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Preliminary post-closure safety assessment for a borehole-type repository for disused sealed radioactive sources in Brazil

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ABSTRACT

Brazil has a relatively large inventory of disused sealed radioactive sources (DSRSs). Until now, no decision has yet been made about the final destination of this category of radioactive wastes, although a repatriation of a small fraction of these sources comprising mainly neutron and high activity sources was already carried out. Borehole type repositories are one disposal solution considered for DSRSs in Brazil. This paper addresses a preliminary post-closure safety assessment for such a facility, using the borehole disposal concept (BDC) applied to different geological conditions and a range of projected inventories. Results from running the AMBER code considering deterministic and stochastic approaches showed that Am-241 is the main source of potential concern in order to comply with the effective dose constraint of 0.3 mSv/y and allowed the establishment of the relation between the maximum Am-241 inventory and the hydraulic conductivity of the geosphere.

1. Introduction

In many countries worldwide sealed radioactive sources have been in use for many decades in medicine, industry and research for various applications (IAEA, 2005, 2014). Medical facilities represent a large user group for sealed radioactive sources, most notably used for radiotherapy purposes. In industry, sealed radioactive sources are commonly used for radiography applications, quality control measures, well logging, energy supply in remote locations and industrial irradiators, among others. With respect to research, radioactive sources are found in irradiators for conducting radiobiological studies and are used in material science. Other applications of radioactive sources have been ionization smoke detectors and radioactive lightning conductors installed in many countries.

After a useful lifetime of usually 5–15 years the radioactive sources are termed as 'spent' or 'disused' (IAEA, 2005, 2014). Like the varied characteristics of the disused sealed radioactive sources (DSRSs), the possible options for appropriate disposal are diverse (IAEA, 2005). Optionally combined with a preceding decay storage, possible solutions for the disposal of DSRSs are trench or vault type near surface facilities, large cavern facilities at intermediate depth (several tens of meters below surface), shaft/borehole type repositories at depths ranging from ~ 30–300 m and deep boreholes and mined geological repositories of depths greater than 300 m. Both, the activities and the half-lives of the DSRSs as well as their quantities are properties of particular interest when choosing a suitable disposal system. The DSRSs containing radionuclides with higher activities (e.g. Co-60, Sr-90, and Cs-137) and longer half-lives (e.g. Ra-226, Am-241, Pu-238, and Pu-239) require a greater degree of isolation, including but not limited to considerations of human intrusion after an institutional control period of typically 100–300 years, what could be achieved by greater depth and a site and waste specific engineered barrier system (IAEA, 2014).

In the countries of the former Soviet Union (USSR), shallow depth borehole type repositories for the disposal of DSRSs have been in operation for over 40 years (Ojovan et al., 2003). A safety assessment of such a disposal facility was presented in Ojovan et al. (2000). Another example for the relevance of borehole facilities for the disposal of DSRSs are the ongoing works in African countries like South Africa or Tanzania (Salehe and Kim, 2013). These works progressed in conjunction with different projects within the International Atomic Energy Agency's AFRA program (IAEA/AFRA) that started in the beginning of the 1990s. Regarding the management of DSRSs, the first major projects particularly addressed issues associated with the conditioning of spent radium sources in stainless steel capsules of standardized dimensions enabling subsequent handling, transport and storage as well as the disposal of (radium bearing) DSRSs in specially designed borehole disposal facilities (BDF) able to provide long-term safety under a wide range of geological and climatic conditions. The development of a

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portable remote handling device ("mobile hot cell") allowed for the conditioning of DSRSs with higher activities, thus making the borehole disposal concept (BDC) a suitable solution for almost all types of DSRSs (IAEA, 2011).

This paper aims to present the results of a preliminary post-closure safety assessment of the disposal of DSRSs from Brazil in a borehole-type repository using the BDC concept, through a two phase approach. Firstly, a deterministic analysis considering the Brazilian inventory was conducted based on a Generic Safety Assessment (GSA) elaborated for the IAEA's borehole disposal concept for DSRSs. Taking into account the results of the deterministic analysis, a probabilistic sensitivity analysis was developed to identify the response in terms of total dose as a function of the Am-241 inventory and the hydraulic conductivity of the geosphere. This analysis was intended to estimate the limits for the applicability of the BDC concept to the Brazilian situation.

2. The BDC and the GSA

The main safety features of the considered BDC are given below, being consistent with the design described in IAEA (2011):

- Fully welded 3 mm thick 316L stainless steel capsules accommodating the DSRSs. The design provides for capsules with fixed wall thickness and length and two different diameters to encase sources of varying physical sizes.
- Thick walled (6 mm) and 250 mm long, fully welded 316L stainless steel disposal containers. In each disposal container one capsule containing the DSRSs is placed surrounded by a cement buffer, also referred to as containment barrier.
- A narrow diameter (minimum 260 mm at maximum depth) borehole in which the disposal containers are emplaced separated by a concrete backfill in 1 m intervals (Fig. 1). The top of the disposal zone is located at least 30 m below ground/the local erosion base accounting for human intrusion and changes of the geomorphology, respectively. The disposal zone reaches depths of more than 100 m and ends with a 0.5 m long concrete plug in the bottom. An anti-intrusion plate is installed at the top of the disposal zone and the remaining part above is backfilled with concrete. The chosen host rocks will preserve favorable geological conditions and thereby the integrity of the disposal containers for the required period of time (up to tens of thousands of years).

Although the BDC considered for the disposal of DSRSs includes several standardized components and features, adaptions to a specific inventory and/or disposal site characteristics are possible bearing in mind the limitations imposed by the safety assessment. Possible alterations are for example capsules and disposal containers manufactured in diverging lengths, disposal containers accommodating more than one capsule, a reduced spacing between the packages and therefore a relative greater quantity of disposal packages per borehole (IAEA, 2011) and an extended depth of the disposal zone up to several hundred meters (IAEA, 2017). When determining the depth and length of the disposal zone, at least the minimum depth of the water table allowing for seasonal and longer term variations, the depth of the local erosion base and the depths of suitable host formations, the groundwater flow regime and the geochemical conditions have to be taken into account (IAEA, 2011). In this context, it is noteworthy that the disposal zone must not overlap with the interface of the unsaturated and the saturated zone but must be located completely in either the one or the other zone in order not to impair the corrosion resistance of the disposal system and to facilitate the modeling of the near field evolution (IAEA, 2009).

A Generic Safety Assessment (GSA) was developed considering different geosphere configurations and release mechanisms: disposal zone (unsaturated and saturated), release mechanism (gaseous, liquid and solid), flow conditions (low, medium and high flow in porous system and high flow in fracture system) (Little et al., 2004; IAEA, 2017). Besides the design scenario, four different defect scenarios were also considered, including a defect weld closure of one waste container (D1), a defect weld closure of one waste capsule (D2), degraded/incomplete disposal/disturbed zone cement grout (D3) and one waste capsule having a defect weld closure within a waste container with defect weld closure (D4). The GSA model has been implemented in a version of the AMBER software tool (version 4.5), a commercial software tool developed by Quintessa Ltd. AMBER uses a compartment model approach to represent the migration and fate of contaminants in the environment.

IAEA (2017) presents the results for the calculation cases in terms of the activity limits for each radionuclide for which the total dose does not exceed the dose constraint of 0.3 mSv/y. The results have shown that the most restrictive activity limits were obtained for the saturated disposal zone with high flow rate in a porous system, with Pu-238, Pu-239 and Am-241 being the more limiting radionuclides. With respect to the design scenario for disposal in saturated, porous media with high

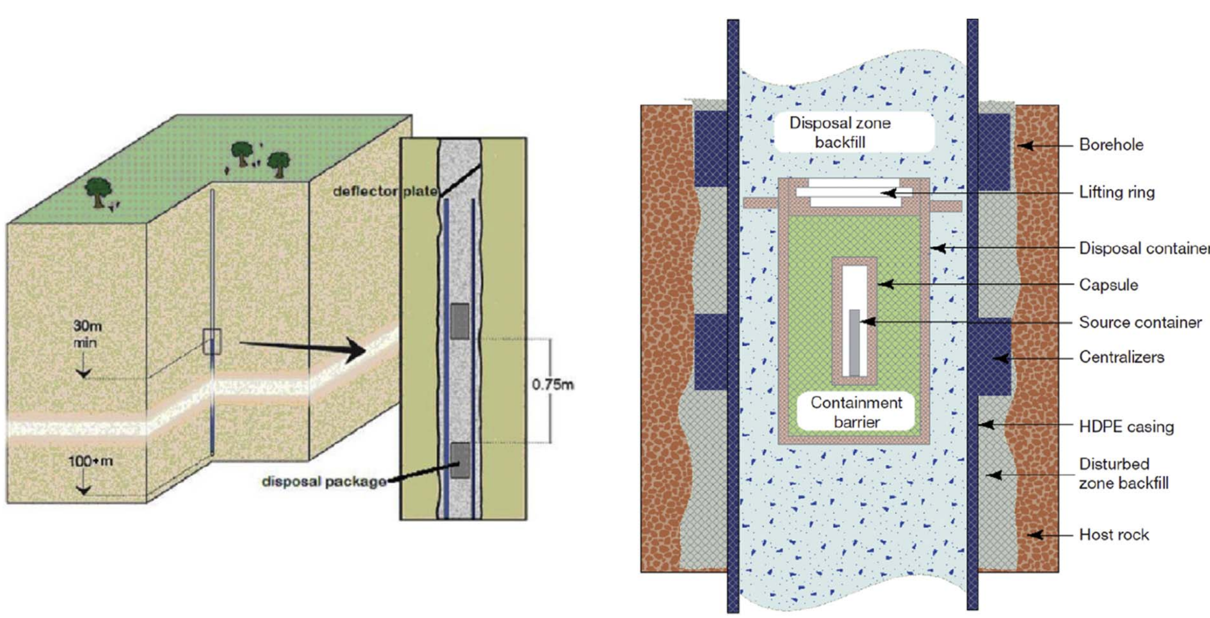

Fig. 1. Scheme of a borehole disposal facility (IAEA, 2011) (left) and illustrative section through the borehole (right) (IAEA, 2009). (Reproductions with permission by IAEA).