Proposal of a Categorization of the Disused Sealed Radioactive Sources with a View to Safe – 17285

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ABSTRACT
In the Nuclear and Energy Research Institute (IPEN-CNEN/Brazil) many works to improve and develop characterization of radioactive waste techniques have been deployed by the Radioactive Waste Management Department (IPEN-CNEN/SP). In this line, this work aims to suggest a new categorization of sealed sources, which considers their activities, as suggested by the International Atomic Energy Agency (IAEA), but also the time required for the activity to decrease to a safe value.

We considered the sealed sources categorization system suggested by the IAEA and we applied such categorization system to various sources currently stored by institutes of Brazilian Nuclear and Energy Commission (CNEN). Then, we also applied the categorization system defined herein, it follows that the categorization system presented by the IAEA has many applications and their use should not be abandoned. However, since the new proposed categorization systems allow to differentiate sources that in the IAEA system are in the same category, they can help define the long-term management of radioactive waste.

INTRODUCTION
A radiation source is all "equipment or material that emits or is capable of emitting ionizing radiation or releasing radioactive materials"[1]. Thus, a sealed radioactive source is "a radioactive source in a hermetically closed capsule, or attached completely surrounding to inactive material, so that, there can be no dispersion of the radioactive substance in normal and severe conditions of use" [1].

Several types of sealed sources are currently used in medicine, industry, scientific research and other applications. And just as in the global scale, the use of this type of radioactive source has grown a lot in Brazil. However, classification of these sources and, subsequently, deposition are still ambiguous subjects.

For sealed sources the dispersion of radionuclides in the environment is of little relevance, however these may be associated with significant radiological hazards if we look to its small size, metallic, shiny appearance. This type of source is easily mistaken for machine parts or metal debris, arouse the curiosity of uninformed people about the origin of the material and can cause accidents associated with the ingestion and inhalation of radioactive material.

It is noteworthy that in recent decades, sealed radioactive sources were involved in most of the radiological accidents, we cite the accident occurred in Goiânia (Brazil, 1987).

In their applications the lifespan of this type of source may vary from a few years to a few decades, however, the half-life of the radionuclide contained can vary from a few days to millions years, so that most of the disused sealed radioactive sources (DSRS) disposed as radioactive waste still present considerable activity and capable of causing harm to health and the environment [2]. So to categorize these sources is important in helping to define the radiological risk they represent, as well optimize the deposition process.

The IAEA Categorization to DSRS.

The IAEA provides a categorization of sealed sources that considers only the values of their activities. According to this categorization, high activity sources can cause severe deterministic effects for individuals that may handle them in a short period of time and low activity sources are not likely to cause such effects. Therefore, this categorization system provides a relative ranking to the activity of the source and can be applied for [3]:

- Provide a logical base that helps to define a system of notification, registration, licensing and inspections;
- Ensuring compatibility between human and financial resources to the category of source;
- Determine security measures;
- Assist in the control of imports and exports;
- Determine the labeling and packaging of sources;
- Ensure that measures and emergency protocols are compatible with the category of source;
- Facilitate communication with the public in order to have bases to explain the risks associated with radioactive sources.

This categorization system also acts in the base of IAEA decisions:

- It's useful for a variety of purposes;
- Although developed with a view to their end uses, does not depend of them;
- Compatible with the previous IAEA categorization syste, that may still be in use in any installation;
- It is logical, transparent and fairly simple.

For many radionuclides the IAEA developed specific activity levels for planning purposes and emergency response, such levels are termed *D*. This is a value above which the radioactive source is considered a 'dangerous source' as it has a significant potential to cause severe deterministic effects if not managed with safety. It define also the exemption level (*E*), which corresponds to the activity that the radioactive waste can be dropped unconditionally like common waste, i.e., the waste containing radionuclides with activities at or below the exemption level does not represent a risk. We consider reasonable to use the *D* and *E* values to sealed sources, though they are defined for general radioactive wastes.

So, the IAEA defines five categories for sealed sources, as specified in Table I. The sources of category 1 are those which, if handled incorrectly, pose a high risk to human health, and the sources of category 5 are those that represent low radiological risk.

TABLE I. Categorization system suggested by the IAEA for sealed sources [3].

Category	Categorization of Common Practices	Activity Ratio (A/D)
1	Radioisotope thermoelectric generators (RTGs); Irradiators; Teletherapy; Fixed, multi-beam teletherapy (gamma knife).	**A/D ≥ 100**
2	Industrial gamma radiography; High/medium dose rate brachytherapy.	**1000 > A/D ≥ 10**
3	Fixed industrial gauges (level, dredger conveyor containing high activity sources, spinning pipe); Well logging gauges.	**10 > A/D≥ 1**
4	Low dose rate brachytherapy (except eye plaques and permanent implant sources); Thickness/fill-level gauges; Portable gauges (e.g. moisture/density gauges); Bone densitometers; Static eliminators.	**1 ≥ A/D ≥ 0.01**
5	Low dose rate brachytherapy eye plaques and permanent implant sources; X ray fluorescence devices; Electron capture devices; Mossbauer spectrometry; Positron Emission Tomography (PET) checking.	**0.01 > A/D ≥ E or D***

*Exempt quantities (E) [4] or Dangerous Value (D) [3].

It should be noted that in the radioactive waste management point of view is much more applicable to have as criterion the risk that the DSRS presents, i. e., use the applications of DSRS as criterion is not efficient in this case.

DISCUSSION

Then, it is verified that categorization system suggested by the IAEA is very effective in categorizing sealed sources. But this system does not apply to long-term DSRS, because it does not provide the degree of isolation required for this type of source.

For example, consider two DSRS with equals activities, but containing different radionuclides. If the first DSRS contains a radionuclide with a half-life on order of months, and the second contains a radionuclide with a half-life on order of millions years, in the IAEA characterization system such sources would be in the same category, although it is clear that should not be handled the same way.

However, the categorization of DSRS requires higher specifications including views to safety and potential risk scenarios. This way, this study aims to suggest two new categorization systems that complement the system suggested by the IAEA when applied to DSRS.

Method – Categorization Systems Suggested to DSRS.
We believe an additional categorization system, based in isolation time, can complete the IAEA categorization system when applied to DSRS. So, we define two criterions:

1st CRITERION - The isolation time required for the DSRS activity to decrease so that it fits in Category 4 of the IAEA categorization system, a category that includes sources that do not anymore offer radiological hazards. That is, this criterion provides the time (in years) that the DSRS should be stored so that its activity falls equal to or less than the *D* value.

It is considered that DSRS with high half-life decays more slowly and therefore requires more storage time until your activity fits in the 4st Category of the IAEA system, they present more laughter to cause deterministic effects. Thus, the first criterion defines a categorization system that considers the risk of particular DSRS provoke deterministic effects to a subject directly exposed.

2nd CRITERION - The isolation time required for the DSRS has an activity less than its *E* value. That is, this criterion provides the isolation time (years) to the DSRS activity is such that it allows its unconditionally disposal.

Consider two DSRS with the same activity. If the first source has very long half-life and the second has very short half-life, the second decays quickly and need less time than first to reach their level of exemption. In this regard, the second criterion defines a categorization system that provides an idea of the risks of contamination in a scenario of environmental dispersion.

So, the 1st and 2nd criterion define two new categorization systems suggested for DSRS. Posteriorly, naming *t* the isolation time, we defined their categories:

- $0 < t \leq 50$ years – is a reasonable range for prolonged storage, since it corresponds to about ten Co-60 half-lives;
- $50 < t < 300$ years – is a reasonable range for storage in superficial repository;
- $t > 300$ years – is a reasonable range for storage in geological repository.

The Table II resume the two categorization system suggested herein for DSRS.

Table II. Description of two new categorization systems suggested in this work for DSRS, where *t* is the isolation time (years), *A* is the activity of the source (Bq) and *E* is the exemption level (Bq) determined to each radionuclides.

	Categories	**Description**
1st categorization	**A**	$t \geq 300$
	B	$50 < t < 300$
t required to 0,01 D < A < D	**C**	$t \leq 50$
2nd categorization	**a**	$t \geq 300$
	b	$50 < t < 300$
t required to A < E	**c**	$t \leq 50$

In Brazil, the National Nuclear Energy Commission (CNEN) has 14 units, among research institutes, laboratories, district agencies and regional offices in nine Brazilian states and its headquarters located in Rio de Janeiro. For this work we received the inventories of the DSRS storaged in the following organs of the CNEN:

• Nuclear Technology Development Center (CDTN, Belo Horizonte - MG);

• Central-West Regional Center of Nuclear Science (CRCN, Goiânia - GO);

• Nuclear Engineering Institute (IEN, Rio de Janeiro - RJ);

• Nuclear Energy Research Institute (IPEN, São Paulo - SP).

These inventories contained: radionuclide contained in the DSRS and amount, the original activity and date of manufacture. Initially we considered the sealed sources categorization system suggested by the IAEA and we applied such categorization system to the sources contained is these inventories. Then, we also applied the two new categorization system defined herein for DSRS.

Results.

The DSRS in the inventory contained 28 different radionuclides and 15468 DSRS were categorized. However, it was found that 5195 sources (i.e. 34%) had activity less than the E value for the radionuclide contained. The Table III shows the total number of DSRS with activity values higher than their exemption level.

TABLE III. Number of DSRS with A > E in each CNEN unit.

Radionuclide	IPEN	CDTN	CRCN	IEN	TOTAL
Am-241	205	2	3	28	238
AmBe-241	62	6	3	8	79
Ba-133	2	0	0	1	3
Cd-109	1	0	0	0	1
Cf-252	1	0	0	0	1
Cm-244	5	0	0	0	5
C0-57	3	0	0	2	5
Co-60	1849	18	9	63	1939
Cs-134	2	2	0	0	4
Cs-137	2256	69	77	114	2516
Fe-55	44	0	0	1	45
Ge-68	1	0	3	0	4
H-3	31	0	0	2	33
I-192	1642	0	0	12	1654
Kr-85	243	2	3	6	254
Ni-63	47	0	2	20	69
Pm-47	95	0	0	0	95
Pu-238	1	0	0	0	1
Ra-226	3006	0	0	2	3008
RaBe-226	6	1	0	0	7
Ru-106	1	0	0	0	1
Se-75	16	0	0	10	26
Sr-90	203	0	12	9	224
Ti-44	1	0	0	0	1
Tl-204	60	0	0	0	60

For each radionuclide a summary table was constructed, showing the values D and E, as well as DSRS numbers containing the radionuclide. These records also contain the categorization of minimum, maximum, average and the sum of the activities of all DSRS containing the radionuclide, such that:

- **CAT I** - corresponds to the categorization system suggested by the IAEA;
- **CAT II** - corresponds to the first new categorization system suggested herein;
- **CAT III** - corresponds to the second new categorization system suggested herein.

The Table IV presents an example of summary table, in this case, constructed for the Co-60.

TABLE IV. An example of summary table, in this case for the DSRS which contains the Co-60.

Co-60				
$T_{1/2}$ (years)		5,72		
D (Bq)		3,00E+10		
E (Bq)		1,00E+05		
FONTES	**TOTAL**	1562		
	IPEN	1472		
	CDTN	18		
	CRCN	9		
	IEN	63		
Activity (Bq)		**CLASSIFICATION**		
		CAT I	**CAT II**	**CAT III**
MIN (Bq)	1,00E+05	5	C	c
MAX (Bq)	9,66E+13	1	B	b
AVER (Bq)	1,05E+12	2	C	b
SUM (Bq)	7,48E+14	1	B	b

Such summary tables can assist in communication, as well as organization, operations planning and optimization of deposit or repository of radioactive wastes.

CONCLUSIONS

Several types of sealed sources are currently used in medicine, industry, scientific research and other applications. And just as in the global scale, the use of this type of radioactive source has grown a lot in Brazil. However, classification of these sources and, subsequently, deposition are still ambiguous subjects. It is noteworthy that in recent decades, sealed radioactive sources were involved in most of the radiological accidents, we cite the accident occurred in Goiânia (Brazil, 1987). So to categorize these sources is important in helping to define the radiological risk they represent, as well optimize the deposition process.

The International Atomic Energy Agency (IAEA) provides a categorization of sealed sources that considers only the values of their activities. According to this categorization, high activity sources can cause severe deterministic effects for individuals that may handle them in a short period of time and low activity sources are not likely to cause such effects.

Then, it is verified that categorization system suggested by the IAEA is very effective in categorizing sealed sources. But this system does not apply to long-term DSRS, because it does not provide the degree of isolation required for this type of source. The categorization of DSRS requires higher specifications including views to safety and potential risk scenarios. This way, this study suggests two new categorization systems that complement the system suggested by the IAEA when applied to DSRS.

We believe an additional categorization, based in isolation time, can complete the IAEA categorization system when applied to DSRS, so, we define two new categorization systems.

The first categorization system suggested herein uses as criterion the isolation time required for the DSRS activity to decrease so that it fits in Category 4 of the IAEA categorization system, a category that includes sources that do not anymore offer radiological hazards. So this system considers the risk of a particular DSRS provoke deterministic effects to a subject directly exposed.

The second categorization system suggested herein uses as criterion the isolation time required for the DSRS has an activity less than its E value. In this regard, the second criterion defines a categorization system that provides an idea of the risks of contamination in a scenario of environmental dispersion.

We received the inventories of the DSRS storaged in organs of the Brazilian National Energy Commission (CNEN) and we applied the categorizations system cited to 15468 DSRS contained in this inventory. As result, summary tables were constructed to 28 different radionuclides and will assist in communication, as well as organization, operations planning and optimization of deposit or repository of radioactive wastes.

The categorization systems suggested in this work should in no way replace the system suggested by the IAEA. However, when dealing with DSRS, the suggested systems can complement the IAEA system to:

- Establish reportable safety standards;
- Allow a clearer view of the inventory;
- Define storage strategies;
- Suggest ways of storage;
- Compose an optimization and organization tool of DSRS deposit/repository.

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