Study on Generic Intervention Levels for Protecting the Public in a Nuclear Accident or Radiological Emergency

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Abstract. Large amounts of radioactive material can be released to the environment in a nuclear accident or radiological emergency. In these cases, social and economical factors should be considered in the actions for protecting the public and to recover the environment, as these actions may affect not only the exposed individuals but also the society as a whole, because of the social impact and high costs. In 1994, the International Atomic Energy Agency, IAEA, published the radiological protection principles for intervention criteria in accident situations involving radioactive materials, as well as numeric values for the generic intervention levels, GIL, for the main countermeasures for protecting the public. These GIL values were selected to achieve broadly the maximum net benefit in many accident situations and, nowadays, those principles still represent the international consensus about this matter. On the other hand, the economic differences between countries can lead the optimization process to get GIL values that are quite different from those recommended. In this context, the monetary value of unit collective averted dose, called alpha-value, is a key element for the determination of the GIL. In this work, the method recommended by the IAEA, based on the human capital approach, was used to estimate the alpha-value for Brazil and the value of US$ 3268 per person-sievert was obtained, considering the year 2000 prices. The *per capita* costs of the countermeasures for protecting the public, as sheltering, evacuation, temporary relocation and permanent resettlement, were estimated and the cost-benefit analysis technique was applied to estimate the respective GIL applicable in the country. Some of the results for the GILs were smaller than those internationally recommended, even the alpha-value being about six times lower than the alpha-value considered by the IAEA. These results were discussed and they were also compared to values estimated by a similar study accomplished for Japan. As the alpha-value obtained was much lower than the officially adopted in the country, that is US$ 10,000 per person-sievert, a sensibility study of the results was performed regarding alpha-value. It was also performed a simple analysis of the results considering the *per capita* costs of the countermeasures.

1. Introduction

The protection of the public against the radiological risks associated to *practices* is obtained applying controls on the radiation source. These controls include safety and protection systems and procedures that reduce the probability of sequence of events that causes or increases exposures to radiation. Although these measures reduce the probability and the potential magnitude of accidents, they cannot eliminate the possibility of occurrence [1].

In the event of a major nuclear accident or radiological emergency, when the control on the radiation source is lost, large amounts of radioactive material may be released into the environment. Even if the primary radiation source is controlled in a short time, the dispersed radioactive material may take a long time to be removed or not be passible of control at all. In these cases, the actions to protect the public and to reduce the radiation doses have to be applied to the exposure routes, as soil decontamination or banning contaminated food, or directly to the members of the public, as sheltering or evacuation. All these protective actions impose constraints to the people's freedom and consume resources to be implemented; some of them also directly cause risks to health and social rupture [2]. Therefore, the decision to introduce a given protective measure should be based on the balance between the reduction of the radiological detriment that is possible to be reached by the measure and the harm caused by its adoption [3]. This balance should include the *tangible* costs and benefits, that is, those specifically identifiable and subject to quantification in a scale of values, as the *intangibles* ones, which contribute to the human satisfaction, but that are not subject to a formal quantification [4].

In significant radiological accidents not always the costs and benefits of an *intervention* are distributed on the same portion of the society, therefore the *intervention* for protecting of the public should be based on well defined principles. These principles have to be technically defensible and should take in consideration ethical and social aspects. The basic principles for *intervention* had a great evolution since they were firstly proposed [2, 3, 5, 6] and, nowadays, the internationally accepted principles may be enunciated as follows [3]:

(a) All the possible efforts should be made to avoid severe *deterministic* effects, introducing protection measures to keep the individual doses below the thresholds for those effects. Since there is always some uncertainty in the prediction of doses, the actions to prevent those effects should be taken in values of projected dose somewhat below the thresholds.

(b) The principle of justification: the proposed group of protection measures should achieve more good than harm, that is, they should only be adopted if the reduction in the detriment, as result of the dose reduction, is enough to justify the harm and the economic and social costs associated to the *intervention*.

(c) The principle of optimization: the form, the extension and the duration of an *intervention* should be optimized so that it will produce a maximum net benefit, being considered the reduction of the radiological detriment and the social and economical costs of the intervention.

Following these principles, when severe *deterministic* effects are foreseen in the affected population, the *intervention* is almost always justified. In situations where the projected doses are below the thresholds for *deterministic* effects, studies that analyze the relationship between the reduction of radiation exposure and the tangible costs inherent to a given protection measure are useful, because they may originate a *generic intervention level*, GIL, below which the introduction of that measure, under the radioprotection point of view, would not be justified, because the costs for its adoption would not compensate the costs associated to the avoided radiological detriment.

Based on those principles, and considering the costs related to highly developed countries, the International Atomic Energy Agency, IAEA, recommended GIL values for the main measures to protect the public [3, 7, 8]. Those values were selected to reach, in a broad way, the maximum net benefit in several accident situations and they are good references to assure that the public will not be subject to improper risks if the appropriate protective measures are taken. The objective of this work is to estimate the GIL for sheltering, evacuation, temporary relocation and permanent resettlement, considering the particularities of the Brazilian scenario.

2. The alpha value

Assuming that the relationship between the *equivalent dose* and the probability of induction of a health effect is linear and that all doses on a population are in the *stochastic* range, it is possible to use the *collective dose* as an objective indicator of the radiological detriment to health imparted to the exposed population. In this way, to attribute a monetary value for the unit of *collective dose* is equivalent to value the detriment itself [9]. Once a monetary value is attributed to the health detriment caused by a unit of *collective dose*, it is natural that the society be disposed to allocate, at least, that same value to reduce the radiation exposure that would lead to that unit of *collective dose*. That quantity is known as *alpha value*.

In order to estimate the *alpha value* for a country, a version of the human capital approach, proposed by IAEA [3], which take into consideration the probability and the cost of the radiological detriment to health, can be used. In relation to the determination of the detriment probability, the following considerations are made [1]: the average loss of healthy life associated with one case of fatal cancer induced by radiation is of the order of 13 years; the nominal probability coefficient for fatal cancer induced by radiation is 5.0×10^{-2} $per^{-1}\cdot Sv^{-1}$; the detriment coefficient for non fatal cancers is considered 1.0×10^{-2} $per^{-1}\cdot Sv^{-1}$; the detriment coefficient for induction of severe hereditary damage in all generations is 1.3×10^{-2} $per^{-1}\cdot Sv^{-1}$; so, it is obtained that the statistical loss of life expectancy associated with 1 per·Sv is one year. Because of the uncertainties associated with the risk coefficients, this value can only be considered accurate within a factor of about two. In relation to the cost of the detriment, it is considered that the minimum monetary value associated with one year of statistical loss of life is equivalent to the annual gross national product, GNP, *per capita* [3].

3. Estimating generic intervention levels

Based on the cost-benefit theory and considering that the cost associated with the avoided radiological detriment is proportional to the *collective dose* averted by the protective measure, where the proportionality is given by the *alpha value*, it can be shown that the GIL associated with one given protective measure may be estimated by the division between the *tangible* individual costs for its implementation and the *alpha value* [3].

3.1. Sheltering

As sheltering consists in advising people to remain indoors and to close doors and windows, in general, there is no need of transportation and the feeding is already available. It is considered that the most important cost is that caused by the loss of productivity in the involved population. This cost may be estimated from the annual GNP *per capita* divided by the number of days in the year. As sheltering for more than two days may become intolerable for the population [3], the GIL for sheltering is estimated for that period.

3.2. Evacuation

In the case of evacuation, there are other costs involved besides the loss of productivity in the affected population. The costs of moving people for the lodging place and posterior return, their accommodation and feeding should be considered if these costs are significant. The duration of evacuation should not exceed some days, although it should be long compared with the time spent for its implementation and long enough so that any risks and initial costs be compensated by the avoided detriment. Generally, a period of seven days may be selected for the determination of GIL for evacuation [3].

3.3. Temporary Relocation

In the temporary relocation, the loss of productivity in the involved population, the cost of moving people for the new place and posterior return and the costs of renting accommodations have to be considered. This protective measure is taken for a period of several months, but the costs in the first month are substantially larger, so that it is considered in separate. The place of the temporary relocation cannot be far from the original dwelling area in order to avoid social impact related to the occupation of the individuals, that is, it should be tried to keep the employment of the individuals, when considering factors as the time of displacement to the work place. There should be also considered the proximity of schools frequented by the children, among other criteria [3]. For those reasons, the local for temporary relocation should be sought in the range of some dozens of kilometers around the original place.

3.4. Permanent resettlement

In the permanent resettlement, there are high initial costs, especially for the construction of dwellings and to transport the population for the new place. In spite of there being costs distributed along the time, these will be much smaller than the initial costs. In general, the place for permanent resettlement is outside a range of hundreds of kilometers from the original place. It happens because it is difficulty getting large open spaces nearby of already formed cities [3]. Because of the distances, the individuals cannot maintain their original employments, leading to difficulties for returning to the labour market.

4. A case study: Brazil

The economic and social reality in Brazil makes that the disposition to pay for the protection against the ionizing radiation effects, reflected in the *alpha value*, and the monetary costs involved in the measures for protecting the public, be very different from those considered by IAEA for highly developed countries. The *alpha value* and the monetary costs involved in the measures for protecting the public were determined considering the Brazilian reality and used to estimate specific GIL.

4.1. Estimating the alpha value

Using the official Brazilian annual GNP *per capita* [10], based on the year 2000 values, and converting it for American dollars, applying the average exchange on December 29th, 2000 [11], the *alpha value* for the country was estimated in 3,268 US$· per^{-1}·Sv^{-1}.

4.2. Estimating the specific costs

4.2.1. Loss of productivity

The loss of individual daily productivity cost may also be estimated by means of the annual GNP *per capita* [10], divided by the number of days in the year. For the year 2000, the estimated value was 9 US$·$per^{-1}$.

4.2.2. Transportation costs

Urban transport companies maintain databanks of their operational costs and some entities develop statistics on those values [12]. Considering the expenses with maintenance of the vehicles, fuel and the payment of employees, the transportation cost in big cities, considering urban buses of forty passengers, was estimated in 1.17 US$·$km^{-1}$.

4.2.3. Feeding costs

The monthly costs of Brazilian families feeding, in the main cities of the country, are collected by some entities [13]. Based on four people families, the following monthly consumption is considered: milk (15 L), sugar (3 kg), powdered coffee (600 g), bread (6 kg), butter (900 g), tomato (9 kg), banana (7.5 dz), wheat flour (1.5 kg), potato (6 kg), bean (4.5 kg), rice (3 kg), beef (6 kg) and soy oil/fat (900 mL/1.5 kg). For that consumption, in December 2000, the cost was estimated in US$ 61.16.

4.2.4. Rental costs

The monthly rental values of houses and apartments are collected by entities associated to real estate agencies [14]. For a typical Brazilian family of four people, in a big city, the rental value of an apartment is estimated in US$ 182.

4.2.5. Civil construction costs

Studies on construction costs are accomplished by entities of real state and civil construction financing in all Brazilian states [15]. Based on costs of ordinary standard residential projects, indexes referring to square meter construction costs are determined. In those indexes, the materials and the hand labour are considered, including the social securities. The expenses with projects, licenses, insurance, administration, financings, mechanical equipments, as elevators and air conditioner, are not included. The builder profits are not also included. Considering the year 2000 costs, the Brazilian national civil construction index was estimated in 166 US$·m^{-2}.

4.3. Estimating the protective measures costs

Based on the specific collected costs, the individual costs for each protective measure were estimated and they are shown in the Table I.

Table I. Estimated costs for the protective measures (base year 2000).

Protective measure	Estimated cost (US$ *per capita*)
Sheltering	18 [a]
Evacuation	82 [b]
Temporary relocation	380 [c]
	174 [d]
Permanent resettlement	4,100

[a] Estimated for two days.

[b] Estimated for one week.

[c] In the first month.

[d] Any subsequent month.

4.4. Estimating the generic intervention levels

Using the values obtained for the individual costs of each protective measure and the *alpha value* estimated for the country, the GIL for each considered protective measure was determined and they are shown in the Table II.

Table II. Estimated generic intervention levels (base year 2000).

Protective measure	GIL estimated (mSv)	GIL recommended [a] (mSv)
Sheltering	6 [b]	10 [b]
Evacuation	25 [c]	50 [c]
Temporary relocation	116 [d]	30 [d]
	53 [e]	10 [e]
Permanent resettlement	1,250 [f]	1,000 [f]

[a] Recommended by IAEA based on 1993 prices [3].
[b] *Avertable dose* in less than two days.
[c] *Avertable dose* in less than one week.
[d] *Avertable dose* in the first month.
[e] *Avertable dose* in any subsequent month.
[f] *Avertable dose* in the lifetime.

As the international recommendations [1, 7] and the national standard [16] establish that the lifetime dose of a worker it should not surpass 1 Sv, the permanent resettlement would be taken because of a projected dose of 1 Sv, and not because of a GIL for permanent resettlement of 1,250 mSv.

4.5. Sensibility study

Every study involves several data, some of which are just estimated, and other need judgements of subjective values. For that reason, it is important to know how strong is the result of an analysis considering its relation to the several involved parameters. The sensibility study verifies the relative importance of the uncertainty sources introduced during the process, as well as of the value judgements [9]. The result of the sensibility study shows if the analytic solution is invariable for any realistic change in the assumptions or in the parameters, so that the decision maker may know in which extent the solution is reliable.

4.5.1. Sensibility in relation to alpha value

In the GIL determination, the risk coefficients for the radiation effects carry many uncertainties, and may only be considered accurate within a factor of about two [3]. For that reason, the estimation of the *alpha value* also carries an uncertainty of this order. It is very useful a sensibility study of the estimated GIL, in order to verify their stability in face of the *alpha value* variability. The factor of uncertainty two, applied on the estimated *alpha value*, would make its value to vary from 1,634 to 6,536 US$·$per^{-1}$·$Sv^{-1}$. On the other hand, IAEA recommends that the minimum *alpha value* should be 3,000 US$·$per^{-1}$·$Sv^{-1}$ [17]. There are also other *alpha values* that are significant and they were included in the sensibility study. The value of 20,000 US$·$per^{-1}$·$Sv^{-1}$ was used by IAEA to establish the current recommended GIL. The factor of uncertainty two makes that value to vary between 10,000 and 40,000 US$·$per^{-1}$·$Sv^{-1}$, so that those values were also included in the sensibility study. The legal value adopted in Brazil is 10,000 US$·$per^{-1}$·$Sv^{-1}$ [16], besides it, that is the value recommended by ICRP for countries that have not determined their own *alpha value* [4].

The Table III shows the GIL values, always based on the protective measures costs calculated for this work, for the several selected *alpha values*.

Table III. Estimated generic intervention levels for different alpha values.

Protective measure	GIL (mSv)					
	α = 3,000	α = 3,268	α = 6,536	α = 10,000	α = 20,000	α = 40,000
Sheltering [a]	6	6	3	2	1	0.5
Evacuation [b]	27.3	25	12.5	9	4.5	2.3
Temporary relocation	126 [c] 58 [d]	116 [c] 53 [d]	58 [c] 26.5 [d]	38 [c] 18 [d]	19 [c] 9 [d]	9.5 [c] 4.5 [d]
Permanent resettlement [e]	1,364	1,250	625	410	205	102.5

[a] *Avertable dose* in less than two days.

[b] *Avertable dose* in less than one week.

[c] *Avertable dose* in the first month.

[d] *Avertable dose* in any subsequent month.

[e] *Avertable dose* in the lifetime.

4.5.2. Sensibility in relation to the protective measure cost

It was studied which variation in the individual cost of the protective measure that would make the respective GIL to vary 10% in relation to the estimated value shown in Table II. The exception was the GIL for permanent resettlement, which variation was established in 50 mSv for more or for less. The *alpha value* was fixed on the quantity determined for the country, that is, 3,268 US$·$per^{-1}$·$Sv^{-1}$. The ranges of protective measures costs determined in this way are shown in Table IV.

5. Discussion

All the protective measures costs estimated for Brazil were below those values utilized by IAEA in its studies. It is because IAEA considered the medium costs associated to highly developed countries and the differences in the economic and social values stand out when costs of materials and services are analyzed. This is also reflected when the GNP are compared.

Table IV. Cost range in which the respective GIL is stable (±10%).

Protective measure	GIL (mSv)	Cost range (US$ *per capita*)
Sheltering	6 [a]	18 to 22
Evacuation	25 [b]	73 to 178
Temporary Relocation	116 [c]	343 to 420
	53 [d]	157 to 192
Permanent resettlement	1,250	3,942 to 4,270 [e]

[a] *Avertable dose* in less than two days.

[b] *Avertable dose* in less than one week.

[c] *Avertable dose* in the first month.

[d] *Avertable dose* in any subsequent month.

[e] Based on a variation of ±50 mSv.

Observing in general, the GIL estimated for Brazil did not differentiate much of the recommended by IAEA, in spite of some of the estimated protection costs are one tenth of those considered by IAEA. It is due, partly, to the fact that the protection costs are linked, in some way, to the GNP of the country, then the factors self-compensate, so that the GIL are not very sensitive to those economic differences between countries. For comparison, there is a work that estimated GIL for some of the protective measures in Japan [18]. The methodology employed in that work is the same recommended by IAEA [3], but the costs of the protective measures were estimated for Japan considering year 1994 prices. In Table V are shown the estimated GIL values for Brazil, those obtained by Wang and Nakashima for Japan [18] and the recommended by IAEA [3].

The fact of intervention levels are relatively stable comparing different economies denotes that the *alpha value* reflects the population *willness to pay* to obtain a certain protection degree against the ionizing radiation.

The GIL studied here were estimated considering that the affected population lives in a residential area, that is, it is not in a highly industrialized area or in the field, where there are agricultural production or intense cattle raising. Some authors showed that the GIL for evacuation and temporary relocation, in highly industrialized areas, could be larger than those determined for residential areas, from the general risk and economic point of view, although the principle that severe *deterministic* effects should be avoided is maintained [19]. In that same work, the authors argue that the optimized durations of those protective measures would be smaller in those areas.

It is observed that the estimated GIL for sheltering and evacuation are smaller than the values recommended by IAEA, while the estimated GIL for temporary relocation and permanent resettlement are larger. The factors that lead to that difference are the costs associated with dwelling, as the rental value and the civil construction cost. It is probably because, for Brazilian people, the dwelling cost is relatively larger than for the individual of developed countries. It is possible that, when the relative cost of dwelling in Brazil be reduced, GIL for relocation and permanent resettlement approaches of those recommended by IAEA.

Table V. GIL estimated for Brazil, Japan [18] and those recommended by IAEA [3].

Protective Measure	GIL Brazil [a] (mSv)	GIL Japan [b] (mSv)	GIL IAEA [c] (mSv)
Sheltering	6 [d]	5 [d]	10 [d]
Evacuation	25 [e]	23,4 [e]	50 [e]
Temporary relocation	116 [f]	22,1 [f]	30 [f]
	53 [g]	*	10 [g]
Permanent resettlement	1,250 [h]	878 [h]	1,000 [h]

[a] Estimated in this work for Brazil, based on year 2000 values.

[b] Estimated for Japan [18], based on year 1994 values.

[c] Recommended by IAEA [3], based on year 1993 values.

[d] Avertable dose in less than two days.

[e] Avertable dose in less than one week.

[f] Avertable dose in the first month.

[g] Avertable dose in any subsequent month.

[h] Avertable dose in the lifetime.

* Not estimated.

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