WASTE MANAGEMENT IN BRAZIL: BASIS TO BUILD THE FINAL REPOSITORY FOR THE RADIOACTIVE WASTES FROM THE GOIÂNIA ACCIDENT

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ABSTRACT

The well know episode resulting from breaking a ^{137}Cs source with an activity of 50.9 TBq (1375 Ci) in September 1987, in the city of Goiânia, capital of the Brazilian State of Goiás, generated approximately 3.5×10^3 m^3 of wastes, with an overall activity between 47.0 TBq (1.27×10^3 Ci) and 49.6 TBq (1.34×10^3 Ci). Such wastes are temporarily deposited in an area of about 8.5×10^4 m^2 at a site near the village of Abadia de Goiás; distance 23 km from the center of Goiânia. This paper deals with the decision making process concerning the construction of the final repository for radioactive wastes of the Goiânia episode.

INTRODUCTION

During the first half of the month of September of the year 1987, in the city of Goiânia, capital of the Brazilian State of Goiás, an abandoned teletherapy device was stolen, and then sold to a scrap metal dealer. The shielding, made of lead and steel, was removed because of its trade value. The remnant ^{137}Cs capsule, with an activity of about 50.9 TBq ($\approx$1375 Ci) at that time, formerly used as the radioactive source for the teletherapy device, was then broken with the help of a screwdriver (1-3). A more detailed description of the Goiânia episode and its earlier consequences and remedial actions can be found elsewhere (1-6). This paper deals essentially with the radioactive wastes resulting from the response to the accident.

Persons, domestic animals, houses, plants, toys, clothing, and a myriad of other objects were contaminated since the beginning of the episode. Exception made to the contaminated persons, who were directed to decontamination centers as soon as they were located, all remaining contaminated objects, either living organisms or inanimate things, were considered, by in large, as waste. Four persons died from acute radiation. They were buried under special precautions to ensure that the corpses would not become available as ^{137}Cs sources.

WASTES

Classification

The wastes produced during the decontamination effort were classified, in accordance with the Brazilian national regulations, mostly as low and intermediate levels depending on the external radiation exposure rates measured at the surface of each package (7). Table I summarizes the classification criteria for solid wastes resulting from the Goiânia accident based on the external exposure rate (eer) measured at the surface of each package.

Although such classification bears importance from the radiation protection view point, it is not the most adequate as the basis to design a final repository for radioactive wastes containing solely ^{137}Cs. Thus, the mean decay time to a level of ^{137}Cs concentration equal to or lower than 87 $Bq \cdot g^{-1}$ (2.35 $nCi \cdot g^{-1}$) was the basis to which one could associate progressively the engineering barriers necessary to be considered in the repository. The reason for choosing such concentration level will be discussed under the heading Criteria for Waste Disposal.

TABLE I

Classification of Solid Wastes Based on External Exposure Rates (eer) at the Package Surface

Radiation Level	External Exposure Level ($R \cdot h^{-1}$)
Low	eer $\leq$ 0.2
Intermediate	0.2 < eer $\leq$ 2.0
High	2.0 < eer

CURRENT PACKAGING

As the decontamination procedures developed, the modes of packaging adopted were essentially the following:

- 40, 100, and 200 liters steel drums used to contain papers, clothing, corpses of animals, plants, hospital wastes, soil, small objects, and so on;
- 1.7 m^3 metallic boxes to hold soil, remnants in general, and large pieces of different sort;
- 32 m^3 maritime containers for large paper roller; and,
- 200 liters cylindrical concrete recipients used to reduce the external exposure rates whenever those were higher than 1 $R \cdot h^{-1}$.

The 40 and 100 liter steel drums were used to allow extra shielding. These drums were reencapsulated into 200 liter drums with the empty spaces being filled with concrete.

Taking into account the decay time T needed to reach a ^{137}Cs concentration level equal to or lower than 87 $Bq \cdot g^{-1}$ (2.35 $nCi \cdot g^{-1}$) the wastes were divided into 5 groups, as shown in Table II.

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The number of 200 liter drums, metallic boxes, concrete recipients, maritime containers, as well as the larger portion of the remnants of the ^{137}Cs source were grouped, in accordance with the classification given in Table II. Table III shows such classification in terms also of volume and activity. The average specific mass of the wastes temporarily stored at Abadia de Goiâs is approximately $<\rho> = 1.7 \times 10^3 \, kg \cdot m^{-3}$. The overall volume of the wastes is about $3.36 \times 10^3 \, m^3$. This corresponds to a mass of approximately 5.7×10^3 metric tons. Such large volume and mass bear relevancy to the decision making process regarding where and how to dispose of such radioactive wastes.

TABLE II

Classification of Goiânia Radioactive Wastes in Groups, Based on the decay time T Needed to Reach a ^{137}Cs Concentration Level Equal or Lower than 87 $Bq \cdot g^{-1}$ (2.35 $nCi \cdot g^{-1}$)

Decay Time - T (years)	Group
$T \approx 0$	1
$0 < T \leq 90$	2
$90 < T \leq 150$	3
$150 < T \leq 300$	4
$300 < T$	5

On the one hand, one can clearly observe from Table III that all wastes classified in group 5 (i.e., those wastes that will have to be kept confined for over 300 years) correspond to approximately 1.5% of the total waste volume. On the other hand, those wastes classified in group 1 (i.e., that can technically be considered non radioactive waste or exempt from regulatory control) correspond to about 46% of the total volume. The concept of exemption of radiation sources and practices from regulatory control is under discussion at the International Atomic Energy Agency (IAEA) for some years (8).

CRITERIA FOR WASTE DISPOSAL

Recently a number of countries have started discussing and defining criteria for radioactive waste disposal. In particular, criteria for the disposal of low and intermediate levels of radioactive wastes have already been issued in some countries. Table IV summarizes such criteria, based on information presented and commented by Wagstaff (9).

It is well recognized that there are difficulties to apply the radiation protection criteria for the long term waste disposal. The principles of justification, optimization and individual dose limitations are interpreted in different ways by different national authorities, mostly when dealing with radioactive

TABLE III

Group, Volume and Activity of the Goiânia Wastes Temporarily Stored at Abadia de Goiás, as Stood in May 1991

Recipient	Quantity	Group	Volume (m^3)	Activity (TBq)	(mCi)
Capsule	1	5	5.7	4.4	1.18×10^5
200 L drum	3	5	0.6	0.25	6.76×10^3
Metallic box	25	5	43	22.5	6.08×10^5
Concrete	8	5	1.6	0.7	1.89×10^4
Sub-total		(5)	51	27.9	7.52×10^5
200 L drum	201	4	40	0.65	1.76×10^4
Metallic box	229	4	389	10.2	2.76×10^5
Sub-total		(4)	429	10.9	2.94×10^5
200 L drum	297	3	59	0.12	3.24×10^3
Metallic box	305	3	519	1.3	3.51×10^4
Sub-total		(3)	578	1.42	3.83×10^4
200 L drum	824	2	165	0.074	2.00×10^3
Metallic box	355	2	604	0.34	9.18×10^3
Sub-total		(2)	769	0.414	1.12×10^4
200 L drum	2622	1	524	0.02	5.41×10^2
Metallic box	406	1	690	0.026	7.03×10^2
Maritime container	10	1	320	0.011	2.97x102
Sub-total		(1)	1534	0.057	1.54×10^3
TOTAL	(5) + (4) + (3) + (2) + (1)		3.36×10^3	41.0	1.10×10^6

TABLE IV

Criteria for Radioactive Waste Disposal as Adopted by Selected Countries
(Data taken partially from Ref. (9))

Country	Dose[a] ($mSv \bullet y^{-1}$)	Control[b] (years)	Comments
France	1.00	300	an average alpha concentration of 370 $Bq \bullet g^{-1}$, based on an individual dose of 1 $mSv \bullet y^{-1}$.
Germany	0.30	none	safety analyses must be based on conservative assumptions.
Brazil	0.30	undefined	optimization is required.
U.S.A.	0.25 (whole body) 0.75 (thyroid) 0.25 (any other organ) 0.10	unclear	an annual dose of 0.50 mSv to the whole body and an institutional control period of 100 years can also be required.
Sweden		1×10^4	low and intermediate level wastes are to be disposed of in a mine repository near Forsmark.
Switzerland	0.10	none	there is neither a requirement to estimate collective dose nor a cost benefit analysis.
U.K.	0.10	300	optimization is required, and the assumed annual risk of death from radiation exposure of 1 $mSv \bullet y^{-1}$ is 10^{-5}.

[a]limitation of individual dose equivalent - usually based on realistic transport models.
[b]institutional control after the sealing of a repository.

waste disposal. Table IV reflects such differences. As one can notice from Table IV, the limitation of individual dose equivalent ranges from 0.10 to 1.00 $mSv \bullet y^{-1}$. In addition, the institutional control after the sealing of a repository vary from country to country.

The limitation of individual dose equivalent of 0.30 $mSv \bullet y^{-1}$ adopted in Brazil corresponds to a concentration of about 87 $Bq\,^{137}Cs \bullet g^{-1}$, based on landfill scenarios and pathways used by the IAEA to obtain derived exempt concentrations (8). However, taking into account that such scenarios and pathways are of generic nature, though claimed to be relatively insensitive to site specific assumptions, one needs to develop a site specific environmental model and evaluate the most relevant parameters involved, before adopting 87 $Bq\,^{137}Cs \bullet g^{-1}$ as a definitive exempt concentration value. In any case, it is not expected that this exempt concentration will change significantly, and consequently the decisions being made at the present will need to be changed accordingly.

Table V summarizes the average concentrations of each group of radioactive wastes, based on information taken from Table II, and assuming an average specific mass of 1.7×10^3 $kg \bullet m^{-3}$. In addition, Table V indicates the decay time necessary for each group of radioactive wastes to reach a concentration level lower than 87 $Bq\,^{137}Cs \bullet g^{-1}$.

Taking into account the average concentration for each group the decay time to reach a concentration level lower than or equal to 87 $Bq\,^{137}Cs \bullet g^{-1}$ was estimated. Figure 1a shows in a graph the decay curves for each particular group. Figure 1a group 5 is the only one with good definition. In Fig. 1b groups 3, 4, and 5 appear distinctively in the graph, while in Fig. 1c all five groups are well defined, and the intersections of the curves corresponding to groups 2, 3, 4, and 5 indicate the

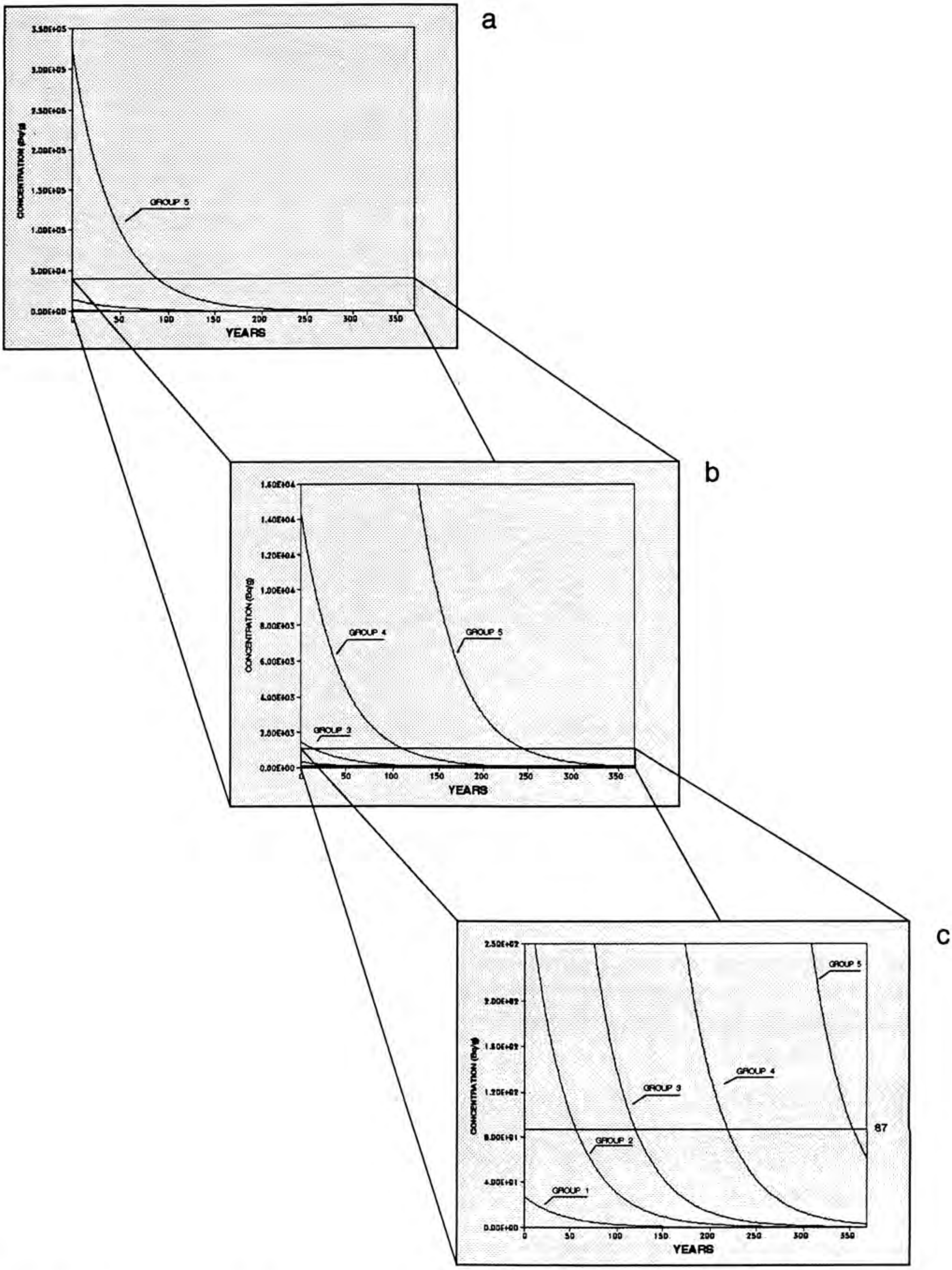

Fig. 1. Decay curves for each group of radiactive wastes: a) only group 5 is distinctly defined; b) groups 3, 4, and 5 are defined; c) all five groups are well defined with the intersections with the 87 $Bq \bullet g^{-1}$ concentration level being shown, except for group 1.

TABLE V

Average Concentration of Each Group of ^{137}Cs Radioactive Wastes Temporarily Deposited in Abadia de Goiás, and the Time Length (i.e., decay time) Necessary to Reach a Concentration Lower than 87 Bq $^{137}Cs \cdot g^{-1}$

Group	Average Concentration $kBq \cdot kg^{-1}$	Decay Time Years
5	3.21×10^5	356
4	1.43×10^4	221
3	1.45×10^3	122
2	3.2×10^2	57
1	26.9	0

decay time to reach the 87 $Bq^{137}Cs \cdot g^{-1}$ concentration level. One can observe in Figure 1c that the radioactive wastes in group 1 have already an average concentration lower than 87 $Bq^{137}Cs \cdot g^{-1}$.

The time frame necessary for the radioactive wastes, deposited temporarily in Abadia de Goiás, to become innocuous from the radiological view point is, in accordance with the data presented in Table V and Fig. 1, less than 360 years.

SITE SELECTION

The concept of sub-surface for waste disposal has been recognized worldwide and recommended by the IAEA (10,11). The Brazilian regulations for radioactive waste disposal require confinement to protect human beings and to preserve the environment at short- and long-term bases (7,12,13). With such concept and requirements in mind, site selection procedures for the final disposal of the radioactive wastes from the Goiânia accident were undertaken in accordance with the following (14):

- the whole State of Goiás was defined as a **region of interest**, taking into account technical, socio-political and economical aspects;
- regional studies to eliminate unfavorable areas and to identify **preliminary areas** were carried out by using maps on the 1:1,000,000 scale, and taking into account restriction factors like demography, mineralized zones, hills, valleys, mountains, hydrology, ecosystems, national and state parks, indian reservations, biological reserves, and seismicity - 189 preliminary areas were identified;
- evaluation of the identified preliminary areas to choose **potential areas** was based on fisiographic and geological aspects, considering a map scale of 1:100,000 for the fisiography and 1:250,000 to eliminate areas due to lithological and tectonic studies - 18 potential areas were chosen;
- "in loco" examination of the potential areas to select **candidate sites**, taking into consideration a punctuation methodology to select the sites (15) - three candidate sites were selected.
- the three candidate sites were presented to the government of the State of Goiás for the **final site** selection.

The punctuation methodology, mentioned above, included the following aspects: geology; land use; land property; depth of the aquifer; soil thickness; access and distance for transportation. The distances of the three candidate sites from the temporary repository are 400 meters, 74 km and 100 km. The nearer site was expected to be chosen because in addition to being similar to the other two, the probability of occurring an accident while transporting such heavy and large volumes containing radioactive wastes could not be ignored in the final stage of the decision-making process. The State of Goiás, jointly with CNEN, selected the site nearer the temporary one to build the final repository for the wastes.

BRAZILIAN LEGISLATION

Environmental impact statement in Brazil obeys certain rules that are regulated by a specific legislation (16). This implies that environmental impact studies (estudo de impacto ambiental - EIA) are to be carried out, and that a summary report (relatório de impacto ambiental - RIMA) of these studies will be submitted for public hearings. Federal, state and municipal approval are necessary to build any new installation like the final repository for the radioactive wastes from the Goiânia accident. The EIA is in the process of being developed as of this writing.

CONCLUDING REMARKS

The decision-making process to build a final repository for the radioactive wastes from the Goiânia accident was preceded by numerous talks and debates with professional and community associations and societies, as well as with the academia. Furthermore, there are ethical and socio-political aspects associated with the disposal of radioactive waste disposal that cannot be ignored in the decision-making process. In the particular case of the Goiânia radioactive wastes, the ethical and socio-political aspects were taken into consideration based on the balance of solving the problem at a permanent basis vis-à-vis the maintenance of a temporary solution for an extended period of time.

A large number of talks and debates are still going on in Goiânia and elsewhere to clarify the meaning of a permanent solution for the radioactive wastes, not only in which concerns with the technical aspects, but also, and mainly, by discussing ethical and sociopolitical aspects. The latter discussion is particularly difficult, because scientists and engineers are not better equipped, in terms of ethical values and socio-political experience, than any other segment of an organized society.

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