.0085
	583	0.03178
	763	$6.76895E^{-4}$
	860	0.00466
	2614	0.0373
K-40	1460.83	0.129014

Table (2) A,B, and C present the gamma doses in a different organs of the phantom from the NORM values as absorbed doses Mev/g/Bq, equivalent doses mSv/year/kg of sludge, equivalent doses mSv/year according tissue weighing factor and the effective dose MSv/year, for different 16 organs. The doses were generally very low for circular distances of 10, 50, and 100 meters in diameter; some organs such as the kidney, pancreas, thymus, spleen, and kidneys were not affected by the gamma rays emitted from the oil sludge under the current study.

Table 2 A. Gamma doses to different phantom organs from NORM in the sludge pavement

Road circular radius/m	Organ	Absorbed dose MeV/g/Bq	Equivalent dosemSv/Year/kg of Sludge	Equivalent dose mSv/Year	Tissue weighing factor	Effective dose mSv/Year
10	Subcutaneous tissues	1.16426E^{-9}	3.94325E^{-4}	17.46721	N.A.	--
	Skin	3.30282E^{-9}	0.00112	49.55168	0.01	0.49552
	Right lung	3.74566E^{-9}	0.00127	56.19554	0.12	6.74346
	Left lung	3.24263E^{-9}	0.0011	48.64866	0.12	5.83784
	Liver	1.88623E^{-9}	6.3885E^{-4}	28.29881	0.04	1.13195
	Stomach	3.17993E-$^{-10}$	1.07701E^{-4}	4.7708	0.12	0.572496
	Urinary bladder	5.13819E^{-10}	1.74026E^{-4}	7.70874	0.04	0.30835
	The two testes	7.52628E^{-9}	0.00255	112.91557	0.08	9.03328
	Brain	1.41741E^{-9}	4.80064E^{-4}	21.26517	0.01	0.21265
	Thyroid	1.48145E^{-9}	5.01754E^{-4}	22.22596	0.04	0.88904
	The two kidneys	8.46509E^{-10}	2.86705E^{-4}	12.70004	N.A.	--
	Pancreases	1.19327E^{-9}	4.0415E^{-4}	17.90244	N.A.	--
	Spleen	1.50831E^{-9}	5.10851E^{-4}	22.62893	N.A.	--
	Thymus	2.11814E^{-9}	7.17396E^{-4}	31.77811	N.A.	--
	The two adrenal glands	1.89157E^{-9}	6.40658E^{-4}	28.37892	N.A.	--
	Gall bladder	1.93468E^{-9}	6.55259E^{-4}	29.02569	N.A.	--

Table 2 B. Gamma does to different phantom organs from NORM in the sludge pavement

Road circular radius/m	Organ	Absorbed dose MeV/g/ Bq	Equivalent Dose mSv/year/kg of sludge	Equivalent dose mSv/year	Tissue weighing factor	Effective dose mSv/Year
50	Subcutaneous Tissues	5.47928E^{-11}	1.85578E^{-5}	20.55114	N.A.	--
	Skin	1.46183E^{-10}	4.95109E^{-5}	54.82888	0.01	0.54829
	Right lung	1.92293E^{-10}	6.5128E^{-5}	72.12336	0.12	8.6548
	Left lung	1.52336E^{-10}	5.15949E^{-5}	57.13669	0.12	6.8564
	Liver	8.95037E^{-11}	3.03141E^{-5}	33.57017	0.04	1.34281
	Stomach	1.46069E^{-11}	4.94723E^{-6}	5.47861	0.12	0.65743
	Urinary Bladder	1.87931E^{-11}	6.36506E^{-6}	7.04873	0.04	0.28195
	The two Testes	3.7036E^{-10}	1.25438E^{-4}	138.91098	0.08	11.11288
	Brain	6.86294E^{-11}	2.32442E^{-5}	25.74084	0.01	0.25741
	Thyroid	4.24067E^{-11}	1.43628E^{-5}	15.90549	0.04	0.63622
	The Two Kidneys	3.76348E^{-11}	1.27466E^{-5}	14.11569	N.A.	--
	Pancreases	4.56973E^{-11}	1.54773E^{-5}	17.13969	N.A.	--
	Spleen	7.65739E^{-11}	2.59349E^{-5}	28.72058	N.A.	--
	Thymus	1.42877E^{-10}	4.83912E^{-5}	53.5889	N.A.	--
	The Two Adrenal Glands	1.39393E^{-10}	4.72112E^{-5}	52.28215	N.A.	--
	Gall Bladder	1.15707E^{-10}	3.9189E^{-5}	43.39824	N.A.	--

Table 2 C. Gamma does to different phantom organs from NORM in the sludge pavement

Road circular radius/m	Organ	Absorbed dose MeV/g/Bq	Equivalent dose mSv/year/kg of sludge	Equivalent dose mSv/year	Tissue weighing factor	Effective dose mSv/year
100	Subcutaneous tissues	1.39287E^{-11}	4.71753E^{-6}	20.89701	N.A.	--
	Skin	3.54948E^{-11}	1.20218E^{-5}	53.25228	0.01	0.53252
	Right lung	4.54028E^{-11}	1.53775E^{-5}	68.11709	0.12	8.17405
	Left lung	4.30194E^{-11}	1.45703E^{-5}	64.54132	0.12	7.74496
	Liver	2.07861E^{-11}	7.04007E^{-6}	31.18505	0.04	1.2474
	Stomach	4.08487E^{-12}	1.38351E^{-6}	6.12846	0.12	0.73542
	Urinary bladder	5.63792E^{-12}	1.90951E^{-6}	8.45848	0.04	0.33834
	The two testes	1.17426E^{-10}	3.97712E^{-5}	176.17234	0.25	14.0938
	Brain	1.89418E^{-11}	6.41542E^{-6}	28.41808	0.01	0.28418
	Thyroid	2.7927E^{-11}	9.45863E^{-6}	41.89843	0.04	1.67594
	The two kidneys	1.13818E^{-11}	3.85492E^{-6}	17.07593	N.A.	--
	Pancreases	1.13126E^{-11}	3.83148E^{-6}	16.97211	N.A.	--
	Spleen	1.65848E^{-11}	5.61713E^{-6}	24.88191	N.A.	--
	Thymus	2.64023E^{-11}	8.94223E^{-6}	39.61095	N.A.	--
	The two adrenal glands	2.141E^{-11}	7.25138E^{-6}	32.12108	N.A.	--
	Gall bladder	1.10015E^{-11}	3.72611E^{-6}	16.50537	N.A.	--

All dose values for all road area radii were very low and less than the relevant public dose limits. Therefore, no harmful effect is expected at least to the studied organs from gamma emitted by NORM from the studied oil sludge if used to pave public roads.

4. Discussion

The results clearly showed that the two testes received the greatest effective doses of 9.03328, 11.11288, and 14.0938 mSv/year from circular area of radii 10, 50, and 100 m, respectively, of the pavement sludge. These cumulative doses assume 24 hours a day and 365.25 days a year of exposure, which is longer than any expected exposure to public or to workers. Compared with the reference gamma dose limit to individual organs of 50 mSv/year (NCRP, 1993), we can conclude that it is radiologically safe to use oil sludge for paving public roads despite its content of NORM, given the paving layer is ≤ 6 cm thick. Therefore, it is recommended to conduct a series of standard experimental studies in several regions investigation the feasibility of using sludge from various oil wells in different public applications including paving public roads. The importance of such studies is the exploring the economical use of the otherwise costly to dispose oil sludge waste, especially since it is large quantities is wasted in many countries. Our research work showed that the oil sludge is not that radioactive risk as was always believed at least from gamma radiation point of view. However, further investigations are recommended to evaluate the internal alpha doses especially to lung from possible releases of Radon-222 from decay of Ra-226 present in oil sludge. .

Conclusion

The two testes received the greatest effective doses (9.03328, 11.11288, 14.0938 mSv/year) from circular area of radii (10, 50, 100 m respectively) of the pavement sludge, assuming 24 hours a day, 365.25 days a year of exposure. These are still lower than the reference gamma dose limit to individual organs of 50 mSv/year. We can conclude that it is radiologically safe to use oil sludge for paving public roads, within paving layer ≤ 6 cm thick.

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