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PRELIMINARY STUDIES ON THE OPTIMIZATION OF COUNTERMEASURES FOR AGRICULTURAL AREAS

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ABSTRACT

The assessment of remediation measures for rural areas is more complex than that for urban ones, due to the influence of large number of variables associated with climate, diet, farming practices and the type of soil. Thus, it is not possible to perform generic studies applicable to all types of area. Specific studies and surveys should be made in the areas most likely to contamination from a nuclear accident. Preliminary studies demonstrated that the different soil types in Brazil is more relevant to the ingestion dose than the regional differences in diets. Other studies have described the prioritization of areas and products for detailed survey on soil types and remediation procedures, for an accident at the NPP in Angra dos Reis, based on radiological and economic aspects. The most relevant product was milk, due to both its relevance to the intake and the loss of income for the counties. The contribution of milk to dose depends on the season of the year when the accident occurs, mainly due to the relative contribution of other items of the diet. The timing of the application of the countermeasure has an important effect on the dose reduction that can be achieved. For I-131, protective measures must be considered within the emergency phase in order to be effective. The main action on reducing ingestion doses is the removal of food items from diet, while providing clean food to the population.

1. INTRODUCTION

The establishment of criteria for prioritizing protection actions and/or remediation for agricultural areas is considerably more complex than for urban ones. Several environmental factors affect the dynamics of concentration in food. Among these are the type of soil on site of crops and pasture and the time of year when the accident occurs due to seasonal effects. The agricultural and livestock practices are also dependent on seasonality, such as planting dates and crop or animal feeding practices. Population habits, in particular diet, which includes, for

local groups the own food production; and, to the population in general, the food distribution system affects ingestion doses.

The dynamics of concentrations in foods is also extremely varied not only according to the type of food and nuclide but also with time after contamination [1]. For any season, the highest concentration in crops at the first month after the accident occurs for leafy vegetables. This is due to foliar deposition process, as observed in Fukushima and Chernobyl accidents [2, 3]. Understanding the mechanisms and processes that influence the transfer and the bioavailability of radioactive substances in ecosystems is still an important subject for research in radioecology. Studies of the Chernobyl accident contributed to a better understanding of the behavior of artificial radionuclides in temperate soils, providing consistent information for the management of contaminated rural areas.

However, radioecological studies conducted in tropical areas ecosystems have shown some suitable conditions for greater absorption of radionuclides by plants. In some cases, the acidity of the soil, the abundance of Al and Fe hydroxides and oxides, and low soil fertility was cited as the likely causes of increased transfer of Cs-137 from soil to plants [4]. In this context, the Brazilian soils are particularly interesting for this kind of study, since over 60% of them exhibit such properties. It is known that the Oxisol and Ultisol are prevalent in Brazil and, besides being highly weathered, occupy extensively cultivated areas [5]. Both represent important natural nutrient reservoirs, with great potential in food production context [4].

It could also be observed that, differently from the urban area, various radionuclides include the potential for significant dose to the public. For ingestion pathway in the short term, the I-131 has special significance and was considered as the main responsible for the cases of thyroid cancer in children after the Chernobyl accident [2]. In the medium and long terms the most relevant radionuclides are then Cs-137 and Sr-90.

The procedures used in the remediation of rural areas have been raised in the literature and incorporated into a database [1]. Initial simulations showed large seasonal variation for evaluating the efficiency of public protection measures.

2. METHODOLOGY

Several studies have been developed in an attempt to assess the most relevant parameters to perform specific studies to agricultural areas. In the first series of studies, parameters for the country as a whole were evaluated. These studies considered the relevance of diet and the importance of soil type.

The relevance of the soil indicated that this is a priority issue to be studied. Thus, it was decided to study rural environments for assess the priority of the municipalities that are part of the planning area established for rural environments, in relation to their relevance as agricultural production center and its relevance in relation to the dose in the population resulting from the agricultural production. The planning area established for rural environment studies has been defined in previous studies and includes all municipalities, partially or totally, in a radius of 50 km around the Central Nuclear Almirante Alvaro Alberto, in Angra dos Reis, Rio de Janeiro. The study area covers municipalities in the states of Rio de Janeiro and Sao Paulo [6].

The Counties selected for the study area are:

(i) State of São Paulo: Arapeí, Areias, Bananal, Cunha, São Jose do Barreiro, Silveiras, Ubatuba; and,

(ii) State of Rio de Janeiro: Angra dos Reis, Barra Mansa, Itaguaí, Mangaratiba, Paraty, Pirai, Resende, Rio Claro, Volta Redonda.

The municipalities were then evaluated in relation to those that would be most affected by a radioactive contamination and its relevance to the total financial loss for the study area, considering the loss of the cost of the production of each municipality and the relevance of the doses due to contamination of local production. Also, the most important agricultural products were assessed, considering both the loss of income due to the loss of the production and the collective dose to the public by the ingestion pathway. These assessments were made on a preliminary basis, considering only the Cs-137 and an adult population.

Finally, an additional study to the preliminary assessment of the effect of dose resulting from ingestion of milk was conducted. In this study, it was considered the effects on dose for adults and children and the effects of milk processing to other products in the doses to the public. For this study, the radionuclides Cs-137, I-131 and Sr-90 were considered. The ingestion habits data were collected from the IBGE [7](2011). The site specific diet data collected for each region in Brazil are summarized in Table 1 [8].

Table 1. Regional food intake rates (kg/y)

ITEM	*N*	*NE*	*SE*	*S*	*CO*	*Brazil*
Cereal	59,54	65,20	59,02	68,54	64,88	62,61
Beans	10,22	12,83	8,31	6,89	8,64	9,56
Leafy veg.	2,21	1,64	3,75	5,34	3,26	3,23
Other veg.	9,62	11,91	12,86	14,53	13,16	12,60
Roots&Tuber	32,69	19,64	12,91	19,84	12,18	17,36
Fruits	20,51	26,75	29,74	36,53	25,97	28,86
Meat	31,42	22,04	23,07	35,72	24,85	25,42
Chicken	19,80	14,52	11,26	13,99	10,40	13,20
Milk	24,00	27,48	50,46	67,41	42,18	43,71

Soil types selected for this study were taken from UFLA [9]. The selection was made in order to minimize the number of soils, while maximizing the covered area of the country and also considering the availability of specific transfer factors data. (LVA - red-yellow oxysol, A - ultisol, LV – not-ferric red oxysol).

Data on agricultural habits (planting and harvesting periods) and productivity were those raised by Vinhas et al [10] to the Southeast region. Transfer factors used for LVA soil were those used by Vinhas et al [10]. For other soils, the values suggested by Wasserman et al [4] for

cereals were used and, for other crops, the factors suggested by Frissel et al were used [11].

Initial environmental contamination was considered as 1 kBq/m^2 of each of the radionuclides Cs-137, I-131 and Sr-90. The comparison between the different types of soil was only done for the Cs-137 radionuclide due to lack of available data for the other radionuclides. The computational model SIEM [12] was used to make the dose calculations for different regions.

The method for classifying areas according soil properties for vulnerability to Cs-137 contamination is of major importance for the preparadness related to nuclear and/or radiological accidents leading to the release of radionuclides into the environment, with contaminated agricultural areas. The priority of the investigation then focused on agricultural areas around nuclear power plant most likely public exposure via ingestion. The purpose of this stage of the work was to create a rank order for the priority areas to be mapped on soil properties by the Brazilian Agricultural Research Corporation – EMBRAPA [13]. The priority defined in this study should then guide the research on the validation of transfer factors and on the appropriate agricultural countermeasures to each area according to the causes of their vulnerability as applied to the most important agricultural crops or products derived from animals for these counties.

For the same soil type, individual doses in agricultural areas, although depending on the items produced in the municipalities, are not expected to differ substantially among different locations due to the self-sustaining status of farming communities. Collective doses can however be very different considering the productivity of selected areas. In addition, the production of different items at the municipalities leads to very distinct loss of income in case of discarding or a ban on food.

Collective doses are restricted to food items, while economic value was considered for all products, including sugarcane for ethanol production to be used as fuel, animal products and forestry products, such as coal, firewood and logs. Information on production and prices of agricultural products were obtained from the agricultural census of IBGE [13]. To estimate the collective doses, SIEM program [12] was used to evaluate the concentration of food one month after the accident. The same accident was simulated as happening in February, May, August and November in order to cover the aspects of seasonality on ingestion doses. The collective dose was estimated by multiplying the concentration of food by the respective county production and by the ingestion dose coefficient.

The food processing retention factor, Rf is the fraction of the radionuclide activity that is retained in the food after processing. The processing efficiency, Pe, is the ratio of the fresh weight of the food processed and the weight of the original raw material. The transformation factor, Pf, is the ratio between the activities of radionuclide concentrations (similar to the transfer factor) for a particular food product. There is a simple relationship between these three factors. Pe is the product of Pf and Rf. In this work, the Pf values were estimated from Rf and Pe values compiled by IAEA [15]. The dairy products assessment require careful consideration because of the variety of processes employed, the diversity of products, and destinations of the by-products of each processing, for example, the disposal as waste or the use in the production of animal feed.

In this work, only the main products of the processing were considered. The values for the efficiency of the procedures were evaluated using the SIEM software [12] for the typical

average diet of southeastern Brazil. Ingestion rates of processed foods were also obtained from the IBGE [7]. Dairy products simulated were powder milk, butter and condensed milk. The simulations were performed for Cs-137, I- 131 and Sr- 90.

3. RESULTS

3.1. Diet

To evaluate the effect of diet only LVA soil was considered. The differences between the total regional 50 years integrated individual doses varied for less than 25% for Cs-137, and from 15% to 30% for iodine and strontium among the different regions. The biggest difference observed was related to Sr-90 and it is due to increased consumption of milk observed in the southern region as compared to the rest of the country.

3.2. Effect of Soil Type

Regarding the 50 years integrated effective dose for an adult, it could be observed that the doses due to non-ferric red Oxysol are much higher than those due to other types of soil, being the lowest dose related to Ultisol, for all diets. It was found that the soil type may have an influence up to about 70% in the integrated dose. This is greater than the difference observed due to different types of diet observed in the country [8].

3.3 Prioritization of Counties and Products

Considering the financial loss of the disposal of products for the entire study area, the five most important products were cow's milk, banana, wooden logs, sugar cane and coconut. From these products, only cow's milk is an important item for the diet of the population; individual consumption of bananas and coconuts are much lower. However, for the producing counties, the yield loss of any of these products would be significant. Considering the absolute values of all production in each municipality, the greatest loss of income will be for Cunha (SP), followed by Rio Claro (RJ) and Piraí (RJ) [6].

3.4. Milk

Considering the importance of milk to the ingestion doses for accidents occurring in all seasons, some additional preliminary studies were then conducted. The first study was aimed to assess the dose in children. A daily intake of 0,8 L of milk was considered for small children (about 1 y old). For adults, the local diet was considered to be comprised by vegetables (323 g/d), meat (103 g/d) and milk (164 g/d).

Figure 1 shows the results for the first year integrated effective dose after an accidental deposition of 1 kBq/m^2 in the soil due to the milk intake for adults and children. Doses for children are higher than those for adults, not only due to differences in dose coefficients, but also due to increased milk ingestion by children. Figure 2 shows the percentage reduction of the first year integrated dose considering various times of introduction of removal of milk from diet, considering an accident occurring in the spring. For children (1 year) it was considered only the intake of milk. For adults, the reduction is that observed in the total diet.

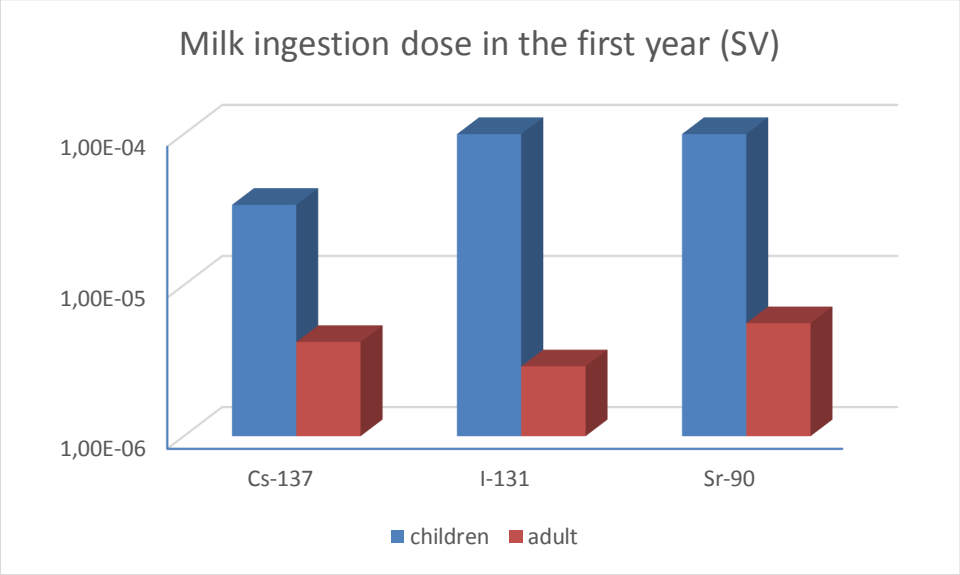

Figure 1. Doses integrated in the first year after a deposition of 1 kBq/m^2 due to milk intake for adults (0.164 L/d) and children (0.8 L/d).

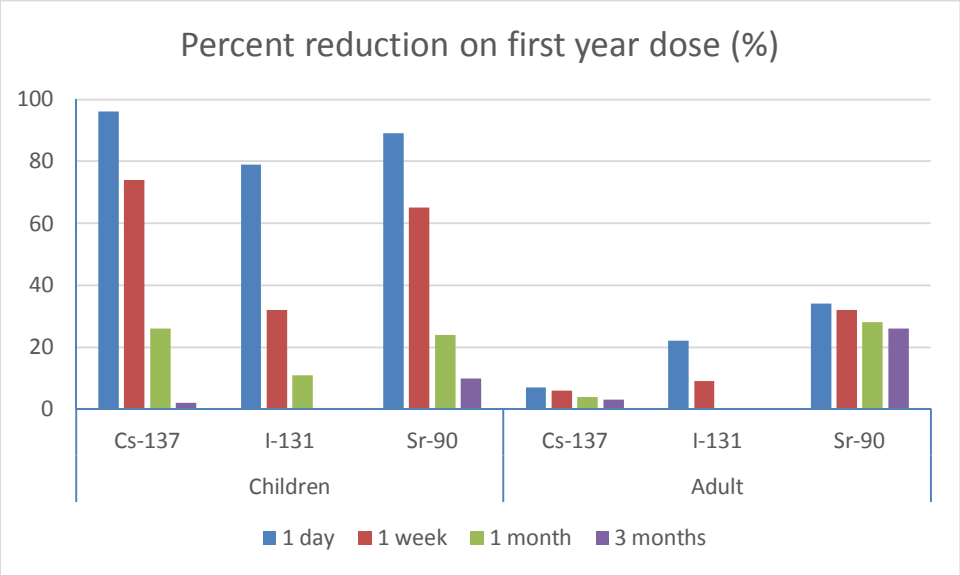

Figure 2. Dose reduction in the first year due to the withdrawal of milk from diet at various times after initial deposition (1 day, 7 days, 30 days and 90 days).

It can be seen that the effect of this protective measure is very dependent on the time that removal is done. In particular, for small children, it is essential to be introduced as soon as possible to be effective, especially in relation to I-131. However, it would be essential to provide clean food in less than a week after the accidental release, even during the initial phase of the radiological emergency giving rise to environmental contamination event [16].

The importance of milk for the economy of the municipalities, however, led to the need to find a solution that avoids the disposal of milk as waste, not only for its economic value but also

due to the large volume of material to be discarded and also because of its relevance to the human diet. Thus, an evaluation was made also of primary and generic form, the major milk processing capabilities into other products in order to try to assess the viability of the use of the material removed from the diet.

As discussed earlier, the doses from milk intake are quite independent of time when the accident occurs, in tropical areas, where the grass grows all year round and cattle are fed by fresh pasture throughout the year. However, the relevance of milk intake dose depends on the season, according to the contribution of seasonal crops to total dose intake. Results for some milk processing procedures are shown in Table 2. The table includes the reduction of the dose due to the removal of milk from diet. It also includes the effect of milk used for the production of by-products and the effects on the total ingestion dose. For removing milk from the diet, the time at which the introduction of processing showed strong influence on seasonal doses.

For Cs-137, the total increased dose due to the introduction of processed milk products is less than 2% in all cases for the dose in the first year and less than 1% at the dose of life. For I-131, all doses are received within the first year; therefore, increases in integrated doses are the same for the first year and lifetime. The effect of the removal of milk from diet may vary up to 56% of the total dose, while the dose is increased about 5% of the total dose intake because of the processed dairy products. For Sr-90, the effect of removing milk from the diet may range up to 67% of the total dose while the dose is increased due to processed dairy products are at a maximum of 5.5% of the total ingestion dose [17]. For all radionuclides, the more efficient process with respect to dose for the public, is the production of butter, while the less efficient process is the production of powder milk. However, it considers the habitual intake rate for these products and not as a substitute for fresh milk. Furthermore, it should be noted that the powder milk can be stored for a period of months, leading to the radioactive decay of I-131.

4. CONCLUSIONS

Decisions on countermeasures related to agricultural areas are much more complex than those for an urban area contamination. There is a strong influence of the season in the doses due to the intake of vegetable and animal products for a specific area. Furthermore, the type of soil has a strong influence on the transfer of radionuclides deposited to plants. This study demonstrated that the different soil types in Brazil is more relevant to ingestion doses than the regional differences in the diets. For accidents, the biggest concern is always with the local intakes of the affected areas and thus areas where the population has a high degree of self-sufficiency, such as agricultural regions, where the contaminated food is originated. It is therefore important to consider the type of soil to correctly estimate the dose in the population and verify the need for protective measures. It is also important to consider which diet items come from unaffected areas not to unnecessarily restrict the consumption of food produced on site affected by the accident.

Considering the municipalities within a radius of 50 km from the Brazilian nuclear power plants, it is suggested to develop radio ecological studies with priority for milk, banana and cassava in the counties of Cunha (SP), Barra Mansa (RJ) and Resende (RJ).

Table 2. Effect of processing milk and on the removal of milk from diet on doses to the public.

Nuclide	Season of the accident	dose reduction from the removal of milk from diet (%)		processed product	increase in dose due to processed product (%)	
		first year	lifetime		first year	lifetime
Cs-137	Summer	10	7	butter	0.01	0.01
				condensed milk	0.41	0.28
				powder milk	0.84	0.59
	Autumn	7	6	butter	0.01	0.01
				condensed milk	0.28	0.23
				powder milk	0.58	0.48
	Winter	23	10	butter	0.01	0.01
				condensed milk	0.93	0.39
				powder milk	1.93	0.81
	Spring	15	8	butter	0.01	0.01
				condensed milk	0.59	0.33
				powder milk	1.22	0.67
I-131	Summer	32	32	butter	0.09	0.09
				condensed milk	1.28	1.28
				powder milk	2.65	2.65
	Autumn	20	20	butter	0.05	0.05
				condensed milk	0.80	0.80
				powder milk	1.66	1.66
	Winter	56	56	butter	0.15	0.15
				condensed milk	2.24	2.24
				powder milk	4.64	4.64
	Spring	30	30	butter	0.08	0.08
				condensed milk	1.18	1.18
				powder milk	2.45	2.45
Sr-90	Summer	39	30	butter	0.03	0.02
				condensed milk	1.56	1.20
				powder milk	3.24	2.46
	Autumn	37	29	butter	0.03	0.02
				condensed milk	1.47	1.17
				powder milk	3.04	2.43
	Winter	67	33	butter	0.05	0.03
				condensed milk	2.68	1.31
				powder milk	5.55	2.71
	Spring	57	32	butter	0.05	0.03
				condensed milk	2.29	1.28
				powder milk	4.74	2.74

Milk is the main product being evaluated concerning doses to the public, in particular to children. The possibility of using the milk processing into other products seems promising but must also be evaluated in respect of waste generated and possible uses, for example, in animals' feed.

Seasonal aspects are relevant to decisions on reprocessing of food after an accidental contamination. The main action in reducing doses intake is removing foods from the diet and providing clean food for the population. However, the disposal of products can be expensive, not only due to loss of production, but also due to the large quantities of waste to be treated and disposed. The processing of foods that were removed from the diet is an important aspect to consider, since the individual dose introduced from processed products can be very small and can even prevent the loss of income for producers; additionally it reduces the need to dispose of large quantities of food.

In the first weeks after the accident, the priority should be directed to the intake of I-131, from milk and leafy vegetables (all radionuclides) due to leaf deposition process with the contamination of the aerial parts of the plant and pasture. Although the consumption of leafy vegetables is relatively low in the general population, it may be significant in areas near the crop production areas. The importance of iodine is due to both the rapid transfer to cow's milk and to the relevance of this product to the human diet, in particular, to children diet. Thus, it is also necessary to provide in the short-term uncontaminated food supply for the population, in particular those related to children's diet.

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