USING OPTIMIZATION TO IMPROVE RADIOACTIVE WASTE INTERIM STORAGE

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INTRODUCTION

Radioactive wastes are generated in practices that use radioactive materials during their operational processes. These practices include all use of radionuclides in industry, medicine and research.

The radioactive waste management contributes with a significant fraction of the costs and doses involved in nuclear applications. For this reason, processes to reduce the radioactive waste volume are used to minimise the interim storage and final disposal area and, as a result, decrease the costs. The limits that identify a material as radioactive waste and the assumption of realist scenarios to release radioactive material in the environment have been discussed. If the limit increases, the radioactive waste volume decreases, and consequently the waste management costs, since a fraction of these radioactive wastes can be considered no radioactive (garbage).

Very low level radioactive wastes are insert in this discussion and have been in evidence for international organizations in the last decades. The strategies used to reduce waste management costs are the revision and improvement of some concepts for minimization, classification and segregation [1, 2].

Many countries have not started the repository construction yet, either by the policy indefinition or by the low volume generated. In these cases, treated radioactive wastes are interim stored awaiting the construction and operation of repository. In some cases, this interim storage can be extended for decades demanding special attention regarding security aspects [3, 4].

Among the IAEA recommendations for radioactive wastes stored for long periods are the packages reconditioning and the packages opening in order to segregate and exempt the waste [5, 6].

This paper presents an exemption and clearance study to solid compactible wastes stored at one research centre.

EXEMPTION AND CLEARANCE STUDY

1. General considerations

The exemption and clearance study was carried out considering the follow:

a) one interim storage facility with 1080 drums stored (200 dm^3 drums under pallets), 334 containing no compactable radioactive solid wastes and 746 containing compactable radioactive solid wastes.
b) that the process is composed by 18 steps that can be followed in the block diagram, Figure 1.
c) each compactable radioactive solid waste package will be evaluated to compare the activity concentration with an exemption limit.
d) the drums that cannot be considered exempted will return to the interim storage awaiting transfer to the repository and the drums that can be considered exempted will be processed, and will be either released as garbage or reclassified as radioactive.
e) all waste considered garbage will be sent to industrial landfill.

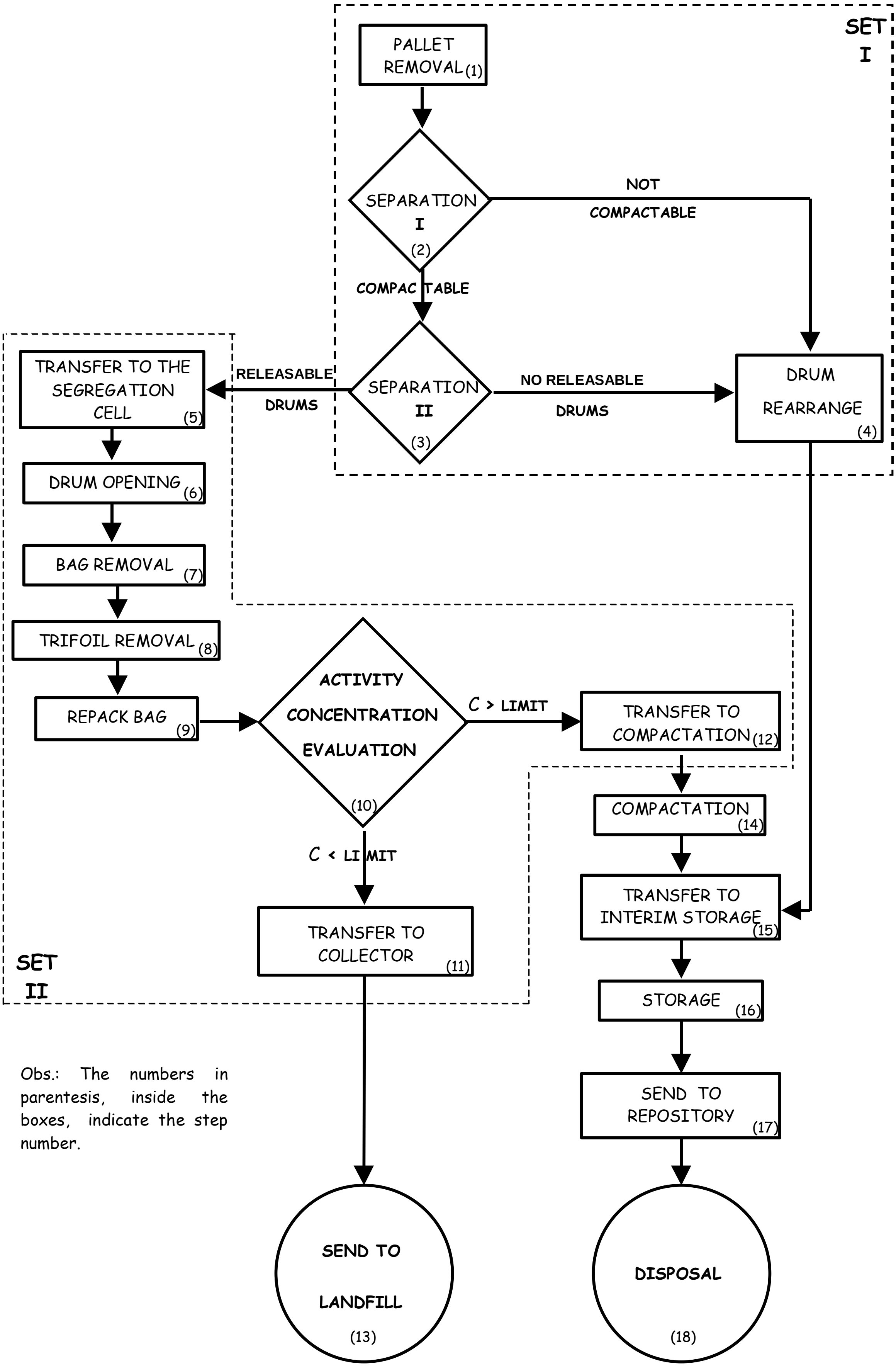

Figure 1 – Block diagram of the segregation process

2. Exemption limits

The exemption limits adopted to carried out the study and the shortening used to identify them are:

a) CNEN – limit established by the national authority of 74 $Bq.g^{-1}$, for all radionuclides, included in the regulation CNEN-NE-6.05 [7];
b) IAEA – distinct limit for each radionuclide, included in the Safety Series 115 [8]. These values are the result of the sum of all routes values in the more restrictive scenario, among those considered in the publication "radiation proutection publication 65" of the European Community [9];
c) EURO – distinct limit for each radionuclide, calculated by the same methodology of the "radiation protection publication 65", but considering just landfill as final disposal scenario;
d) LAP – distinct limit for each radionuclide, calculated by the same methodology of the "EURO", but using the Annual Limit for Public (1 $mSv.y^{-1}$) as radiation protection criteria.

It is important to emphasise that these limits are based on potential doses. The three former limits are based on an annual dose of 10 μSv and a collective dose lower than 1 person.sievert.

By comparing the activity concentration of each drum containing radioactive solid waste compressed with each limit adopted, one could classify the drums in four categories:

a) exempted – if the up to dated activity concentration is lower than the exemption limit considered;
b) potentially exempted – if the up to dated activity concentration is higher than the considered exemption limit, but there are bags of distinct origin in it. This means that inside the drum one can find either bags containing radionuclides with short half-lives and bags containing long lived radionuclides or bags containing radionuclides that present high exemption limit and bags containing radionuclides with low exemption limit.
c) not exempted – if the up to dated activity concentration is higher than the exemption limit considered and there are no characteristics that indicate the possibility of a fraction of its content being released;
d) not identified – if the data is not enough to carry out the exemption studies.

The two former categories constitute the releasable group and the two later constitute the no releasable group. Table 1 presents the exemption studies results, including the number of drums per each category and each considered limit.

Table 1 – Drums classification for each exemption limit considered

Class	Total drums according exemption limit			
	CNEN	IAEA	EURO	LAP
Exempted	196	148	151	292
Potentially exempted	133	150	151	134
Total of releasable drums	**329**	**298**	**302**	**426**
Not exempted	408	439	435	311
Not identified	9	9	9	9
Total of no releasable drums	**417**	**448**	**444**	**320**

3. Costs and doses evaluation

The costs evaluation was made for each step or set of steps, separately, to allow the determination of cost by package processed (pallet, drum or bag), since the amount varies according to the exemption limit considered and also according to the fraction of exempted packages after the activity concentration measurements.

To conduct the evaluation of doses received by workers during all steps of the process, some considerations were adopted:

a) the drums and bags handling will be done at an average distance of one meter;
b) in the steps "13 – send to landfill", "17 – send to repository" and "18 – disposal" the doses resulting from loading and unloading tasks were considered;
c) in the step "17 – send to repository" it was also considered the dose received by the driver during the transportation - 20 μSv/h during 8 hours;

The time requested to each step varies with the number of drums or bags handled, which varies with the exemption limit considered. Then, the fractions of 0%, 50% e 100% were considered for all limits, representing the fraction of drums containing potentially exempted waste that will be actually exempted.

After determining the unitary cost of each step, the number of package handled for each exemption limit considered, the time requested of each worker and the dose rates involved, it was possible to determine the costs and individual and collective doses of all process, considering interim storage of one and 10 years. These data are presented in Table 2.

Table 2 – Costs and doses determined for the optimization studies

100 % RELEASING IN THE DRUMS CONTAINING POTENTIALLY EXEMPTED WASTE						
OPTION NUMBER		**5**	**4**	**3**	**2**	**1**
10 storage	COST (1,000 U$)	873.00	640.00	663.00	660.00	570.00
	COLLECTIVE DOSE	3,91	5,13	5,07	5,05	4,88
	INDIVIDUAL DOSE	0,79	1,16	1,17	1,16	1,18
one storage	COST (1,000 U$)	839.00	617.00	639.00	636.00	549.00
	COLLECTIVE DOSE	2,49	4,41	4,35	4,34	4,20
	INDIVIDUAL DOSE	0,16	0,82	0,82	0,82	0,85
50 % RELEASING IN THE DRUMS CONTAINING POTENTIALLY EXEMPTED WASTE						
OPTION NUMBER		**5**	**4**	**3**	**2**	**1**
10 storage	COST (1,000 U$)	873.00	698.00	727.00	725.00	627.00
	COLLECTIVE DOSE	3,91	7,16	7,13	7,11	6,82
	INDIVIDUAL DOSE	0,79	2,22	1,89	1,88	1,85
one storage	COST (1,000 U$)	839.00	672.00	700.00	699.00	604.00
	COLLECTIVE DOSE	2,49	5,79	5,73	5,73	5,51
	INDIVIDUAL DOSE	0,16	1,57	1,23	1,23	1,24
0 % RELEASING IN THE DRUMS CONTAINING POTENTIALLY EXEMPTED WASTE						
OPTION NUMBER		**5**	**4**	**3**	**2**	**1**
10 storage	COST (1,000 U$)	873.00	754.00	791.00	789.00	684.00
	COLLECTIVE DOSE	3,91	8,31	8,43	8,43	7,94
	INDIVIDUAL DOSE	0,79	1,88	2,24	2,25	2,20
one storage	COST (1,000 U$)	839.00	726.00	762.00	760.00	659.00
	COLLECTIVE DOSE	2,49	6,94	7,06	7,05	6,62
	INDIVIDUAL DOSE	0,16	1,23	1,60	1,60	1,59

Obs.: The options were numbered from 1 to 5 as follow: option 5 – radioactive wastes stored awaiting for the transportation to final disposal; options 4, 3, 2 e 1 – opening, segregation and exempt the waste (option 4 consider the national limit CNEN, option 3 consider the limit IAEA, option 2 consider the limit EURO and the option 1 consider the limit LAP.

4. Optimization study

Knowing all costs and doses one could carry out the optimization study. Summarising, the optimisation study helps in the decision either of maintenance of the current situation (radioactive wastes stored awaiting for the transportation to final disposal) or the segregation and release of a fraction of the radioactive waste as garbage. Besides, it allows to evaluate if the application of different exemption limit changes this decision.

The technique to aid-decision making known as integral cost-benefit analysis was used to carry out this study. The data used in this study are those presented in Table 2.

To obtain the results, there were summed , for each option, the cost and the result of multiplication of collective dose and α, that is, "X + αS". The "α"value used was U$ 10.000,00 person.sievert. The options were numbered from 1 to 5, in the same way as shown in Table 2.

The Tables 3 and 4 present the results of the optimization study.

Table 3 – Integral cost-benefit analysis for 1 year of interim storage

Option number	fraction of drums containing potentially exempted waste that will be actually exempted (%)					
	0		50		100	
5	X = 839,000.00	αS = 25.00	X = 839,000.00	αS = 25.00	X = 839,000.00	αS = 25.00
	X + αS = **839,025.00**		X + αS = **839,025.00**		X + αS = **839,025.00**	
4	X = 726,000.00	αS = 69.00	X = 672,000.00	αS = 58.00	X = 617,000.00	αS = 44.00
	X + αS = **726,069.00**		X + αS = **672,058.00**		X + αS = **617,044.00**	
3	X = 762,000.00	αS = 70.00	X = 700,000.00	αS = 57.00	X = 639,000.00	αS = 43.00
	X + αS = **762,070.00**		X + αS = **700,057.00**		X + αS = **639,043.00**	
2	X = 760,000.00	αS = 70.00	X = 699,000.00	αS = 57.00	X = 636,000.00	αS = 43.00
	X + αS = **760,070.00**		X + αS = **699,057.00**		X + αS = **636,043.00**	
1	X = 659,000.00	αS = 66.00	X = 604,000.00	αS = 55.00	X = 549,000.00	αS = 42.00
	X + αS = **659,066.00**		X + αS = **604,055.00**		X + αS = **549,042.00**	

Obs.: The options were numbered from 1 to 5 as follow: option 5 – radioactive wastes stored awaiting for the transportation to final disposal; options 4, 3, 2 e 1 – opening, segregation and exempt the waste (option 4 consider the national limit CNEN, option 3 consider the limit IAEA, option 2 consider the limit EURO and the option 1 consider the limit LAP.

Table 4 – Integral cost-benefit analysis for 10 years of interim storage

Option number	fraction of drums containing potentially exempted waste that will be actually exempted (%)					
	0		50		100	
5	X = 873,000.00	αS = 39.00	X = 873,000.00	αS = 39.00	X = 873,000.00	αS = 39.00
	X + αS = **873,039.00**		X + αS = **873,039.00**		X + αS = **873,039.00**	
4	X = 754,000.00	αS = 83.00	X = 698,000.00	αS = 72.00	X = 640,000.00	αS = 51.00
	X + αS = **754,083.00**		X + αS = **698,072.00**		X + αS = **640,051.00**	
3	X = 791,000.00	αS = 84.00	X = 727,000.00	αS = 71.00	X = 663,000.00	αS = 50.00
	X + αS = **791,084.00**		X + αS = **727,071.00**		X + αS = **663,050.00**	
2	X = 789,000.00	αS = 84.00	X = 725,000.00	αS = 71.00	X = 660,000.00	αS = 50.00
	X + αS = **789,084.00**		X + αS = **725,071.00**		X + αS = **660,050.00**	
1	X = 684,000.00	αS = 79.00	X = 627,000.00	αS = 68.00	X = 570,000.00	αS = 49.00
	X + αS = **684,079.00**		X + αS = **627,068.00**		X + αS = **570,049.00**	

Obs.: The options were numbered from 1 to 5 as follow: option 5 – radioactive wastes stored awaiting for the transportation to final disposal; options 4, 3, 2 e 1 – opening, segregation and exempt the waste (option 4 consider the national limit CNEN, option 3 consider the limit IAEA, option 2 consider the limit EURO and the option 1 consider the limit LAP.

5. Results and discussion

The first important result is that to any considered interim storage time (one or 10 years) and to any fraction of considered potentially exempted drums (0, 50 or 100%) the performance of option 5 (maintenance of the real situation) is lower than any other. In other words, the options that consider the opening, segregation and release of a fraction of the radioactive wastes are preferred, independent of the adopted limit.

Considering that option 5 is to maintain the current situation, the total cost remains unaltered, independent of the fraction of potentially exempted drums. Besides, it becomes evident that the bigger the fraction of potentially exempted drums is, the bigger the difference between the cost of option 5 and the others is. It can also be verified that for any interim storage time and any fraction of potentially exempted drums, the preference order is not altered. To the studied scenario, option 1 is always the analytical solution, followed by options 4, 2, 3 and 5 in decreasing preference order. It is important to distinguish that option 1 is the only that considers the Annual Limit to Public as dose criteria, thus the exemption limit considered in this case is 100 times higher, in average, than those based on 10 μSv of potential dose.

The preference for the segregation options, independent of the adopted limit, over the option of maintenance of the real situation is justified since the cost of all segregation process is low when compared to interim storage and final disposal costs and also because the collective and individual doses involved in the process are very low (Table 2).

By analysing the results "X + αS" of Tables 3 and 4 one can verify that to all cases, the contribution of the term "αS" is insignificant if compared to the contribution of term "X". To make the values comparable, it would be necessary to increase "αS" by a factor 10^4. An increasing of a factor 10^2 would lead to around 1% of "X" value. This means that even if the time evaluated in the 18 steps were 10 times higher (and that would consequently increase the doses by a factor 10), the "αS" would be a thousandth of "X" value.

Considering the derivation of costs, one can note that, around 80% of the cost of all options is resulting from step "18 – disposal".

At last, it can be noted that the difference between the options IAEA, that considers the most restrictive scenario from the 31 assessed, and EURO, that considers just the landfill scenario, is very small. So, for the radionuclides inventory studied in this paper, the disposal scenario in landfill presents values that are very close to those of the most restrictive among the 31 adopted by European Commission.

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