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BOREHOLE DIMENSIONS NEEDED TO FIT THE BRAZILIAN INVENTORY OF DISUSED RADIOACTIVE SEALED SOURCES FROM LIGHTNING RODS AND SMOKE DETECTORS

José Claudio Dellamano[1] and Goro Hiromoto[2]

Gerência de Rejeitos Radioativos
Instituto de Pesquisas Energéticas e Nucleares – CNEN/SP
Av. Professor Lineu Prestes, 2242
05508-000 São Paulo, SP
[1] jcdellam@ipen.br
[2] hiromoto@ipen.br

ABSTRACT

Brazil has a large inventory of disused sealed radioactive sources (DSRS), accounting over two hundred thousands sources being safely stored at Brazilian National Nuclear Energy Commission institutes. The majority of them can not be disposed of in near surface repository due to long lived alpha emitters, mainly Ra-226 needles formerly used in brachytherapy and Am-241 sources from smoke detectors and lightning rods, which correspond to more than 90% of the total number of the sources currently stored. Therefore, an alternative strategy to dispose of these classes of DSRS is to adopt the IAEA Borehole Disposal Concept (BDC); in this sense, due to the usually small diameter of the disposal container, knowledge of the volume of each of these sources is needed. All Ra-226 needles and Am-241 sources from lightning rods do not have significant variations in geometry and size, but Am-241 sources from smoke detectors have more than 20 different sizes covering a range from a few millimeters to about sixty millimeters in length. Of course, this fact will strongly affect the borehole design. The main objective of this paper was to determine accurately the capacity of the BDC disposal capsules required to condition these sources as a function of the different diameters of the capsules. Results showed that the borehole linear extension necessary to fit the Brazilian inventory of Am-241 sources from lightning rods and smoke detectors can reach hundreds of meters, depending on the BDC capsule diameter chosen. These findings showed that the final destination of this class of DSRS of the Brazilian inventory should be carefully examinated.

1. INTRODUCTION

Disposal of disused sealed radioactive sources (DSRS) formerly used in a wide range of industrial, medical and research applications poses a particular problem for the establishment of the waste management policies in many countries, especially in the developing ones. Brazil has a large inventory of DSRS, accounting over two hundred thousands sources currently stored at Brazilian National Nuclear Energy Commission facilities. The majority of them will not be disposed of in near surface repository due to the very high activity, or because the long lived alpha emitters, mainly Ra-226 needles from medical users and Am-241 or Ra-226 sources removed from smoke detectors (SD) and lightning rods (LR). Sources from SD and LR correspond to more than 90% of the total number of the sources stored. One alternative option to dispose of these classes of DSRS is to adopt the IAEA Borehole Disposal Concept (BDC). Due to different geometries and dimensions of such sources, and considering that borehole usually has been designed with very narrow diameter, it is important to determine the bulk volume of LR and SD sources, as a function of the disposal capsule diameters that will accommodate them. The aim of this paper is to make an accurate estimate of the borehole length necessary to fit the Brazilian inventory of Am-241 sources removed from SD and LR.

1. TYPES of Am-241 SOURCES

The types and the inventory of the Am-241 sources presently stored at Nuclear and Energy Research Institute (IPEN), a research institute and centralized waste storage facility that belongs to the Brazilian Nuclear Energy Commission, are shown in Fig.1 and Table 1, respectively.

All Am-241 sources removed from lightning rods are of the same type and have approximately the same dimensions, presenting an estimated average activity of 7.1 MBq per source. On the other hand, the geometry and dimensions of the sources drawn from smoke detectors are quite diverse, having been catalogued to date 20 different types, with length ranging from 3 to 62 mm and nominal activity from 3.7 kBq to 2.5 MBq/source, all them above clearance limits, established for unconditional release of radioactive material, according to the Brazilian regulations [1].

Figure 1: Types of Am-241 sources of smoke detectors (rows 1 and 2) and lightning rods (row 3)

3. DETERMINATION OF THE BULK VOLUME

The bulk volume V (cm^3) of each type of these sources was experimentally determined using ten PVC cylindrical tubes of 22 cm length, with diameters ranging from 1.27 to 14.50 cm, and filling them with a known number of sources of each source type.

$$V_{i,k} = \pi r_k^2 \frac{h_k}{N_i}$$

where

r_k = radius of tube k (cm)

$h_{i,k}$ = height reached by the column of sources of type I, in the tube k (cm)

N_i = number of sources of type I, in the tube k

Table 1. Number of Am-241 sources removed from lightning rods and smoke detectors stored at IPEN, as of December 2017.

Source type	Number of sources	Total activity (Bq)	Source type	Number of sources	Total activity (Bq)
LR	72,372	5.1 10^{11}	SD11	3,098	6.2 10^{9}
SD1	17,475	5.2 10^{8}	SD11a	6,196	2.1 10^{9}
SD2	12,058	3.6 10^{8}	SD12	1,226	3.6 10^{7}
SD3	302	7.8 10^{6}	SD13	87	6.5 10^{6}
SD4	4,359	1.6 10^{7}	SD14	819	2.7 10^{7}
SD5	1,615	1.5 10^{8}	SD15	21	1.6 10^{6}
SD5a	1,615	1.5 10^{8}	SD16	144	1.1 10^{7}
SD6	2,954	4.9 10^{7}	SD17	838	2.8 10^{7}
SD7	1,556	5.2 10^{7}	SD18	662	2.2 10^{7}
SD8	4,822	1.1 10^{9}	SD19	3,029	1.0 10^{8}
SD9	1,242	4.1 10^{7}	SD20	192	1.4 10^{7}
SD10	972	2.7 10^{8}	Total	137,654	5.3 10^{11}

4. RESULTS

The calculated bulk volumes of each type of source, for a given capsule diameter, are presented in Table 2.

The type SD1, SD2, SD11 and SD15 sources are especial cases.

Type SD1 sources, corresponding to 27% of the total amount of stored sources, did not fit into the tubes with 1.72 and 2.12 cm diameter.

Type SD2 sources, corresponding to 18%, and type SD15 sources, corresponding to only 0.03% of the total amount of stored sources, did not fit into the tubes with 1.72 cm diameter.
Type SD11 sources, corresponding to 4.8% of the total amount of stored sources, did not fit into tubes with diameter smaller than 6.63 cm. These sources are composed by eight strips identical to type SD19, fixed to a disk of 6.2 cm diameter. These strips could possibly be separated and the disk discharged as inactive waste after decontamination or given a final

destination other than borehole disposal. However, the disassembling operation is not yet provided for, by now, since it demands the installation of a proper glove-box with instrumentation for handling of the sources.

Considering the amount of each type of sources presented in Table1 and the associated volumes presented in Table 2, the total bulk volume was calculated. The equivalent borehole disposal length, taking into account two possible scenarios, is shown in Fig. 2 and Fig. 3.

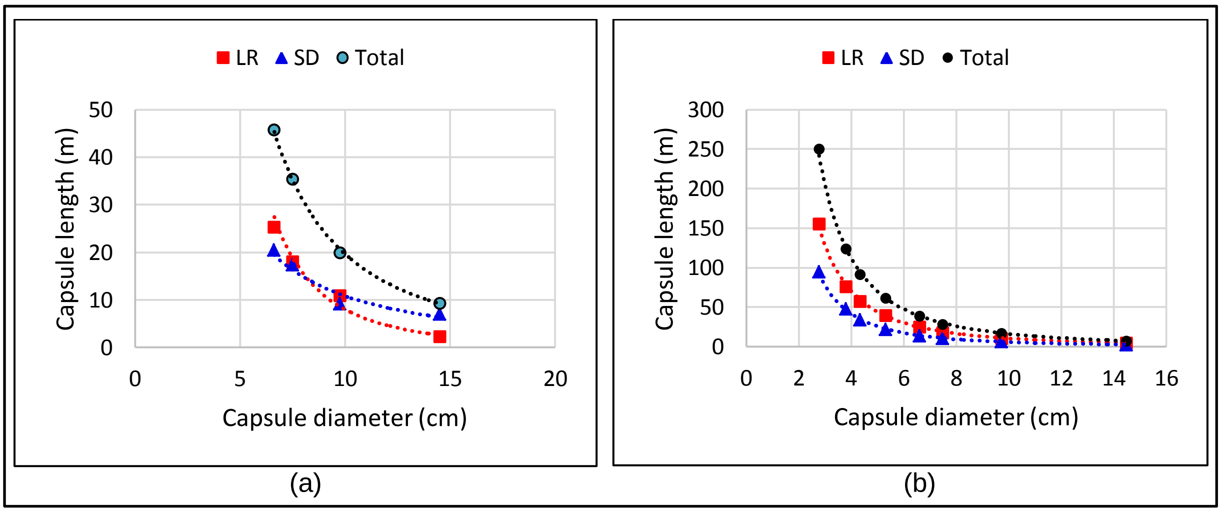
Scenario 1: All type SD11 sources are not disassembled. It is assumed that the disks are arranged neatly on the top of each other and the adjacent empty volume of capsules with larger diameters is filled optimally with other sources. Therefore, in this case, the capsules necessary to fit the entire inventory should not be smaller than 6.2 cm diameter.

Scenario 2: The Am-241 strips will be further separated from the supporting disk. In this case, capsules to fit all the inventory should not be smaller than 2.8 cm diameter.

Table 2. Bulk volume of each type of Am-241 source, as a function of the capsule diameter. Blank cell means that source size is larger than capsule diameter.

Type of source	Tube diameter (cm)									
	1.72	2.12	2.78	3.80	4.35	5.33	6.63	7.50	9.75	14.50
LR	1.55	1.28	1.30	1.19	1.17	1.22	1.21	1.10	1.12	ND
SD1			2.42	2.27	2.09	2.00	1.95	1.92	1.85	1.87
SD2		0.59	0.60	0.59	0.58	0.58	0.53	0.53	a	0.54
SD3	0.84	0.70	0.67	0.61	0.61	0.59	0.58	a b	a b	a b
SD4	0.06	0.06	0.06	0.06	0.06	0.06	0.06	a b	a b	a b
SD5	0.35	0.31	0.31	0.29	0.30	0.29	0.28	0.26	0.26	0.26
SD5A	0.01	0.01	a	a	a	a	a	a	a	a
SD6	0.42	0.41	0.42	0.41	0.41	0.42	0.39	0.39	0.41	0.39
SD7	0.30	0.26	0.27	0.24	0.24	0.25	0.24	0.23	0.21	a b
SD8	0.15	0.15	0.15	0.14	0.14	0.14	0.13	0.13	a b	a b
SD9	0.12	0.11	0.11	0.12	0.11	0.11	0.11	a b	a b	a b
SD10	2.02	1.80	2.02	1.42	1.45	1.41	1.26	1.32	1.33	1.20
SD11							7.50	7.50	7.50	7.50
SD11A	0.01	0.01	a	a	a	a	a	a	a	a
SD12	0.81	0.79	0.78	0.76	0.72	0.67	0.40	0.38	0.37	a
SD13	2.73	3.35	3.78	3.34	2.97	3.3	3.03	b	b	b
SD14	0.30	0.26	0.25	0.22	0.22	0.20	0.22	0.19	b	b
SD15		2.93	2.82	2.21	b	b	b	b	b	b
SD16	1.16	1.10	0.88	0.74	0.71	0.71	a b	a b	a b	a b
SD17	0.02	a	a	a	a	a	a	a	a	a
SD18	0.12	0.10	0.10	0.09	a b	a b	a b	a b	a b	a b
SD19	0.01	0.01	a	a	a	a	a	a	a	a
SD20	1.27	1.35	1.21	1.07	1.06	0.97	0.97	a b	a b	a b

a. Not measured; it was assumed that the bulk volume is no longer dependent on larger diameters.
b. The amount of existing sources is too low to an accurate height measurement.



LR = sources from lightning rods; SD = sources from smoke detectors;
Total = total length in scenario 1; dashed lines = power function adjusted curve.

Figure 2. Continuous linear capsule-length to fit all Am-241 sources from LR and SD stored at IPEN in scenario 1 (a) and scenario 2 (b)

The data were fitted to a power function of the type $y = ax^b$, resulting in the following equations:

Scenario 1:	*Lightning rods,*	$y = 7926x^{-2.996}$
	Smoke detectors,	$y = 285.1x^{-1.420}$
	Total lenght,	$y = 2112x^{-2.032}$
Scenario 2:	*Lightning rods,*	$y = 1261x^{-2.083}$
	Smoke detectors,	$y = 820.3x^{-2.152}$
	Total lenght,	$y = 2079x^{-2.108}$

Therefore, continuous linear capsule-length y_i can also be estimated as a function of the number of pieces of lightning rods and smoke detectors, assuming that the ratio of the amount of each of the 20 types of smoke detectors, in relation to the total, will be maintained:

For scenario 1: $y_i = 0.6571 N_{LR}\, x_i^{-2.996} + 0.005369 N_{SD}\, x_i^{-1.420}$

where

N_{LR} = *number of lightning rods from which Am-241 sources were drawn*

N_{SD} = *number of smoke detectors from which Am-241 sources were drawn*

0.6571 = 7926/12062, were 12062 is the number of the lightning rods used to fit the power function.

0.005369 = 285.1/53097, were 53097 is the number of the smoke detectors used to fit the power function.

x_i = *capsule diameter (cm)*

For scenario 2: $y_i = 0{,}1046 N_{LR}\, x_i^{-2.083} + 0{,}01545 N_{SD}\, x_i^{-2.152}$

where

0,1046= 1261/12062, were 12062 is the number of the lightning rods used to fit the power function.

0,01545 = 820.3/53097, were 53097 is the number of the smoke detectors used to fit the power function.

Note that the data presented here refers only to the sources stored at IPEN, as of December 2017. For a real project of borehole, at least 4 other factors, that will directly affect the design, need to be taken into consideration: (1) The sources stored at other waste storage facilities in the country will increase in about 44% de borehole length [2]. (2) The sources, of course, will not be arranged in a single continuous capsule, as it was assumed in the present study. The additional length of the borehole will depend on the spacing between two adjacent capsules and the number of the capsules needed, which in turn, depends on the chosen diameter of the capsule. (3) The projection of future demand. It is estimated that about 75,000 lightning rods were installed over the country in the past [3]. This means that only about 20% of them were collected up to date. In the last 5 years, the annual number of LR and SD received for storage at IPEN has been relatively constant, increasing the present amount in about 1,000 sources from LR and about 3,000 sources from SD each year. (4) Other types of stored DSRS, as Ir-192, Co-60, Cs-137, Ra-226, Am-241 etc. will need borehole disposal. However, only a small fraction of such sources has been so far disassembled from the original shielding devices, not allowing, by now, a reliable estimate of their total volume.

5. CONCLUSION

The lightning rods and smoke detectors accounts for approximately 90% of the total number of DSRS stored in the country. In the absence of an alternative to the final destination of the sources from lightning rods and smoke detectors, as repatriation or recycling of the Am-241, this class of DSRS could be the driving factor for the borehole design. Disposal capsules with inner diameter less than 6.5 cm will not fit type SD11 sources from smoke detectors (4.8% of the total), unless they are disassembled. Disposal capsules with inner diameter less than 3 cm will not fit type SD1 and type SD11 sources from smoke detectors which, combined, account for 32% of the total. Last, disposal capsules with inner diameter smaller than 2 cm will not fit types SD1, SD2, SD11 and SD15 sources from the smoke detectors which, combined, account for 50% of total of the LR and SD sources. From the above considerations and with a relatively large borehole length needed to accommodate all the present stored DSRS sources, it seems that capsule dimension should not have less than 6.5 cm of inner diameter, if no alternative final destination of LR and SD are planned.

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