REMEDIATION STRATEGIES AFTER NUCLEAR OR
RADIOLOGICAL ACCIDENTS: PART 2 - ACCIDENT SCENARIOS
FOR ASSESSING EFFECTIVENESS OF CLEANUP PROCEDURES

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ABSTRACT

The selection of protective measures and remediation strategies after an accident needs to be based on previously established criteria, to minimize unnecessary stress and the exposures involved in cleanup operations that are not effective in reducing doses to the public. In a first stage, a database describing the countermeasures has been developed including their efficiency on removing contamination from surfaces. However, to assess the effectiveness of cleanup procedures in reducing doses to members of the public, it was necessary to derive specific scenarios in order to simulate the long term behavior of the material in the environment, since the contribution of different surfaces to doses changes with time after contamination. A basic release and exposure scenario was developed to assess the dose reduction due to the mostly used procedures. Exposure scenarios were selected to fit the surroundings of the Brazilian nuclear power plants in Angra dos Reis. Simulations were performed using SIEM, the integrated system for dose assessment after contamination events, developed at IRD. The contamination of urban environments was assessed for Cs-137, as this was found to be the most relevant long term radionuclide to contribute to doses to member of the public. The effects on reducing external exposures were assessed for periods up to 50 years after the contamination. For agricultural areas, the focus was on ingestion doses from contamination with I-131 for periods up to 1 year after contamination. Results will be complemented on the database in order to support multi-criteria decision making processes after accidents.

1. INTRODUCTION

One of the main concerns on emergency preparedness worldwide is the assessment of possible consequences of events that may lead to environmental contamination and hence to public exposure. Since the Goiânia accident [1], IRD-Institute of radiological Protection and Dosimetry, from CNEN – National Nuclear Energy Commission has been developing supporting tools to the decision making process after nuclear or radiological accidents, aiming the protection of the public if such events occur [2,3]. The environmental modeling project has developed the SIEM code - Integrated system for emergency assessment of doses
to the public [4]. Several activities have been developed aiming to improve the output of these models by incorporation of data adequate to Brazil, considering aspects linked to climate, soil type, building material and agricultural practices [5, 6, 7, 8, 9, 10].

The most recent activity under the environmental modeling project was the development of a database of protective and remediation measures to be applied for the radiological protection of the public [11]. The database includes now 78 measures that may be applied to urban, agricultural or aquatic environments and measures are described according to their efficiency on removing the contamination or on the reduction of dose rate from the surfaces. In order to address a multi-criteria decision making process, the following aspects are covered in the database:

(a) generic aspects, describing the target surface, target nuclides and overall procedures;

(b) technical aspects: exposure pathways, timing for application, technical restrictions, effectiveness in removing contamination or reducing dose rates, factors affecting averted dose and dose to workers involved in the application of the measure;

(c) infrastructure: required equipments and materials, required skills, safety requirements;

(d) waste: type and amount of wastes generated by the application of the procedures;

(e) other aspects, such as non-radiological impacts, practical experience worldwide and references

The effectiveness of each countermeasure, according to literature data, is mostly provided under qualitative aspects or they are related specifically to the surface or environmental media to which it is applied [12, 13, 14].

However, to assess the effectiveness of cleanup procedures in reducing doses to members of the public, it was necessary to derive specific scenarios in order to simulate the long term behavior of the material in the environment, since the contribution of different surfaces to doses changes with time after contamination [15, 16].

The objective of this work was then to define some basic release and exposure scenarios to assess the effect of mostly used measures in reducing the doses to the public in the short, medium and long-term after the contamination event, as a function of the moment when the measure is applied to a specific surface or environment.

2. METHODOLOGY

All simulations were performed with SIEM code [4] that includes two main environmental models: CORAL, that is used to assess the consequences of the contamination of rural environments and that was developed based on the German model ECOSYS, widely used
through out the European community countries [15,16]; and, PARATI, developed at IRD to assess the consequences of a contamination of urban environments [3].

The contamination of urban environments were assessed for Cs-137, as this was found to be the most relevant long term radionuclide to contribute to doses to member of the public. A basic release leading to a deposition in an open horizontal lawn surface of 1 MBq m\(^{-2}\) was considered and exposure scenarios were developed to assess the dose reduction due to the mostly used cleanup procedures.

Exposure scenarios were selected to fit the surroundings of the Brazilian nuclear power plants in Angra dos Reis [6, 17]. The effects on reducing external exposures were assessed for periods up to 50 years after the contamination.

For each procedure, the simulation output was the indoors dose rates and integrated doses since the moment of the contamination event. The population group selected is composed by adults and occupancy rates indoors were considered as 24 hours a day.

Six scenarios have been considered as follows: House 1 simulates a low shielding wood house typical from European environments, following the characteristics described by Meckbach et al. [18]; House 2, 3, and 4 were used to simulate typical Brazilian residences with shielding following the results provided by Salinas et al. [7] for brick houses such as House 2 has no plaster on the walls, House 3 has one side covered by plaster, and House 4 simulates a house with bricks covered with plaster inside and outside. House 5 simulates a typical German masonry house also with double plaster finishing on walls, with the characteristics described by Meckbach et al [18]. At this first approach, all houses were considered as composed by a single floor with roof slab built on the same material as the house, without roof tiles, located in the center of a grassed area.

One outdoor park environment has also been included in the simulation and comprises a large open grassed area with trees.

Cleanup measures were simulated to be applied at different times after the contamination event. The periods for applying the measures were one week, 15 days, one month and 6 months after contamination and the simulated measures were cutting grass surrounding each house and at the park area, the cutting of grass, including mat, with the 1 cm associated top soil layer and the removal of the 5 cm top soil layer.

For agricultural areas, the focus was on ingestion doses from contamination with I-131 for periods up to 1 year after contamination. Ingestion doses were assessed for the first year after the contamination and the group exposure was composed by children. Pathway considered was the ingestion of milk from cows grazing in permanent open pasture environment.

I-131 has been considered to be responsible by the thyroid cancer observed on children that were infants at the time of the Chernobyl accident, living in contaminated areas of Belarus, Ukraine and Russia [19, 20].

A basic release scenario leading to a contamination of 1 MBq m\(^{-2}\) of I-131 in an open grassed surface was considered. Protective measures simulated were the dilution and the removal of contaminated milk from the children diet, at varying rates and/or time after the contamination event.
3. RESULTS

The results presented here are just examples of the work being developed to derive quantitative dose related effectiveness information on protective and remediation measures, in order to be used on multi-criteria decision making processes after environmental contamination events, for the protection of the public.

3.1. Comparative Assessment for Urban Scenarios

Figure 1 presents the results of integrated doses for the six urban scenarios, without the use of cleanup procedures. It can be observed that all houses provide significant shielding as compared to outdoors park areas. However, the shielding effect varies among the houses, according to the type of building material. Houses build on low density brick without plaster, typical from Brazilian favelas offer a shielding protection similar to European wood houses, while our masonry houses with double plaster on walls offer a shielding significantly lower than that provided by European masonry houses, due to the differences in brick composition and density, as observed by Salinas et al. [7].

These differences confirms the need for assessing the effects of cleanup procedures based on local/regional parameter data as the use of the a percent reduction on the activity of a surface will have different dose reduction actually received by people residing in different types of houses.

![Simulated Environments without Remediation Actions](image)

**Figure 1. Integrated dose due to 1 MBq m-2 Cs-137 deposition over a horizontal lawn surface without considering cleanup procedures.**

Figure 2 presents the percent reduction on integrated doses due to cutting lawn one week after the contamination event. It can be observed that there is only a slight difference among the curves in the short term due to difference on the contribution of the lawn surface to
indoors doses for the different types of simulated environments, while at the longer term the percent reduction is very similar considering all environments.

Figure 2 – Percent reduction on integrated doses due to cutting lawn seven days after the contamination event.

The same type of behavior can be observed for the grass removal with mat and associated 1 cm top soil layer (Figure 3) and for the removal of the 5 cm top soil layer (Figure 4). Results are very similar for countermeasures including the top soil layer removal despite the depth as after one week all deposited material is still in the upper 1 cm top soil layer.

Figure 3 - Percent reduction on integrated doses due to cutting lawn removal mat and associated 1 cm top soil layer seven days after the contamination event.
3.2. Assessing the effect of the time after the accident when the measure is applied

Figure 5 presents the results on integrated doses for House 4 without countermeasure and the effect of lawn removal after 7, 15, 30 and 180 days. It can be observed that cutting lawn has a higher efficiency for reducing indoor dose rate if applied within 1 month after contamination. After 6 months, the measure has no effect on dose reduction and can then only be seen as a short term measure.

Figure 6 shows the results for the percent dose reduction, also for House 4, for the top soil layer removal, also after 7, 30, 180, 365 and 730 days. It can be seen that the effectiveness of this measure is high, even if applied 2 years after the contamination, with effects varying from 50 to 95 % reduction on lifetime integrated dose.

Although effective, soil removal has drawbacks, such as the large amount of wastes generated and the exposure of large number of persons in waste management procedures. The previous removal of the grass in the short term can be performed in short time and the collection of waste can be done automatically, if such equipments are readily available at the site. About up to 20 % of lifetime dose for inhabitants of the area can be avoided by this procedure, while soil removal need more planning due to the large amount of wastes and shall reduce up to 80 % of the lifetime dose to inhabitants, even if applied 1 year after the contamination event.

Combining the two measures could be achieved at an optimized procedure taking into account other aspects such as doses to workers, acceptability by the local population, and costs associated to waste management options.
**Figure 5.** Integrated dose, dose rate and percent reduction on integrated dose due to cutting lawn on the surroundings of House 4 at different moments after the contamination event.

**Figure 6.** Reduction on integrated dose due to the removal of the 5 cm top soil layer on the surroundings of House 4 at different moments after the contamination.

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3.2. Results for the Rural Area Scenario

For the rural scenario, the example presented here refers to the ingestion of milk by an infant (less than 1 year old child at the moment of the contamination). Ingestion rate is considered to be 200 g per day. Countermeasure simulated is the suspension on the milk distribution (while providing alternative clean milk). The radionuclide here considered is I-131. Due to the short half-life of this nuclide, protective measures are simulated to be used up to 1 month after the contamination event and effects are considered related to the first year committed effective integrated ingestion dose.

Results for the removal of contaminated milk from infants’ diet are shown in figure 7. It is quite clear that measures to protect from I-131 are to be implemented at very short term after the contamination, as soon as possible. The removal from diet after one month has no more effect on reducing doses.

![Figure 7. Effect of removal of contaminated milk from infants’ diet at different moments after the contamination event](image)
3. CONCLUSIONS

This work is part of the emergency preparedness program being developed by IRD since the Goiânia accident. The examples shown will be used to establish criteria for simulating other countermeasures. The information gathered on the effect of time on dose reduction for different standard scenarios will be organized and incorporated to the database on protective and remediation measures. Next step will include the building of a multi-criteria decision tool to support a decision making process after an event leading to environmental contamination, under the point of view of radiological protection.

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