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SCENARIOS FOR THE ASSESSMENT OF URBAN EXPOSURES AFTER RADIOACTIVE CONTAMINATION

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ABSTRACT

Accidents involving radioactive material are not frequent but may include releases of radionuclides to the air, land or waterways. These releases are usually uncontrollable and may lead to doses in the public in excess of the reference levels established by regulations defined by the national regulatory agencies of each country. Although they had occurred sporadically since the last century, it was observed that, after the emergency phase, the public concern is enhanced when they feel that there is an unpreparedness of authorities responsible for remediation actions, due to the lack of definition of strategies to be adopted in the long term after such events. The aim of this work is to describe reference urban scenarios, considering the characteristics observed in residential and free access areas of urban centers. These scenarios were developed based on the counties surrounding the Brazilian nuclear power plant. Considering the counties within 50 km from the nuclear power plant, nine belong to the state of Rio de Janeiro and seven belong to São Paulo state; the highest population densities were observed in five counties of Rio de Janeiro. Based on the different types of residences and outdoor areas observed in these 16 counties, six reference scenarios for urban areas were developed including areas comprised by four types of residential houses (with low, medium and high shielding building material and houses in a row), apartments in buildings, and park areas with lawn and trees. The characteristics of each of these scenarios were raised through Google Earth images considering 1 km^2 of different locations comprised by each type of area defined. In a next step, the information obtained in each scenario shall be used in computer simulations to characterize the effects and consequences on public exposure of the application of decontamination procedures.

1. INTRODUCTION

After the occurrence of an accident that leads to the release of radionuclides to the environment, the use of protective and remediation measures may be needed to reduce the doses on members of the public due to exposures to the dispersed and deposited nuclides in their living environments. The procedures chosen by the authorities must be efficient and an important work must be done in advance, considering the expected stress of the population that usually become concerned about the accident consequences and about the decisions made by the authorities after the occurrence of the accident [1, 2, 3].

In order to be prepared to deal with the nuclear or radiological accident consequences, it is important to develop research works that allow the knowledge of the environmental behavior of those nuclides, that are the most probable to be released in such accidents [4, 5] and to

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develop calculation tools that are able to simulate the dynamic behavior of the radionuclides that are dispersed in the environment.

Since the radiological accident in Goiânia, in 1987 [6], the development of tools aiming to support decision-making process after a radioactive contamination of the environment stated in Brazil [7]. These tools include the development of a multi-criteria model on decisions about protective and remediation procedures for tropical environments [8].

However, the effectiveness of a specific procedure depends on the characteristics of the area where it is applied. As so, the assessment of the consequences of a specific release and of the efficacy of a remediation procedure is site dependent. Relevant characteristics of urban areas are, for example, the layout, the type of building and building materials and population density.

The objective of this work is the development of standard scenarios comprising the main types of urban environments observed at the surroundings of the Brazilian nuclear power plants. These scenarios shall be used for performing simulations of environmental contamination and assess the consequences of the public exposure to deposited radionuclides and the efficacy of different procedures in reducing these exposure. The same scenarios shall be used to estimate occupational doses during clean-up procedures and the wastes generated by each procedure on each scenario.

2. METHODOLOGY

In this work, only urban areas were considered. The priority was to focus the counties surrounding the Brazilian nuclear power plant due to the probability of receiving higher contamination levels in case of an accident including releases of radioactive material to the environment. The definition of the study area was defined on previous works [9] and comprises all counties that are totally or partially within a 50 km distance from the power plant, located at Angra dos Reis County (Figure 1). Typical urban environments found in the main cities of the counties were searched and included living environments, streets and park areas.

It is however important to stress that this work is not intended to be used at the emergency phase of the accident when urgent protective measures, such as evacuation and sheltering, are to be applied. The study area under the scope of this work refers to the remediation phase, without immediate urgency needs, considering the recovery of areas that may or not have been evacuated previously at the emergency phase.

The main characteristics of the study area were studied by images from Google Earth® e from the web pages of the municipalities. Data for describing the scenarios were normalized for 1 km^2. The town of Rio de Janeiro was chosen to rise the parameters for each type of environment selected, because it contains large areas of different types of environments thus allowing the quantification of parameters such as number of residences, length of streets, number of trees, among others, within 1 km^2 of each type of environment. These parameters are relevant to assess the averted dose to the public, the doses for decontamination workers and the amount of waste generated by each type of decontamination procedure.

Relevant characteristics for collective doses to the public are the individual dose in each defined compartment, that are calculated using the PARATI software, the time spent on each compartment, and the number of residents and visitors of each type of area. Relevant characteristics for collective doses to workers are the number of people working on each decontamination team, the time spent by each team on a particular procedure per unit on each type of environment and the number of units in the area to be decontaminated. Relevant features for characterizing wastes are the type and concentration of the surface being cleaned up and the amount of that surface on each type of area.

Figure 1. Area within 50 km surrounding the Brazilian nuclear power plants (CNAAA) in Angra dos Reis. Source: Google Earth®.

3. RESULTS AND DISCUSSION

The selected counties are located in the states of São Paulo and Rio de Janeiro. Nine counties are in the Rio de Janeiro State and five of them have a resident population in excess of 100,000 inhabitants. High demographic densities are also associated to these areas. The seven counties located in São Paulo State are mainly small towns with less than 100,000 inhabitants and large agricultural areas, being important producers of several crops (Table 1). The selected counties are (Figure 2):

(i) Rio de Janeiro State: Angra dos Reis, Barra Mansa, Itaguaí, Mangaratiba, Parati, Piraí, Resende, Rio Claro and Volta Redonda;
(ii) São Paulo State: Arapeí, Areias, Bananal, Cunha, São José do Barreiro, Silveiras and Ubatuba.

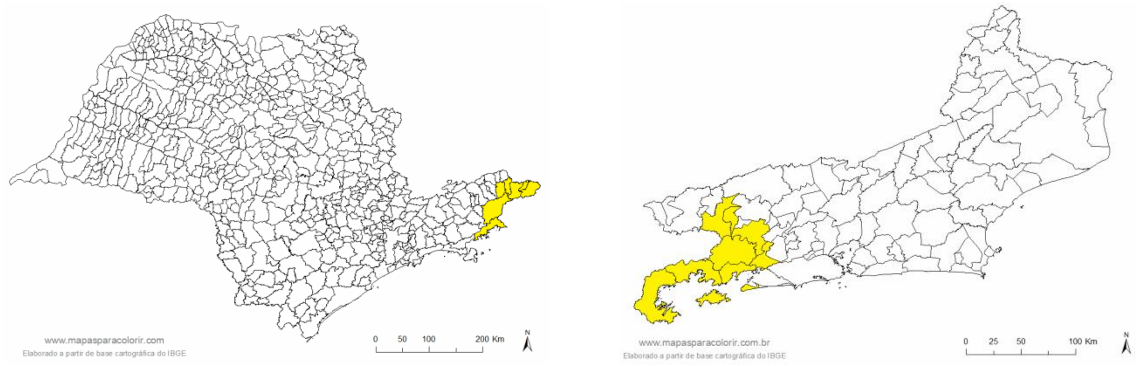

Figure 2. Counties selected for comprising the study area, located in São Paulo (left) and Rio de Janeiro (right) states.

Table 1. Demographic data for the selected counties [10].

No.	State	County	Estimated population for 2014	Area (km^2)	Demographic density (inhab/km^2)
1	RJ	Angra dos Reis	184940	825,088	205,45
2	RJ	Barra Mansa	179697	547,226	324,94
3	RJ	Itaguaí	117374	275,867	395,45
4	RJ	Mangaratiba	40008	356,408	102,29
5	RJ	Paraty	39965	925,053	40,57
6	RJ	Piraí	27579	505,375	52,07
7	RJ	Resende	124316	1095,253	109,35
8	RJ	Rio Claro	17768	837,265	20,81
9	RJ	Volta Redonda	262259	182,483	1412,75
10	SP	Arapeí	2532	156,902	15,89
11	SP	Areias	3849	305,227	12,11
12	SP	Bananal	10728	616,428	16,58
13	SP	Cunha	22167	1407,318	15,54
14	SP	São José do Barreiro	4188	570,686	7,14
15	SP	Silveiras	6121	414,782	13,96
16	SP	Ubatuba	85399	723,829	108,87

Considering the different housing characteristics for these 16 counties, the following standard scenarios were developed for urban areas:

- low shielding houses;
- medium shielding houses;
- high shielding houses;
- houses in a row;
- park areas with lawn and trees; and,
- buildings (more than 4 stores) – reference residence is an apartment at the 4^{th} floor.

Besides those ones, specific scenarios for paved streets with sidewalks and trees and for unpaved streets have also been derived. Although these are simplified scenarios, they allow comparing environmental consequences such as surfaces concentrations, dose rates and effective doses, related to the use of different cleanup procedures.

Low, medium and high shielding houses follow the description provided by Salinas and collaborators [11, 12]. Examples of the main types of living environments as used for defining area parameters can be seen in Figure 4.

High shielding houses

Medium shielding houses

Low shielding houses

Houses in a row

Figure 4. Examples of houses considered for defining specific scenarios.

Main characteristics defined for 1 km^2 of each type of area can be seen on Table 2. Figure 5 shows some of the pictures taken from Google Earth® used to derive parameter values for the study areas.

Table 2. Main Characteristics of urban scenarios.

Properties	**High shielding houses**	**Medium shielding houses**	**Low shielding houses**	**Building with gardens**	**Houses in a row**	**Parks**
House or apartment/km^2	2329	6659	16292	21429	10000	—
Street width (m)	11	6	3	10	6	—
Street length (m/km^2)	23156	37269	76697	7812	50000	—
Street area (m^2/km^2)	254713	223617	230090	78120	300000	—
Trees/km^2	2500	1313	1089	2083	1100	13000
Lawn area (m^2/house)	300	75	0	—	—	—
Lawn (m^2/km^2)	698611	499417	0	244000	—	1000000
Walls (m^2/house)	240	104	87	—	180	—
Walls (m^2/km^2)	558889	692525	1417366	75556	1800000	—
Roof (m^2/house)	120	90	60	—	70	—
Roof (m^2/km^2)	279444	599301	977494	—	700000	—
Building area (m^2)	—	—	—	1000	—	—
Paved area (m^2/km^2)	—	—	—	434000	—	—
Stores	2	1	1	12	2	—
Swimming pool area (m^2/km^2)	—	—	—	30000	—	—
Building area (m^2/km^2)	—	—	—	223000	—	—
Inhabitants/ km^2	9315	26636	65166	85714	40000	—
Visitors/day	—	—	—	—	—	2000

Figure 5. Photos of areas used for defining scenarios parameters. Source: Google Earth®.

4. CONCLUSIONS

The study of the main urban areas of the 16 counties selected as potentially exposed to a radioactive contamination after an accident at the Brazilian nuclear power central lead to the definition of six main urban scenarios that shall be used to assess the consequences of cleanup procedures. Secondary scenarios for different types of streets have also been derived. The results of computer simulations for each scenario will be used to derive numerical criteria under a pre-defined standard already developed [8] in order to make it possible to rank clean up procedures considering the averted dose to residents, the doses to cleanup workers and characteristics of waste generated.

It must however be remembered that these generic scenarios are to be used for the remediation phase after an accident, after the initial period when urgent protective measures and decisions related to immediate health effects have already been implemented. However, the model is built in a way that new environments can be easily created by properly combing current environments available. For example, houses in a row may be used with paved or with unpaved streets, with or without trees, and so on.

5. REFERENCES

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