2009 International Nuclear Atlantic Conference - INAC 2009
Rio de Janeiro,RJ, Brazil, September27 to October 2, 2009
ASSOCIAÇÃO BRASILEIRA DE ENERGIA NUCLEAR - ABEN
ISBN: 978-85-99141-03-8

SAFETY INDICATORS IN BOREHOLE DISPOSAL OF SEALED RADIOACTIVE SOURCES

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ABSTRACT

The Radioactive Waste Management Laboratory (RWML) at the Energy and Nuclear Research Institute of São Paulo, Brazil, is developing the concept of a geological repository adequate for the Brazilian inventory of disused sealed radioactive sources. Sealed sources are numbered to hundreds of thousands, have increasingly been used in industry as well as in medical applications in the last decades, and are believed to have a growing number of applications in the near future. The concept of repository under development is a borehole, drilled to a depth of some four hundred meters bellow ground surface in the crystalline bedrock, preferably in the same site of the national low-level waste disposal facility. In this paper, we present the work being carried out at RWML to identify safety indicators and explore their use as a tool to demonstrate the safety of a borehole disposal facility for disused sealed radioactive sources in Brazil.

1. INTRODUCTION

The Radioactive Waste Management Laboratory (RWML) at the Energy and Nuclear Research Institute of São Paulo, Brazil, is developing the concept of a geological repository suitable to the disposal of the Brazilian inventory of disused sealed radioactive sources. The concept of repository under development at RWML is a borehole, drilled to a depth of some four hundred meters bellow ground surface in the crystalline bedrock, preferably in the same site of the national low-level waste disposal facility.

Sealed sources are numbered to hundreds of thousands, have increasingly been used in industry as well as in medical applications in the last decades, and are believed to have a growing number of applications in the near future. At the end of their service life, most sealed sources still have enough activity to represent a radiological threat to human health and must be isolated from the biosphere until the radioactivity has decayed to acceptable levels.

Table 1 shows the classification of sealed sources in Groups I to III, an arbitrary classification of Brazilian inventory of sealed sources based on their half-lives, and respective activities [1].

Currently, most sealed sources do not meet acceptance criteria of shallow ground disposal for low- and intermediate-level wastes, because they require isolation times that span centuries or even several millennia. Sources of Ra-226 and Am-241 are examples of such sources but Ni-63, Sr-90 and Cs-137, depending on the total activity, are also not acceptable. Shallow ground disposal sites are not designed for isolation times that long and therefore geological repositories are required for disposal of sealed sources.

Table 1 – Classification of the Brazilian inventory of sealed sources

	Radionuclides	Total activity (Bq)	$T_{1/2}$ (years)
Group I	Th-228	$4,1 \times 10^{5}$	$1,9 \times 10^{0}$
	Cd-109	$1,2 \times 10^{10}$	$1,2 \times 10^{0}$
	Na-22	$2,9 \times 10^{8}$	$2,6 \times 10^{0}$
	Fe-55	$1,7 \times 10^{11}$	$2,7 \times 10^{0}$
	Pm-147	$7,2 \times 10^{12}$	$2,6 \times 10^{0}$
	Tl-204	$3,2 \times 10^{10}$	$3,8 \times 10^{0}$
	Cf-252	$1,8 \times 10^{12}$	$2,6 \times 10^{0}$
	Co-60	$3,3 \times 10^{16}$	$5,3 \times 10^{0}$
Group II	Ba-133	$1,1 \times 10^{9}$	$1,1 \times 10^{1}$
	Kr-85	$4,8 \times 10^{12}$	$1,1 \times 10^{1}$
	H-3	$8,5 \times 10^{11}$	$1,2 \times 10^{1}$
	Eu-152	$3,9 \times 10^{8}$	$1,3 \times 10^{1}$
	Cm-244	$2,0 \times 10^{11}$	$1,8 \times 10^{1}$
	Sr-90	$1,6 \times 10^{12}$	$2,8 \times 10^{1}$
	Cs-137	$2,4 \times 10^{14}$	$3,0 \times 10^{1}$
Group III	Ni-63	$4,2 \times 10^{10}$	$1,0 \times 10^{2}$
	Sm-151	$3,7 \times 100^{9}$	$9,3 \times 10^{1}$
	Pu-238	$8,2 \times 10^{11}$	$8,8 \times 10^{1}$
	Pu-238-Be	$1,6 \times 10^{12}$	$8,8 \times 10^{1}$
	Am-241	$3,7 \times 10^{13}$	$4,3 \times 10^{2}$
	Am-241-Be	$4,0 \times 10^{13}$	$4,3 \times 10^{2}$
	Ra-226	$1,2 \times 10^{12}$	$1,6 \times 10^{3}$
	Ra-226Be	$9,3 \times 100^{9}$	$1,6 \times 10^{3}$
	C-14	$4,9 \times 10^{9}$	$5,7 \times 10^{3}$

Developed countries are postponing decision on the disposal route of their sealed sources but most probably will use their geological repositories for high-level wastes and spent nuclear fuel when they become available. In developing countries, this option is highly improbable and the alternative can be a deep, dedicated borehole, were the sources should be kept isolated from the human environment for the millennia required, at a fraction of the cost of other repository concepts [1].

One principle of radioactive waste management is that the same level of protection should be provided for future generations as that provided for the current generation. [2]. Therefore, the licensing of a repository for radioactive wastes requires that the disposal system pose no significant long-term hazard to human health. The desired level of safety and security is relied upon the isolation of the waste by a system of multiple, natural and engineered barriers, that is characteristic of disposal concepts.

Current knowledge about the dose-effect relationship and about the behavior of natural or engineered barriers in the repository allows repository designers to demonstrate compliance, with reasonable confidence, with that requirement for the present and the few next generations. However, it is difficult to demonstrate compliance with safety criteria over long time-scales using predictive models because the uncertainty associated with the results increases with time.

It is recognized that disposed wastes will some day show up in the accessible environment of the living organisms on the Earth, by natural processes on the crust. For a repository to be considered safe, the breakup of isolation is to occur after radioactivity has decayed to safe levels. It is also required that any phenomena that give rise to an early dispersion of the radioactive material into the biosphere, or that facilitates the intrusion of living organisms, including man into the repository, have low probability of occurrence.

The challenge is to demonstrate that the isolation will conceivably hold for the required time. The reason is that the longer the assessment time frame, the weaker the evidence of good performance of the systems in the safety case. Consequently, more detailed, comprehensive, and complex analyses are required. Available methods of safety analysis are those developed for disposal of nuclear fuel cycle back-end wastes. These are costly, time consuming, and resource demanding, at levels that a developing country barely can afford. Moreover, the use of such methods in the disposal of disused sealed source could be questionable in face of the small magnitude of the problem when compared with the disposal of high-level waste or spent nuclear fuel. If these methods are adopted, the cost of the disposal of sealed sources will inevitably make their use unfeasible in virtually all applications, taking into account that the disposal costs should be borne by users.

Safety indicators could help in presenting the safety case in a simpler, yet convincingly strong form, [3] without the burden of traditional safety analysis costs.

One common example of safety indicator is the maximum radiation doses received by the most exposed hypothetical individuals. A less complex indicator is the ratio of the waste activity to the natural radioactivity present in the environs of the repository.

Safety indicators of a repository are the characteristics of disposal systems that relate to the risks and potential damages resulting from their construction and operation, for example, individual radiation doses or risks, total radioactivity, or total radiotoxicity of disposed radioisotopes.

Safety indicators can be used to compare different disposal options, concepts, sites, designs, or engineering barriers in the location and design phase of the project. They can also be used as a communication tool to the broader audience not acquainted with the specialized technical terminology of waste disposal and safety assessment, but whom, nevertheless will, or should be heard in the decision-making process. Another use of SI could be as an instrument to demonstrate compliance with safety and performance goals in the licensing process. In this sense, the SI could be used in the assessment and demonstration of safety in the license application for the installation, complementing the use of traditional methods or even replacing them completely.

The acceptability of SI in this function depends on their possessing some necessary characteristics. The required properties are:

a. reliability – SI must be based on well recognized principles;
b. relevance - SI must be related to relevant aspects of safety;

c. simplicity - SI must facilitate the communication;
d. straightforwardness - SI must be direct and unambiguous;
e. comprehensibility - SI must be easily understandable;
f. practicability - SI must be related to quantities easily measurable and computable.

Effective equivalent dose, the universal safety indicator in the radiation protection field, for instance, has many of those characteristics. It is directly related to the risk of health detriment, is supported by tradition and national regulatory framework, is measured or calculated by standardized methods, and is expressed by numbers that can be directly compared with a relevant reference value, be it regulatory limits or natural background. However, in regard to be easily understandable by a layperson, radiation doses have some shortcomings, even when expressed as a fraction or multiple of background, because of the widely publicized view that any dose is dangerous, no matter how low it is.

For the environmental impacts and health consequences of a waste repository to be understood and perceived as acceptable by the nonprofessionals, other indicators should be used.

2. METHODS

The research work will identify SI already reported in the literature that can be applied to the safety analysis of the borehole repository, or new indicators that can be devised in a careful examination of the safety related components of the disposal system. A source of such new indicators is the set of requirements, recommendations, and exclusionary criteria compiled by Vicente [4] in an exercise of safety analysis of the borehole concept.

The SI set may also include 'additional performance indicators', as defined by IAEA (5). Examples of candidate indicators are:

a. time for activity to decay below a reference value;
b. depth of the emplacement zone;
c. location of the repository;
d. age of the geological environment;
e. time span since the last significant movement of the ground;
f. indexes of potential of human intrusion.

The work will define and characterize each candidate SI, calculate or estimate the range of their values, and judge them against a set of requirements to qualify them to the final set of SI selected to demonstrate the safety of the facility.

Qualification requirements include the capacity of the SI to allow:
a. comparison of alternative concepts, designs, materials, sites, and waste emplacement methods;
b. regulatory decision making, concerning the safety and a license issuance;
c. verification of compliance with safety criteria;
d. confidence building on the performance of the facility;
e. comparison with other industrial, social activities;
f. communication of safety aspects with the public.

3. RESULTS

Some preliminary results of the research work are presented below.

For each group of sources presented in Table 1, the total activity, or the corresponding potential ingestion dose, for instance, plotted as functions of time, can give evidence of the safety. Figure 1 shows that all sources of Group I will became 'not radioactive' in less than about two centuries. Figure 2 shows that in about 240 years, in any conservative scenario of source ingestion, the entire Group I sources will become radiologically insignificant.

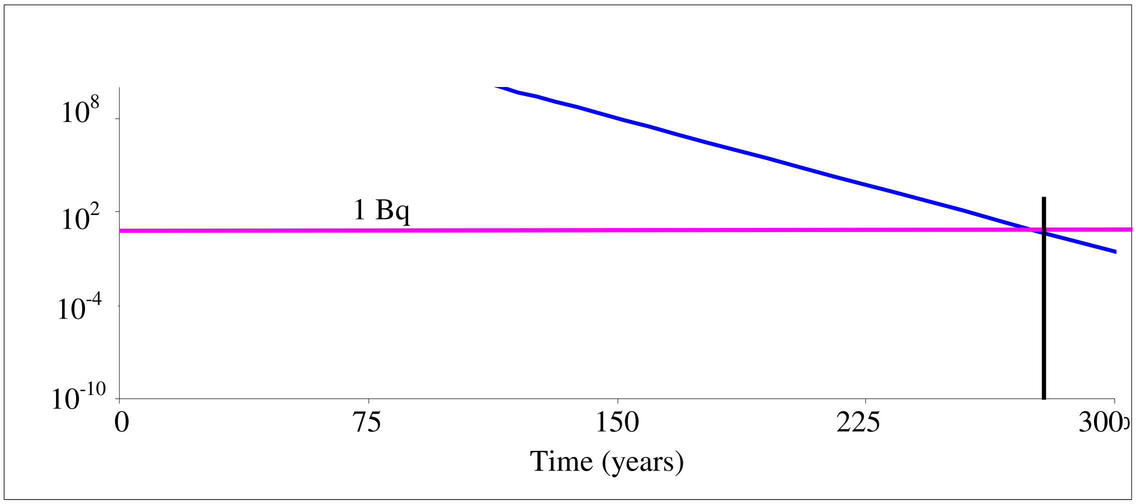

Figure 1 – Group I total activity crossover time, using 1 Bq as criteria. In the ensuing work, exemption activities for each radionuclide will be used instead.

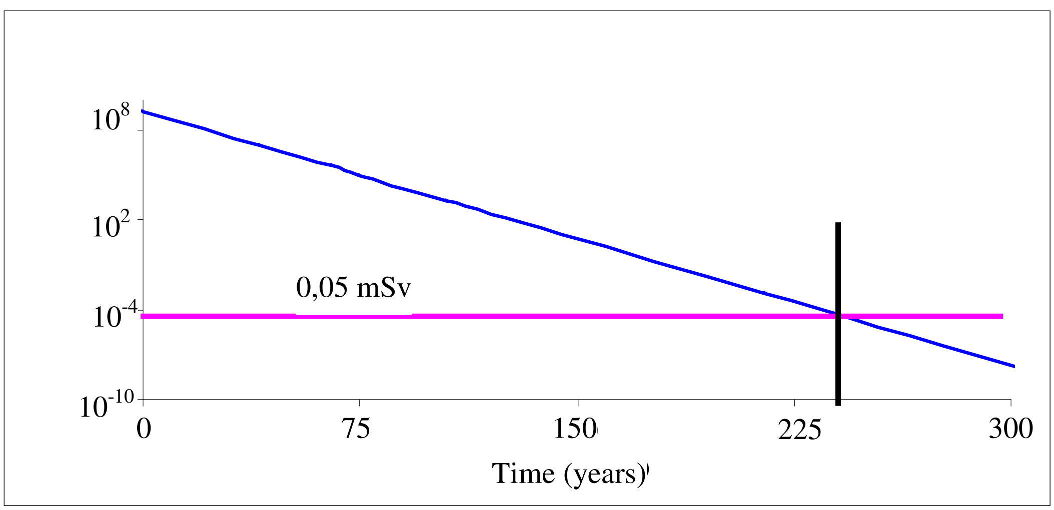

Figure 2 – Group I potential dose crossover time calculated as the summation of the potential ingestion doses of all radionuclides.

Crossover times for activity, radiation dose, or any other quantity of the wastes, are compared with relevant periods of time that can be scientifically recognized and socially accepted without further concern about safety and security. Calculations will be repeated for the most active single source, or for all sources of each radionuclide inventory.

This line of reasoning is an example of the description of the safety of the facility that the authors intend to develop in the present research work.

4. CONCLUSIONS

This paper discusses plans and preliminary results of a research work that has just started at the RWML of the Nuclear Energy Research Institute, in São Paulo, Brazil on safety of borehole disposal facilities. This research aims at identifying safety indicators and exploring their use as tools to demonstrate the safety of a borehole disposal facility for the Brazilian inventory of disused sealed radiation sources.

It must be emphasized that the present paper is a brief communication of a work in progress, of academic nature, that will require much more research before any definitive conclusion can be drawn on the applicability of safety indicators as the solely tool for safety analysis of a disposal facility. It is necessary also to recognize that, for the proposed method to replace the traditional method of safety analysis, a change of paradigms will be required.

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