Criteria and actions facing a radiological environmental contamination

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Abstract. An approach to improve the management of the radiological risk due to an environmental contamination is presented. The experience gained in emergency response has clearly demonstrated the importance to have an efficient emergency system including planning, procedures and operational internally consistent criteria. The lack of these components in the emergency system could lead to important radiological and non radiological consequences. The setting of internationally agreed criteria and guides is very important in the anticipated emergency response plan. The paper firstly reviews the approaches proposed by international recommendations and norms. From this review, a substantial coincidence on the basic principles is stated, in spite of small differences in its formulation. Also, a need for harmonization is endorsed. So, generic levels, in terms of imparted dose or avoided dose due to intervention, and, in some cases, derived levels, in terms of activity concentration, are proposed. Numerical values for emergency actions are also identified. The second part deals with the adaptation of the existing prediction and decision systems to the above radiological criteria. Relations among deposition, activity concentrations and annual doses for different scenarios, exposure pathways and age groups are established. Also, the sensibility of the radiological impact against different characteristics of the intervention scenarios is stated. This makes easy to assess the radiological significance of different contamination situations by comparison to the existing action generic levels. Furthermore, the radiological impact can be numerically incorporated in a decision system which includes non radiological aspects of the applicable intervention options. Agricultural, urban and mixed scenarios are presented and solved for a ^{137}Cs contamination. The results can be further used to develop a methodology guide for setting action generic levels in post-accidental interventions and other "de facto" situations, allowing the qualification and quantification of the different scenarios and potential actions regarding its radiological impact.

KEYWORDS: Emergency management, Intervention, Recovery.

1. Introduction

Until a few years ago, the international orientations for the preparation of the response to the emergency were based on a technical-analytical methodology that modelized the contamination scenarios, analyzed the options to reduce the doses and selected the ideal option to be implemented in agreement to the priciples of the intervention [1]. During the last years there has been a displacement in the practice towards a strategy of management, from which the requirements for a detailed planning and response [2] and the necessary systems to satisfy these requirements in a most efficient and effective way would be derived, facilitating the attainment of the prearranged goals. This new approach has met reflected, recently, in an agreement of the international community with regard to the establishment and use of standards [3] for the preparation and response to the radiological and nuclear emergencies.

The decisions for the attainment of these goals can have sanitary, economic, agricultural, commercial and political implications in the long term. Therefore, there will be necessary to incorporate into the current configurations of response for short and medium term, a long-term strategy [4] enough flexible to be able to select the more suitable intervention scenarios, not only for the mitigation or elimination of the immediate consequences of the radiological or nuclear event, but also for a sustainable rehabilitation of the living conditions in the affected zone. The generic criteria of intervention and the action plans will have to be developed, in advance, for the corresponding organizations and will be adapted to the majority of possible accidents or incidents that could be given, though they must support the sufficient flexibility to be modified if the real situation needs it. The operational criteria will depend on the national circumstances, though they will be comparable with the internationally established protection objectives.

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These Operational Levels of Intervention (OLI), specifics of the scenario, will be derived from parameters that could be measured directly and easily during the emergencies. In addition to the national organization in charge of the response in nuclear or radiological emergencies [5], a specific group will have to exist, with a series of responsibilities in the actions of recovery that will include the characterization (extension and nature of the environmental contamination), identification of potential options and action strategies, including the disposal of the generated wastes, establishing priorities and identifying temporary scales and costs of the different options to considering.

2. Conceptual and normative framework

Intervention is defined as [6] an action leading to reduce or avoid the exposure or probability of exposure due to sources that do not take part of regular activities or that have been originated as consequence of an accident. The dose limits or restrictions established for practices will never determine if an intervention has to or not to be carried out, since it might imply disproportionate measures with regard to the attainable benefit.

Any intervention needs to fulfill the basic requirements of the radiological protection: justification and optimization. An important magnitude in the decision is the level of individual dose that can be avoided by the action and the number of affected persons. Nevertheless, in the chronic exposures, it is equally important to achieve the return to the normal living conditions as soon as possible. This implies considering not only the expected consequences of implementing a strategy, but how the proposed strategy will contribute to return the normality. In any case, when a case of intervention is analyzed, the concept "dose level" or the level of any another directly measurable magnitude on which the decisions could be based, constitutes an indispensable reference.

Independently of the origin of the intervention situation, the result will be the immediate activation of the pre-established plan of emergency, which will include a series of actions and different phases of action. The emergency phase will be activated in the moment in which the emergency situation is declared and will finish when it is estimated that the situation is under control. In the emergencies, the optimization will have to be used in the phase of planning to determine the action levels in intervention and, during the real emergency, will be applied in a flexible way to take into account the predominant circumstances. The phase of chronic exposure, or recovery phase, includes all those actions directed to restore the normal life conditions in the affected zones. This type of actions also need reference levels that can be developed in generic way, be harmonized before the accident and to be optimized after the accident, taking into account the specific circumstances of the accident.

It is increasingly evident that the decision on intervention must be the result of the cooperation among experts in radioprotección and other experts together with the representatives of the groups of population directly affected by the measures to be taken [7]. The individual avoidable dose for the different actions, as well as the number of affected persons and the individual residual dose, would be the main radiological aspects to consider in the decision. The existence of previously established generic intervention levels can be considered to be a reference in the complex task of decision.

The Spanish “Reglamento Sobre Protección Sanitaria Contra Radiaciones Ionizantes” (**RPSRI**) [8] indicates to the Consejo de Seguridad Nuclear (CSN) as the responsible of the establishment of warning levels of the need of intervention, that is to say, generic levels of intervention that will constitute indications to determine in what situations an intervention is suitable. Also, it indicates that the actions, in case of radiological emergency in nuclear power plants, will be the established ones in the internal emergency plans of the plants, as well as in the corresponding external emergency plans of Civil Protection, derived from the **PLABEN**. Para el resto de las instalaciones nucleares y radiactivas y para otras actividades distintas de las anteriores, las actuaciones a llevar a cabo serán las establecidas tanto en los planes de emergencia interior o de autoprotección de cada instalación o actividad, como en los planes de emergencia radiológica derivados de las directrices básicas de planificación y otras normas de Protección Civil que correspondan. For the rest of the nuclear and radioactive facilities and for other activities different from the previous ones, the actions to carry out will be the established ones in the internal emergency plans of every installation or activity, and those established in the radiological emergency plans derived from the rlated basic directives of planning of Civil Protection .

2.1 Recommendations in the emergency phase

The Spanish **PLABEN** [9] contains the procedures and essential criteria for the elaboration, effective implementation and efficient maintenance of the nuclear emergency plans of civil protection in Spain.

The generic levels of intervention established by the CSN in the PLABEN refer to " urgent measures of protection ": confinement (average individual avoidable dose of 10 mSv in a period of confinement not longer to 2 days), prevention (equivalent average individual avoidable dose to thyroid of 100 mSv) and evacuation (average individual avoidable dose of 50 mSv in a period not longer to one week). In addition, other urgent complementary measures of protection are identified, as control of accesses, civil self-defence and self-defence of personnel of intervention, persons decontamination, etc.

In the zones affected by the step of the radioactive cloud, during the emergency phase, it is possible to adopt restrictions for consumption of some foods and water, as preventive measures, though they are included as protective measures of long duration. The definitive adoption of these measures of protection will depend on the levels of intervention that the CSN determines, for every case. The CSN will consider the maximum levels of radioactive contamination in food products and feeds, fixed by the European Union, after a nuclear accident or any other case of radiological emergency.

Though the PLABEN applies only to urgent measures, it also defines measures of long duration, because, during the emergency phase, typical actions of the recovery phase can be performed or planned. Among these, they are the temporary movement of persons (level of intervention: avoidable dose of 30 mSv in the first month and 10 mSv in the following month) and the permanent movement or relocation (when the expected dose accumulated in one month is below 10 mSv after one or two years of the start of the temporary movement, or when the dose projected in the whole life overcomes 1 Sv)

The Internacional Atomic Energy Agency (**IAEA**), in its Basic Safety Standards (BSS), [1], recommends to identify a level of dose close to the one that might produce deterministic serious effects, for which the intervention would be almost always justified. Since the threshold of deterministic effects changes among individuals and circumstances, the most useful thing in the planning of the response to the emergencies is to adopt thresholds values lower than those of known biological effects. Also, the BSS marks directives for the establishment of intervention levels in emergency exposures. Taking into account these factors, generic optimized intervention levels are established, which can be taken as the starting point to establish the criteria to keep in mind in the decision to select levels of intervention for the case of emergency exposures.

2.2 Recommendations in the recovery phase (Chronic exposures)

For not urgent actions, it is slightly probable that the generic existing levels could be the optimal ones. Also, there is born in mind that, even after an accident, the consequences of the application of an action in the long term is difficult to predict in a precise way, which means that the studies of optimization for the protection measures would not also be able of identifying the optimal option. The different international organizations with competences for radiological protection have not reached the sufficient degree of agreement to establish levels in a similar way to the case of emergencies. The difficulty rests on, for optimization, a high number of particular cases needs to be taken into account.

As in the case of emergencies, the **IAEA** indicates levels of dose close to the low thresholds of the known biological effects, for whose in almost all the circumstances some type of action would be justified. The IAEA indicates that the levels of intervention must be established for every specific scenario, across a decision process in which a positive balance of all the attributes related to the contamination have to be reached. In addition to the annual avoidable individual and collective doses, it will be considered, at least: the reduction in the anxiety produced by the situation, the social costs, the disturbance and the environmental effects that could derive from the application of the corrective measures. In the decision process, there will also be taken tinto account the residual doses and other aspects that might identify the involved parts.

The Internacional Commission on Radiological Protection (**ICRP)** has elaborated recommendations with regard to the protection of the public against the prolonged exposures to the radiation. In the Publication 82 [10], generic reference levels for intervention, in case of prolonged exposures, are proposed, in terms of effective total annual dose (included the natural background), with values of approximately 100 mSv, above which the intervention would be almost always justified, and a value of the order of 10 mSv, below which it is not probable that an intervention will be justified. On the other hand, ICRP considers, with the denomination of annual additional dose, the effective annual dose from a specific exposure as the relevant magnitude for prolonged exposures. The reduction of this type of dose that would be obtained by the intervention would be the avoidable dose.

The optimization process would consist of establishing the scale and duration of the actions following the general approach used in the case of practices. The national and international authorities should predetermine specific reference levels (such as intervention levels, action levels and exemption levels in the intervention) for the case of prolonged exposures with potential of intervention. These have to expressed in terms of annual avoidable doses or in terms of any another subsidiary related magnitude. For exemption of the intervention, a generic level close to 1 mSv is recommended for the individual annual dose coming from the type of goods that predominantly could need intervention; such it would be the case of construction materials. On this base, the international and national organizations should obtain specific values for every radionucleido for individual goods.

The new ICRP Recommendations [11]establish that, in emergencies**,** the optimization will have to be used in the phase of planning to determine the levels of action in intervention and, during the real emergency, will be applied in a flexible way to take into account the predominant circumstances. For controllable preexisting situations, the optimization is used as a part of the protective actions selection and implementation process. The procedure to judge if it is reasonable a major reduction of dose involves to compare a serie of feasible options of protection aimed to reduce the potential doses to the individuals. These options should first consider direct actions on the source, but they should include also environmental actions. The implication of social agents ("stakeholders") has demonstrated to be an important contribution to the optimization, improving substantially the quality of the decision, solving conflicts of interests and improving the confidence in the institutions.

The **Council of the European Community** has published norms, with regard to the maximum permissible levels of contamination in foods destined to be commercialized, of application in future accidents that could happen in any part of the world (" Council Food Intervention Levels, CFILS "). These norms try to assure a uniformity of criteria in the European Union (EU) and the proposed levels represent the ideal balance, in the opinion of the EU, between the positive and negative consequences of introducing restrictions for food in the EU.

Different **EURATOM** Reglaments establishes maximum levels of radioactive contamination in milk products and other food in order to allow its marketing after accident or any other radiological emergency. They will be adopted immediately after having official knowledge that the established levels have been, or could be, reached, and the period of application will not overcome three months. Also, the import conditions for agricultural foods from countries outside the EU are established.

Nowadays, the directives for the international market with regard to the levels of radionucleidos in food after a nuclear contamination are gathered by the **Food and Agriculture Organization** in [12] and are applicable for one year after a nuclear accident. Each of these groups must be treated independently. The comparison inside a group is realized adding the partial contributions of the radionucleidos of the same one. The levels apply to foods ready for consumption. The foods of minority consumption needs special consideration.

3. Methodological approach

A methodology (**TEMAS methodology**) [13] is proposed, that follows a conceptual scheme of classification of scenarios based on how the radioactive contamination is transferred among the different radiecological compartments and reaches the individual, as well as in the characteristics of the above mentioned scenarios with influence in the response of the countermeasures.

This approach provides the opportunity to consider complex scenarios with different ecosystems (urban, agricultural and forest), since the applied categorization finally divides the contamination scenario in elementary units of intervention (EI), so that, on each of these EI, a unique parametrization for the predictive models is applicable. The application of a dosimetric specific model allows to establish the relation between the level of deposition in every EI with its contribution, as individual controllable source, to the radiological total impact on the critical groups of population. This relation is further used for obtaining a quantity derived from the generic reference levels for each of the protective applicable actions in the EI, expressed in terms of deposition activity, (what we have defined as optimized intervention level).

3.1 Case Studies

3.1.1 Agricultural contaminated scenarios

In the approach used by TEMAS for the agricultural module [13], the agricultural plots are the elementary units that are considered to be EI. The agricultural contaminated scenario is located in a climatic specific region (Mediterranean, continental, maritime or sub-Arctic) and is divided in a set of plots associated with a certain use of the soil (arable, permanent cultures or pastures) and characterized by its surface area, a type of soil and a deposition level. In addition, every plot will be associated with a certain type of management that associates it to one o more cultures in rotation.

The activity concentration in the cultures is estimated considering the contributions due to the direct deposition (using the model FARMLAND) and / or the rooth transfer. Also the time evolution of the radionuclides concentration is calculated in the rooth zone. The transfer to the culture is evaluated using transfer factors. The methodology TEMAS has a database with recommended transfer factor values for the combination of 4 types of soil with 7 groups of cultures. A transfer model modifies these values for every class of soil depending on the rea magnitude of exchangeable cations, Ca and K, in the soil. In relation to the cultures, its specific information (dry matter, edible fraction, temporary variation of biomass, perspiration, potassium extractable, optimum pH, residual biomass after crop) is gathered in databases together with other data of the region (dates of sowing and crop, production yield and costs of production)

The model of food chain characterizes each of the possible routes of processing between cultures and final products of consumption in terms of factors of processing, transfer factors and use factors, established in agreement with regional statistics. The forages are categorized in groups of use in the animal diet. The producing animal systems are characterized in agreement to animal typical diets, ingestion of dry matter, productivity (milk / meat) and transfer of activity from the ingestion to the product.

The population is distributed in six groups of age. To determine the incorporation of radionuclides by ingestion, the individual annual average consumption, in the ecological region under study, is calculated for every group of diet, and this consumption is considered among the different groups of age established. When the production of the contaminated cultures, once distributed among the different products of consumption, is sufficient to cover the individual annual diet of a group of age, it is supposed that the critical individuals consume only such products; if the production is lower, the contribution to the diet of the contaminated products is weighted.

The deposition level is related to the activities in the harvested cultures, in the edible and not edible fractions; the activity in the consumption products of vegetable and animal origin, that could be affected by the contaminated cultures, is calculated and the individual dose by the ingestion of these products is estimated for six different groups of age. This estimation of the individual dose takes into account the local diets and the making processes of the consumption products. In the case of milk and meat, it have been considered how the different cultures form a part of the forages that constitute the diet of the different animals of milk or meat production.

The predictive capacity of TEMAS allows to value the need for actions in agricultural scenarios by means of the analysis of the response under different conditions of soil, use and dimension. Finally the values of activity deposited in soil that would produce an annual dose for ingestion of the order of 1mSv / year are obtained.

On an environment accidentally contaminated, it is analyzed the influence of the textural characteristics of the contaminated soils, its fertilization, the type of cultures and the dimension of the contaminated surface, with regard to the dose to the population by the food chain,. The calculations are realized considering the situation one year after the accidental contamination, since it is supposed that in the first year, under the emergency phase, was decided the surface plough of the culture fields in order to abort the crops that were in phase of growth for the reduction of the external irradiation and the elimination of the crops directly contaminated by the radioactive cloud.

3.1.2 Urban contaminated scenarios

In the urban module of TEMAS [13], the scenarios of intervention are classified in elementary subenvironments, in which the different urban structures (houses, squares, gardens) are placed in a characteristic way. For each of these structures, deposition and intervention zones and permanency zones are identified. The interaction of the different deposition zones on the permanency zones is estimated by Monte-Carlo simulations of the transport of photons. The fluence of photons on the different zones of permanency is used for calculating the rates of kerma in air and, further, the individual dose rates to the different groups of age applying times of permanency and uses for the different zones of permanency. The calculation of the collective dose rate needs to add occupation factors to each of these zones (number of persons for surface unit). Each of the deposition zones has a specific model of contamination time evolution (processes of migration and meteorization) that is used in the calculation of the individual annual dose and the collective dose. The methodology TEMAS includes several types of urban scenarios like:

- **Residential urbanization scenario**: There is supposed a residential scenario of solid houses (not of wood) of two floors, surrounded with small gardens used as one-family housings by a population who resides in this environment but works and is educated out of the same one. The external dose that the different groups of age would receive along a period between 12 and 24 months after an accidental deposition of 1 kBq/m^2 of Cs-137 (measured on flat soil) is calculated

- **Inhabited rural scenario with environment of work and school:** It is constituted by small houses, also of two floors, and it is supposed that the adults have local works and the young men are trained in rural schools inside the scenario. The distribution of individual dose for the different groups of age supposing the same level and circumstances of deposition that in the previous case and also for a period between 12 and 24 months after the deposition is calculated. There can be estimated also the influence of the period passed after the deposition and the inluence of the house surroundings. It is verified that, in the inhabited scenario, the higher contribution to the dose comes from the gardens.

- **City, housing, working and school scenario:** An urban environment of apartments is supposed in houses multifloors with gardens, destined to housing and offices and with schools in the same environment. The external dose that the different groups of age would receive along a period between 12 and 24 months after an accidental deposition of 1 kBq/m^2 of Cs-137 (measured on flat soil) is calculated.

3.1.3 Results and conclusions

For every residential considered scenario, the external dose that the different groups of age would receive, one year after a deposition of 1 kBq m^{-2} of Cs-137 measured on a flat horizontal surface and the deposition that would produce in the same circumstances 1 mSv/year has been calculated.

The first case, of exclusive housing use (the population works and studies in a not contaminated environment) presents an annual dose very similar for the four groups of major age, between 1.1 and 1.4 μSv/year, but increasing inversely to the age. The dose is significant higher for ages lower than 1 year (2.2 μSv/year) due to the fact that they are supposed times of permanency in the housing equivalent to that of the remaining groups including housing and work or school.

The second scenario includes the uses school and work besides housing; in consequence, the individual doses rises. The doses for the groups of major age range between 1.8 and 2.1 μSv/year with the same trend of variation respect of the age, and the dose corresponding to the babies remains equal.

The only change of the third scenario respect of the second one is the time passed after the deposition (1 month in this case). The doses follow the same trend in a range between 2.5 to 3.1 μSv/year.

The fourth scenario has been elaborated to reveal that the major contribution to the dose comes from gardens and natural soils. In this scenario, with regard to the second one, only the green spaces have been replaced with paved zones. The distribution of dose is contained in the range between 0.2 and 0.3 μSv/year.

The last analyzed scenario refers to an urban scenario with constructions of five floors in which all the activities of the population are developed. The urban environment contains abundant green spaces. The individual dose depends here on the height on each one of the housings or places of work. In average, the doses are distributed between 1.0 and 1.2 μSv/year, values slightly lower than the received in urban environments with houses of two floors but highes than the to received inr the same houses with completely paved surroundings.

4 Summary and conclusions

After an exhaustive review of the International Regulations and Recommendations, numerical values for the actions in emergency are identified. For chronic exposures the situation is different; the different organizations coincide only in the concepts and methodological approach, but a general consensus in the adoption of numerical values has not been reached.

In this paper, numerical relations among deposition, activity concentrations and annual doses for different scenarios, exposures pathways and groups of age are established. The sensibility of the impact in relation to different characteristics of the intervention scenarios has been established. It facilitates the evaluation of the radiological meaning of the different potential situations of environmental contamination by comparison with the generic existing action levels or allows to incorporate the numerically above mentioned impact in a complex system of decision that includes non radiological aspects of the possible applicable intervention options.

Finally, once different intervention scenarios are studied, the following step would be to develop a methodology of work that could be used as a guide for the establishment of generic action levels in case of post-accidental interventions and in other "de facto" situations.

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