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DEFINITION OF CRITERIA RELATED TO OCCUPATIONAL EXPOSURE FOR USE IN MULTI-CRITERIA DECISION MAKING PROCESS FOR NUCLEAR ACCIDENTS IN BRAZIL

Diogo N. G. Silva[1], Elaine R. R. Rochedo[2] and Jean R. D. Guimarães[1]

[1] Instituto de Biofísica Carlos Chagas Filho
Universidade Federal do Rio de Janeiro
Avenida Carlos Chagas Filho, 373, Bloco G
21941-902 Rio de Janeiro, RJ
dneves@biof.ufrj.br
jeanrdg@biof.ufrj.br

[2] Programa de Engenharia Nuclear
Instituto Militar de Engenharia
Praça General Tibúrcio, 80, 4º andar
22290-270 Rio de Janeiro, RJ
elainerochedo@gmail.com

ABSTRACT

After the occurrence of nuclear or radiological accidents, the selection of strategies for remediation of contaminated areas and of protective measures for members of public should be based on previously established criteria. Hence, it becomes possible to reduce the stress of population and to prevent the exposure of workers, especially if an implemented measure is not effective in reducing doses for each particular situation. When an accident with radioactive material causes environmental contamination, decisions about remediation of affected areas are complex because there are many factors associated with decontamination processes. Such complexity is related to technical procedures, public acceptance, the feasibility of implementing the measure, costs and legal aspects. This work is part of a project which aims to develop a multi-criteria tool to provide support for decision making processes in cases of nuclear or radiological accidents in Brazil. Primarily, a database containing information about protective and remediation measures for contaminated areas which can be applied nationally was created. Some criteria have already been defined for the classification of these measures regarding aspects of relevance of pathways to public exposure and of the infrastructure necessary to implement the measure. In this paper, the issues related to the exposure of the workforce are assessed and compared to the dose averted to members of the public resulting from the implementation of each remediation procedure. The procedures described in the database are then ranked according to selected criteria. In the next step, these ratings will be incorporated by the multi-criteria tool.

1. INTRODUCTION

Currently, one of the main concerns of the authorities of the nuclear area in the world is the possibility of accidents with environmental consequences, since population can be affected both directly and indirectly by contamination, as a result of such events. When considering accidents involving radioactive materials, the consequences may include exposures to individuals in public, as well as to the workers responsible for the remediation of contaminated areas [1, 2].

When an accident with radioactive material occurs and leads to release to the environment, it is important to implement protection and remediation measures in order to minimize human exposure to radionuclides via air, land or water. Therefore, it is necessary that the measures to be chosen by the country responsible authorities are considered based on its efficiency that can be defined by previously established criteria. Thus, it becomes possible to reduce the stress of the population, who is usually very apprehensive due to the accident and suspicious of decisions taken by the authorities [1, 3, 4]. When well established, the measures also contribute to prevent unnecessary exposure of workers involved in decontamination processes [2, 4, 5].

In such cases, the decision making process becomes complex because it is dependent on a number of factors associated with the decontamination, involving radiological, technical, social, legal, feasibility of the measure and costs [6].

Concerned with the possibility of an accident with radioactive materials, various institutes worldwide began studies in order to determine the effectiveness of protective and remediation measures to protect the public and to determine which strategies are the most appropriate. The main countries involved in this type of study were the European nations mostly affected by the Chernobyl accident, in 1986, and Russia [5, 7, 8, 9, 10].

In Brazil, since the radiological accident in Goiânia, in 1987, it was started the development of tools to support the processes of decision making in case of emergencies of this nature [2]. These processes include the establishment of a multi-criteria model to support a process of decision making on the implementation of protection and remediation measures of contaminated areas in tropical environments [11].

Initially, it was developed a database containing protection and remediation measures that can be applied in cases of nuclear or radiological accidents in Brazilian tropical territory. The description of each measure considers many aspects (technical, radiological, political, social and economic ones). The measures were classified into three groups according to the area type: urban, rural, and aquatic [6]. In developing the multi-criteria decision tool, two types of criteria need to be defined. The so-called subjective criteria have been derived from questionnaires distributed to specialists on accident management [12], while the technical criteria are being developed through simulations of accidents and the consequences of applying each countermeasure described in the database [13, 14, 15, 16, 17].

The aim of this paper is to discuss the definition of criteria for the technical aspects of occupational doses, related to the implementation of protection and remediation measures in urban areas, after the occurrence of a nuclear or a radioactive accident in Brazil.

2. METHODOLOGY

Doses to workers have been assessed based on the information gathered on the countermeasures database [18] and on the description of reference urban environments [19]. For this study, it has been considered an urban environment composed of medium shielded houses with main characteristics described on Table 1. The remediation measures simulated and their main characteristics are described on Table 2.

Table 1: Main characteristics of the urban environment used in simulations

Characteristic	Value
type of house	medium shielding
house/km^2	6659
street width (m)	6
street length (m/km^2)	37269
street area (m^2/km^2)	223617
tree/km^2	1313
roof/km^2	7331
lawn area (m^2/house)	75
lawn (m^2/km^2)	499417
wall (m^2/km^2)	692525
roof (m^2/km^2)	599301

Dose rates for the occupation of different compartments of urban areas and the concentration of urban surfaces used in this assessment were obtained with the SIEM code [20]. For the procedures that lead to dust generation, inhalation doses have also been assessed considering a resuspension factor of 10^{-6} m^{-1}. Public exposures averted from the application of each countermeasure have also been estimated using dose rates obtained with the SIEM code, considering the public uses of the environment as described on Table 3.

Table 3: Characteristics of public exposure considered to determine averted doses

Number	Measure	Type of public and occupation
1	Measures in dwellings	Adult for 24 h/day inside the residence
2	Measures in common areas – parks and squares	2,000 adults visiting the park area for 4 h/day + 12 park employees/km^2 for 8 h/day
3	Measures in common areas – streets and sidewalks	Adults living next to the area for 1 h/day on the streets + 5 people/km^2 working for 8 h/day on the streets

One important limitation of this study is that, at its current stage, only adults are considered as they represent an average member of the public.

Table 2: Main characteristics of the remediation measures used in simulations

Measure	*External exposure*	*Exposure to other surface*	*Internal exposure – inhalation*	*Exposure time*	*Number of workers*
Measures in dwellings					
Pruning trees in dwellings	external area of the dwelling	tree	resuspension	3 h/tree	3
Pruning shrubs	external area of the dwelling	shrub	resuspension	1 h/shrub	2
Cutting grass in dwellings	external area of the dwelling	—	resuspension	0.005 h/m^2	2
Top soil removal (1 cm)	external area of the dwelling	—	resuspension	0.0075 h/m^2	2
Grass removal manually (5 cm)	external area of the dwelling	—	resuspension	0.0075 h/m^2	2
Washing walls with water	external area of the dwelling	wall	—	0.033 h/m^2	2
Chemical washing of walls	external area of the dwelling	wall	—	0.033 h/m^2	2
Scraping walls	external area of the dwelling	wall	resuspension	0.5 h/m^2	2
Washing roofs	external area of the dwelling	roof	—	0.1 h/m^2	2
Chemical washing of roofs	external area of the dwelling	roof	—	0.1 h/m^2	2
Scraping tiles	external area of the dwelling	roof	resuspension	0.067 h/m^2	2
Roof exchange	external area of the dwelling	roof	—	0.4 h/m^2	2
Measures in common areas – parks and squares					
Pruning in parks	external area of the park	tree	resuspension	3 h/tree	3
Top soil removal (1 cm)	external area of the park	—	resuspension	0.0075 h/m^2	2
Top soil removal (5 cm)	external area of the park	—	resuspension	0.0075 h/m^2	2
Cutting grass in parks	external area of the park	—	resuspension	0.005 h/m^2	2
Cutting grass in parks on foot	external area of the park	—	resuspension	0.05 h/m^2	2
Measures in common areas – streets and sidewalks					
Washing streets	street	—	—	0.0015 h/m^2	2
Washing with vehicle	street	—	—	0.015 h/m^2	3
Scraping streets	street	—	resuspension	0.01 h/m^2	4
Scraping with vehicle	street	—	—	0.001 h/m^2	4
Pavement removal of streets	street	—	resuspension	0.04 h/m^2	2
Pavement removal with vehicle	street	—	—	0.004 h/m^2	2

3. RESULTS AND DISCUSSION

The results on the ratio of the workers dose to the averted public dose are present on Table 4.

Table 4: Ratio between collective doses to workers and the averted integrated effective collective dose to the public due to the application of remediation measures

Averted effective dose in:	1 year	50 years	1 year	50 years	1 year	50 years
Application of measure after:	7 days		30 days		180 days	
Measures in dwellings						
Pruning trees in dwellings	5.7 E-3	5.6 E-3	6.1 E-3	5.9 E-3	2.1 E-2	1.6 E-2
Pruning shrubs	1.5 E-3	1.4 E-3	1.7 E-3	1.6 E-3	6.8 E-3	5.3 E-3
Cutting grass in dwellings	2.2 E-4	7.0 E-5	3.3 E-4	6.8 E-5	9.1 E-1	1.4 E-2
Top soil removal (1 cm)	2.1 E-4	3.2 E-5	1.8 E-4	2.6 E-5	2.8 E-4	2.2 E-5
Grass removal manually (5 cm)	2.6 E-3	3.9 E-4	2.2 E-3	3.1 E-4	3.2 E-3	2.5 E-4
Washing walls with water	1.1 E-2	4.4 E-3	8.6 E-3	3.7 E-3	3.1 E-2	3.5 E-3
Chemical washing of walls	2.5 E-2	8.2 E-3	2.2 E-2	6.7 E-3	3.4 E-2	6.1 E-3
Scraping walls	6.8 E-2	1.4 E-2	5.8 E-2	1.2 E-2	9.1 E-2	9.8 E-3
Washing roofs	5.4 E-2	5.4 E-2	9.6 E-2	9.6 E-2	1.6 E+1	1.6 E+1
Chemical washing of roofs	2.1 E-2	5.7 E-3	2.8 E-2	5.1 E-3	8.0 E-2	4.4 E-3
Scraping tiles	4.2 E-3	5.3 E-4	3.9 E-3	4.2 E-4	6.0 E-3	3.3 E-4
Roof exchange	3.3 E-3	4.2 E-4	3.1 E-3	3.3 E-4	4.8 E-3	2.6 E-4
Measures in common areas – parks and squares						
Pruning in parks	2.6 E-1	2.5 E-1	4.8 E-1	4.6 E-1	1.9 E+0	1.5 E+0
Top soil removal (1 cm)	2.2 E-2	3.4 E-3	1.9 E-3	2.7 E-4	2.9 E-3	2.3 E-4
Top soil removal (5 cm)	2.8 E-2	4.2 E-3	2.3 E-2	3.3 E-3	3.4 E-2	2.7 E-3
Cutting grass in parks	4.6 E-3	1.4 E-3	8.3 E-3	1.7 E-3	1.8 E+1	2.9 E+2
Cutting grass in parks on foot	3.1 E-3	9.8 E-4	5.6 E-3	1.2 E-3	1.2 E+1	2.0 E+2
Measures in common areas – streets and sidewalks						
Washing streets	2.8 E-3	1.3 E-3	1.8 E-3	7.9 E-4	1.9 E-3	5.0 E-4
Washing with vehicle	4.2 E-4	1.9 E-4	2.7 E-4	1.2 E-4	2.8 E-4	7.5 E-5
Scraping streets	9.1 E-3	1.9 E-2	6.2 E-3	1.2 E-3	7.0 E-3	7.3 E-4
Scraping with vehicle	7.9 E-4	1.6 E-3	5.0 E-4	9.6 E-5	5.0 E-4	5.2 E-5
Pavement removal of streets	2.5 E-3	5.1 E-4	1.6 E-3	3.1 E-4	1.7 E-3	1.7 E-4
Pavement removal with vehicle	2.4 E-4	4.9 E-5	1.5 E-4	2.9 E-5	1.5 E-4	1.6 E-5

It can be seen that, for all procedures, the averted dose to the public is higher than the dose received to workers if the measures are applied about one week after the accident (doses ratio < 1). However, in this period, urgent protective measures are probably still under way and there is not enough time to gather the resources needed to implement the remediation measures. Decontamination procedures are most probably to be applied on the period of 1 month up to a few years from the accident. Also, considerations about the dose values to the workers are not considered here as at this phase of the accident, dose limits are to be applied to all workers. The pruning of trees on park areas should be carefully considered in this first week after the accident based on more realistic assessment of doses averted to the public, to make sure that these are enough to compensate the occupational doses and the protective measures, such as the use of respiratory protection devices should be considered.

When the measures are applied after 1 month, all measures are still effective, regarding the averted dose to the public in face of the occupational dose. Realistic assessment and special protective devices to workers however have to be considered mainly for the pruning of trees and bushes in park areas.

For the application of the measures 6 months after the accident, several measures are not worth applying as the occupational doses may be higher than the averted ones to the public. This is mainly due to the dynamics of the environmental contamination in grass and tree leaves that have already weathered to the underlying soil. These measures are only efficient if applied in the period of 1-2 months after the accident.

Based on this results, the following criteria are suggested to be applied to classify the exposure of workers at the multi-criteria analysis (Table 5), considering that a ratio of occupational dose to averted public dose higher than 1.0 makes the measure not recommended to be applied and that the efficiency of this application, regarding occupational exposures, increases with lower ratio values.

Table 5: Proposed criteria to classify remediation procedures according to its efficiency regarding occupational exposures

Ratio value	Criteria value
> 1	0
0.1 – 1.0	1
0.1 – 0.01	2
0.01 – 0.001	3
0.001 – 0.0001	4
< 0.0001	5

4. CONCLUSIONS

The approach through the multi-criteria analysis allows the criteria to be previously established, leading to a selection of options that are technically justifiable and making the decision making process more transparent and reliable for individuals of the public. These aspects are critical for the acceptance by the public of decisions made and the protection and remediation measures implemented [21, 22].

In this paper, we presented the criteria related to technical aspects of occupational doses, necessary to determine which remedial measures are appropriate for a given situation, considering only urban areas. It was also proposed the criteria for the classification of this aspect. The final classification of the procedures, however, needs considering other types of urban areas and the inclusion of children exposures in the assessments. These assessments are to be performed using the same methodology derived in this work.

Other aspects to be specifically included while considering the workforce dealing with long-term consequences of the accident shall also be developed, regarding the need of protective individual equipments and the need of specific skills or training to implement the procedures.

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