

## Safety Assessment in the Predisposal Management of DSRS

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### 1. Introduction

Sealed radioactive sources (SRS) are formed by a small mass of concentrated radioactive material hermetically encapsulated. Since the enclosure of the radioactive substance must ensure the strength and tightness of the SRS even under adverse conditions, it is understood that, except for conditions of breach or leakage (which result in internal or external contamination of individuals and the environment), the risk associated with the use of SRS is radiation exposure. However, many of them, even though they present high levels of radiation, become unsuitable for the practices they were associated with, and thus are classified as disused sealed radioactive sources (DSRS). Most have high specific activity, and therefore are relatively small, increasing the likelihood of problems such as loss, misplacement, and accidents under conditions of absence of specialized management.<sup>1</sup> Therefore, DSRS need to be collected by the National Nuclear Energy Commission (CNEN) to be managed as radioactive waste.

In Figure 1, the typical structure of a high-activity sealed source<sup>2</sup> of <sup>137</sup>Cs is exemplified, consisting of two welded stainless-steel capsules, one internal and one external, which enclose the radioactive substance.



Figure 1: Typical structure of a high-activity SRS

During the lifespan of SRS, situations of improper exposure and the respective protection of members of the public and occupationally exposed individuals (OEI), typically represent a relevant issue only during the application of techniques that utilize these sources. Therefore, safety can be ensured by observing and complying with standards and measures throughout their use. However, due to the use of a variety of radionuclides whose half-lives can last even thousands of years, the use of SRS creates a management problem, as the safety measures currently adopted need to be effective in a distant future, even after the end of the lifespan of these sources. Therefore, it is essential to assess safety (identifying hazards and risks) during the technical and administrative stages of DSRS management,

considering radiological and non-radiological aspects, to determine accident prevention measures and unnecessary exposures.

The safety assessment of DSRS management is divided into two phases: predisposal and post-disposal as radioactive waste. The predisposal assessment corresponds to the risk analysis of the set of unit operations, which are the administrative and technical activities involved in the collection, segregation, handling, treatment, packaging, transportation, storage, and deposition of the DSRS in a waste repository. The post-disposal safety assessment corresponds to the identification and assessment of natural and anthropogenic events or processes that could lead to the degradation of the natural or engineered barriers of the repository and the exposure of individuals in the future. The purpose of this research is to formalize risk analysis and assess the safety of each stage of predisposal management of DSRS. To achieve this, mathematical models are proposed based on the analysis of scenarios of normal and accidental radiation exposure.

## 2. Methodology

Each of these operations is called a unit operation, a term commonly used in chemical engineering, which refers to the sequential stages that comprise the DSRS management process. Describing the process as a sequence of unit operations allows for the evaluation of the risks involved in each, enabling a comprehensive study of process safety. Typical risks involved in these operations include operator exposure to radiation, contamination of the workspace with radioactive substances from the sources in cases of failure or rupture in source encapsulation, accidents involving the handling of heavy objects such as source shields, among other possibilities. For the purposes of this study, a unit operation is considered to include: receiving at the site where they will be managed as DSRS (screening and inspection); storing the DSRS in a temporary storage facility until they are sent to the dismantling site; removing the original packaging and transferring to shielding (lead, stainless steel, or paraffin, in the case of DSRS emitting neutrons); characterization through inspection and radiometric methods; packaging in a standardized disposal container; temporary storage in an intermediate storage facility; transportation to the disposal site; and deposition. These are synthesized by the flowchart in Figure 2.

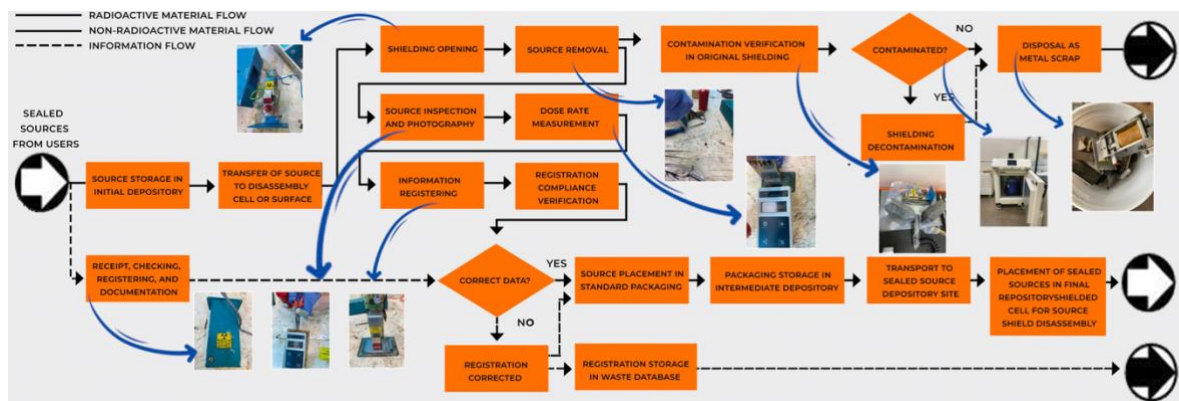


Figure 2: Sequential stages that comprise the processes related to the management of DSRS

To achieve the objective, the topic has been approached from a descriptive perspective based on literature review, on-site observation of operations carried out in the management of DSRS at the

Nuclear and Energy Research Institute (IPEN), analysis of normal operations, and the design of accidental scenarios.

The origin of DSRS is primarily from practices, although rarely they can also result from interventions such as accidents, orphaned sources, consequences of regulatory non-compliance inspections at facilities, or even from the cancellation of authorization for a practice, as is the case of  $^{241}\text{Am}$  and  $^{226}\text{Ra}$  sealed sources contained in lightning rods. The unjustified practice of using  $^{241}\text{Am}$  SRS in lightning rods constituted a means of proliferation of radioactive waste, as there was no technical proof of its effectiveness compared to conventional lightning rods. Therefore, the CNEN determined the suspension of authorization for the use of radioactive material in lightning rods from April 4, 1989, and the collection of remaining radioactive material from deactivated radioactive lightning rods by the CNEN, to prevent the dispersion of radioisotopes in the environment.

The promulgation of Resolution 04/89 was effective in halting the manufacturing and installation of new radioactive devices. However, the responsibility for deciding the replacement of already installed lightning rods was delegated to the municipal government, under the possibility of regulating building codes. In São Paulo, the Municipal Decree nº. 33.132, dated April 23, 1993, established that all lightning rods should be replaced (implying their consideration as radioactive waste) and that all lightning protection systems should comply with NBR-5419 of the Brazilian Association of Norms Techniques (ABNT).<sup>3</sup> To understand the magnitude of the problem, it is elucidated that despite being sealed,  $^{241}\text{Am}$  and  $^{226}\text{Ra}$  sources (in lightning rods) do not prevent the dispersion of radioactive material, being subject to wind erosion. Therefore, such sources never provided effective isolation of the material.

According to the Brazilian inventory of DSRS,<sup>4</sup> estimated as of December 31, 2014, there were approximately 3,429 DSRS of  $^{226}\text{Ra}$  stored in CNEN institutes (CDTN, CRCN, IEN, and IPEN) during that period, totaling an activity of  $5.5\text{E}+11$  Bq and occupying a total apparent volume of  $857.25\text{ cm}^3$ . Due to the deposition technology (placement of packages with limited capacity in deep boreholes), the total apparent volume of the sources is an important parameter for the management of DSRS.<sup>5</sup>

An effective dose received by an occupationally exposed individual can be determined based on the incorporated activity. In cases of external exposure, where there is no ingestion, inhalation, or skin contamination, the gamma dose rate constant<sup>6</sup> ( $\Gamma$ ), expressed in  $\text{mSv}\cdot\text{m}^2\cdot\text{h}^{-1}\cdot(\text{MBq})^{-1}$ , is a relevant parameter. For the assessment of accidental scenarios, it is defined that the dose generated by gamma-emitting radionuclides can be calculated by Equation 1:

$$D = \frac{\Gamma \times A \times t}{d^2} \quad (1)$$

The exposure time ( $t$ , in hours) and the distance between the OEI and the source ( $d$ , in meters) are determining factors. In cases of accidents involving inhalation, the more conservative value of the dosimetric factor is considered:  $e(g)1\mu\text{m}$  ( $3.2\text{E}-06\text{ Sv}\cdot\text{Bq}^{-1}$ ).<sup>7</sup> The values of  $A_P$ ,  $A_A$ , and  $A_{MED}$  refer to the most probable, high, and medium activities,<sup>4</sup> respectively.

It is assumed that a  $^{226}\text{Ra}$  source was inserted into a shielding, placed in its respective packaging, and transported to the site where it would be managed as radioactive waste. The normal operation of receiving the DSRS is carried out by a lead operator, a radiation protection technician, a radiation safety supervisor, and a trainee operator. After inspections, the packaging was opened, and the DSRS was removed, but as it was being placed in the new shielding, it fell. It remained on the ground for a short period until it was retrieved.

### 3. Results and Discussion

The Table I presents the doses emitted by a  $^{226}\text{Ra}$  DSRS in both normal and accidental scenarios. The Gamma Ray Constant<sup>5</sup>  $\Gamma$  ( $^{226}\text{Ra}$ ) is  $3.274\text{E}-06 \text{ mSv}\cdot\text{m}^2\cdot\text{h}^{-1}\cdot (\text{MBq})^{-1}$ ; the dose rate ( $\dot{D}$ ) is  $5.00\text{E}+00 \mu\text{Sv}\cdot\text{h}^{-1}$ ; the most probable activity ( $A_P$ ) is  $3.30\text{E}+04 \text{ Bq}$ ; the high activity ( $A_H$ ) is  $2.84\text{E}+10 \text{ Bq}$ ; the average activity ( $A_{\text{AVERAGE}}$ ) is  $1.96\text{E}+09 \text{ Bq}$ .

Table I:  $^{226}\text{Ra}$

$^{226}\text{Ra}$				
Normal exposure				
Operator	1°	2°	3°	4°
Exposure time (t) – min	7.5	7.5	7.5	7.5
Effective dose – $\mu\text{Sv}$	6.25E-01	6.25E-01	6.25E-01	6.25E-01
Collective effective dose – $\mu\text{Sv}$	2.50E-00			
Accidental exposure – $A_P, A_H$ e $A_{\text{AVERAGE}}$				
IOE	1°	2°	3°	4°
Exposure time (t) – min	0.25	0.25	0.25	0.25
Distance between the OEI and the source (d) – cm	50	300	350	400
Effective dose ( $A_P$ ) – mSv	1.80E-09	5.00E-11	3.67E-11	2.81E-11
Collective effective dose ( $A_P$ ) – mSv	1.92E-09			
Effective dose ( $A_H$ ) – mSv	1.55E-03	4.30E-05	3.16E-05	2.42E-05
Collective effective dose ( $A_H$ ) – mSv	1.65E-03			
Effective dose ( $A_{\text{AVERAGE}}$ ) – mSv	1.07E-04	2.97E-06	2.18E-06	1.67E-06
Collective effective dose ( $A_{\text{AVERAGE}}$ ) – mSv	1.14E-04			

Accidents of this nature demand an immediate and appropriate response to minimize risks to the operator's health. Adherence to safety protocols and provision of adequate training for OEI to handle emergency situations at all stages of predisposal management of DSRS are imperative. Accidental exposures can lead to undue doses, underscoring the critical relevance of stringent safety and control measures to minimize health risks for radiation-exposed workers.

### 4. Conclusions

The analysis of risks and hazards is essential for the safe management of disused sealed radioactive sources (DSRS) during unit operations. When considering the processes involved in handling, storage, and transportation of these sources, it is crucial to identify and evaluate the potential risks faced by Occupationally Exposed Individuals (OEIs). This analysis enables the implementation of appropriate safety measures to mitigate the identified risks, ensuring effective protection against harmful radiation exposures. Furthermore, by understanding the inherent hazards of unit operations, it is possible to develop effective emergency response plans, preparing teams to handle adverse situations quickly and efficiently.

## 5. References

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