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Methodological aspects and updates of computational models

A proposed countermeasure simulation model for the new ICRP recommendations

C. LANDMAN, J. PÄSLER-SAUER, W. RASKOB, D. TRYBUSHNYI

ABSTRACT **In April 2011 the European Platform on Preparedness for Nuclear and Radiological Emergency Response and Recovery (NERIS-TP) decided to expand the two European Decision Support Systems JRodos and ARGOS with respect to the new ICRP-103 recommendations. The extension should be applicable for nuclear accidents and radiological emergencies and comprise a new screening model, the possibility to optimise dose reducing actions with the models ERMIN (European Model for Inhabited Areas) and AGRICP (Agricultural Countermeasure Program), respectively, and scenario preparation tools to support the user in defining countermeasure strategies. This paper describes the screening model that was developed by the authors and is foreseen for realisation and inclusion in JRodos and ARGOS in 2012/2013.**

Keywords: Decision support / countermeasure strategies / screening model / RODOS / ARGOS

1. Introduction

The screening model extension of the two European Decision Support Systems JRodos (Ievdin *et al.*, 2010) and ARGOS (Hoe *et al.*, 2002) with respect to the new ICRP-103 recommendations (ICRP, 2007) takes into account all terrestrial exposure pathways, including ingestion, and considers sheltering, evacuation, relocation, food restrictions, and the use of iodine tablets for thyroid blocking, for reducing or avoiding doses. The screening goal is the identification of action strategies that limit the total effective equivalent dose received from all pathways over a given time period, the "criterion dose", below a given reference level.

The proposed model represents a consistent and holistic approach to solve such a problem, by treating in one screening assessment sheltering, evacuation and relocation together, and linking the outcome *via* the criterion dose and the reference level to the ingestion pathways. Due to its specific characteristics, thyroid blocking does not fit well into the procedure. With respect to the intake of stable

KIT – Karlsruhe Institute of Technology, Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany.

iodine, we therefore suggest estimating only areas where this action is necessary on grounds of a thyroid dose criterion, and additionally the areas where the intake suffices to reduce the criterion dose below the reference level, and to exclude that action from the general strategy considerations.

All calculations will be carried out on the basis of the respective JRodos and ARGOS grid cells. However, some countries make decisions about actions on the basis of administrative units, and a possibility will be offered to condense the results to such higher level unities.

Long lasting events shall be covered by one run of the respective atmospheric dispersion and deposition model of JRodos or ARGOS; the generated information will be transferred to the screening model and provide the basic input for the calculations. The model must be able to cope with action starting times that differ between sections of the calculation grid *e.g.* in releases with longer duration, and with doses that were received at some point in time and cannot be mitigated thereafter, for example because a release was going on undetected for a while. For these reasons, the user can specify location-dependent "action offset times" T_{offset}. Before time T_{offset}, "no action" exposure is assumed in each grid cell when calculating the criterion dose between the beginning of the releases and T_{offset}.

The screening module will be equipped with a set of reference scenarios and test cases covering typical and extreme situations that can be used for demonstrations as well as for scenario development and installation and update control. The screening model will contain interfaces to the European Model for Inhabited Areas, ERMIN, (Charnock, 2010), and the Agricultural Countermeasure Program, AGRICP (Gering *et al.*, 2010), for enabling the user to perform optimisation investigations for selected strategies and areas.

2. Screening model for sheltering and evacuation/relocation

2.1. The criterion dose

The criterion dose for use in the screening model is calculated in each cell of the calculation grid and consists of the exposure pathway sum of effective equivalent doses to adult members of the general population received in a given time interval. The time interval is basically assumed to represent the first year after the accident, however, the proposed approach is not limited to that particular setting. Equation 1 summarises the criterion dose CD that will be used in the screening model.

CD_{adults}(grid cell) =	effective equivalent dose from cloud g exposure
	+ effective equivalent dose from ground g exposure in 1st year
	+ effective equivalent dose, committed, by inhalation from the cloud
	+ effective equivalent dose, committed, by inhalation of radioactive material resuspended from ground, in 1st year
	+ effective equivalent dose, from ingestion of selected foodstuffs, in 1st year

Equation 1: Criterion dose for use in the screening model.

Equation 1 comprises contributions from terrestrial non-ingestion pathways and also some contribution from the ingestion pathways that will be described in more detail in Section 3. Exposure from the contamination of skin and clothes can contribute significantly only for very specific scenarios, and the calculation implies significant uncertainties with respect to the assumed exposure duration. Currently it is not foreseen to include a skin contribution in the criterion dose.

2.2. Determination of areas requiring sheltering or evacuation/relocation

When determining the potential areas that require sheltering or evacuation/relocation (S/E/R), two conditions are distinguished:

- A grid cell where the criterion dose CD under "no action" assumption exceeds the reference level gets a general "S/E/R action" tag.
- A grid cell where "open air" exposure may potentially lead to deterministic health effects gets a "DET" tag.

For the assessment we propose a simple model based on threshold levels to the whole body and individual organs/tissues below which (severe) deterministic effects are not expected. The user can select if the tagging bases on effects to adults, or the foetus.

With respect to "no action" exposure, the user can choose between "open air" and "normal living". We deliberately exclude summing open air doses for short term exposure and normal living doses for longer term exposure. Because such mixes treat different exposure periods under different aspects and with different aims, they can lead to inconsistencies and are difficult to transmit to the general public, although being scientifically justifiable.

2.3. Finding a sheltering/evacuation/relocation strategy

To identify an action strategy with sheltering and evacuation/relocation, sheltering is tested first. The sheltering test area consists of all grid cells with the "S/E/R action" tag but no "DET" tag. The test looks for grid cells where the criterion dose with "sheltering" assumption drops below the reference level. For such cells the S/E/R screening problem is considered to be solved, otherwise, testing for evacuation/relocation is carried out.

Sheltering is assumed to start at time T_{offset}. With respect to the maximum shelter duration, the user may choose between 24 hours or 48 hours. The user has also the possibility to switch off the consideration of sheltering as an action option.

During sheltering, the people are assumed to stay in buildings with windows closed and ventilation switched off. Regarding the shielding factors for external gamma exposure and inhalation required for the dose calculations, in the pilot version the data currently in the geographical data base of the respective decision support system will be used. More detailed local data could be provided at some later stage; they may be difficult to obtain and also be afflicted with considerable uncertainties. After the end of sheltering, "no action" exposure is assumed in the calculation of the criterion dose ("open air" or "normal living", as selected by the user).

The evacuation/relocation test area consists of all grid cells with "DET" tag, and of all cells with the "S/E/R action" tag where the criterion dose with "sheltering" assumption did not drop below the reference level, or all cells with the "S/E/R action" tag when sheltering was excluded as an action option. The test looks for areas where the criterion dose drops below the reference level, if absence from the area for up to 1 year is assumed, possibly preceded by sheltering. If this goal cannot be reached, the grid cell gets an "S/E/R residuum" tag.

To test for the "minimum stay-away" time, initially "days" will be considered, then "weeks" and "months", respectively, until the end of the first year. The user has the possibility to specify a lower limit for the stay-away time (by default the end of the atmospheric dispersion and deposition phase, that is, the "scenario duration" in JRodos and ARGOS), and a "maximum stay-away time" T_{maxday} (default: 365 days) – if the minimum stay-away time required exceeds T_{maxday}, the grid cell gets the "S/E/R residuum" tag. This takes into account a statement in ICRP Publication 111 (ICRP, 2009), p. 3-4, that, whenever possible, a long-term goal should be the rehabilitation of areas for allowing people to return to their normal habits, and enables to define a strategic goal with respect to the absence time in addition to the radiological one.

Evacuation/relocation is assumed to start at time T_{offset} and can optionally be preceded by a sheltering period (limited by the maximum allowed shelter duration). After return to the grid cell, "no action" exposure is assumed in the calculation of the criterion dose ("open air" or "normal living", as selected by the user).

With respect to any of the S/E/R actions, the general "action offset time" T_{offset} sets a limit to the saveable dose: if the criterion dose with "no action" assumption exceeds the reference level before time T_{offset} in a grid cell, it automatically gets the "S/E/R residuum" tag because no action can achieve any dose reduction.

2.4. Results

Figure 1 gives a schematic representation of the two primary results of the screening assessment for sheltering and evacuation/relocation:

- A screening map showing the "action areas", *i.e.* the grid cells where the "no action" criterion dose exceeds the reference level, the actions identified by the screening and the respective stay-away times, and possible "S/E/R residuum" areas (Fig. 1a),
- A screening map showing the "criterion dose remainder", *i.e.* the dose differences between the reference level and the criterion dose under the

"action assumption" in the action areas, and the criterion dose under the "no action assumption" outside the action areas, respectively (Fig. 1b).

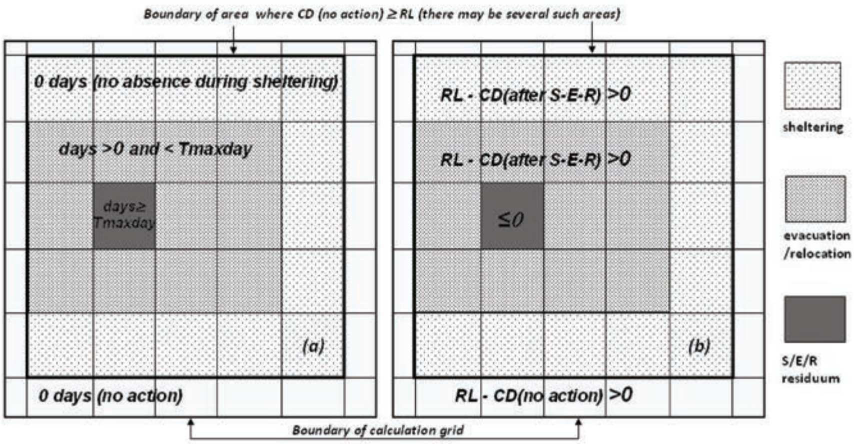

Figure 1 – ***Schematic representation of a screening map. (a) With stay-away times, days. (b) With criterion dose remainder, mSv.***

In "S/E/R residuum" areas, the stay-away time can be less than 365 days, if the user specified a shorter T_{maxday}; the criterion dose remainder is ≤ zero because no dose reduction can be achieved. This indicates the necessity for other actions, and S/E/R residuum areas will be passed to ERMIN for further analysis with respect to urban area actions.

The map with the criterion dose remainder constitutes the starting point for the screening assessments with respect to the ingestion pathways.

The areas with potential deterministic health effects are presented as a separate primary result. Further output will serve to understand the results of the calculation, or to define Operational Intervention Levels.

3. Screening assessments for the ingestion pathways

For screening assessments concerning the ingestion pathways three foodstuff classes will be considered:

- Key foodstuffs relevant for home-grown and home-prepared local consumption, for example milk and leafy vegetables,
- average annual food basket contaminated just below user specified levels (*e.g.* permitted EC concentration levels in food), or, alternatively, a user-specified average annual dose value from ingestion,
- drinking water from public water suppliers.

The aim of the model is to provide an automatic procedure for identifying areas where attention with respect to the above foodstuff classes is required; there is no intention to assess realistic one year dose distributions for real consumers under consideration of realistic non-local foodstuff production. Two distinct approaches are offered: Approach A is basically intended for foodstuffs that can easily be replaced or the consumption of which can easily be avoided. Examples are home-grown vegetables (can usually be replaced by vegetables grown elsewhere), mushrooms (usually not vital for survival). Approach B is basically intended for foodstuffs that cannot easily be replaced or the consumption of which cannot easily be avoided by people. Examples are drinking water (replacement for a larger number of people over longer times may be difficult), or a measurable but legal general contamination level in food. The approaches are complementary in the sense that some foodstuffs can be treated *via* approach B, others *via* approach A, in the same calculation, as specified by the user.

Approach A makes use of the criterion dose remainder (CDR) map from S/E/R screening that sets a limit upon the effective dose equivalent contribution from consumption of foodstuffs. Using time dependent activity-in-food and ingestion dose results from the respective food chain and dose model of JRodos and ARGOS, maps will be derived that identify the grid cells where the consumption of individual foodstuffs exceeds CDR, and the time the consumption must be interrupted until this is no longer so. If the CDR is exceeded for the complete first year, the grid cell gets an "ING residuum" tag. This indicates the necessity for other actions, and such areas will be passed to AGRICP for further analysis with respect to agricultural area actions.

For approach B foodstuffs, their contribution is included in the criterion dose for S/E/R screening *via* the "selected foodstuffs" in Equation 1.

During sheltering, evacuation, and relocation, the ingestion of foodstuffs is assumed to be interrupted, and after the end of sheltering or return to the area, is continued as if there was no interruption in between. With respect to the EC maximum permitted levels of radioactive contamination of foodstuffs and of feeding stuffs (Euratom, 1987; Euratom, 1989), the user may choose if they should be in operation or not when calculating the ingestion doses; it is also foreseen that the user may supply different limiting values.

4. Screening with respect to thyroid blocking

One of the demands on the screening model was to include the intake of stable iodine tablets in the considerations, an action that is effective only against thyroid doses from radioactive iodine nuclides. The current thyroid criteria doses can differ significantly between countries. With respect to the intervention levels, some countries have different intervention levels for adults and children, and some additionally an age limit resulting from harm–benefit analysis (*e.g.* 45 years in Germany), which divides the population in the same area into fractions with and without getting "protection".

The screening assessment with respect to thyroid blocking will be carried out for children and adults separately from S/E/R and ingestion screening because the action in general does not apply to the population as a whole. We consider only iodine inhaled from the passing radioactive cloud – presuming that food restrictions will prevent any significant iodine intake from ingestion – and assume intake at time T_{offset} and repeated intake for scenarios of longer duration. A thyroid dose criterion based on projected dose will be used for the initiation of the action. The aim of the assessment is to identify "iodine tablet required" areas, and also areas where the intake of stable iodine reduces the criterion dose from Equation 1 with "thyroid blocking" assumption below the reference level.

The effective equivalent dose, committed, by inhalation from the cloud with "thyroid blocking" assumption is calculated with Equation 2:

$$ER = E - w_t (D_{t,iod} - DR_{t,iod})$$

where ER, E = effective equivalent dose with "thyroid blocking" and "no action" assumption, respectively, w_t = weighting factor for organ thyroid, and DR, D = committed organ equivalent dose to the thyroid by radioiodine with "thyroid blocking" and "no action" assumption, respectively.

Equation 2: Criterion dose for sheltering or evacuation screening, with thyroid blocking accounted for.

Equation 2 is derived from the definition of the effective equivalent dose, $E = \sum_{i,n} w_i D_{i,n}$, where i indicates any organ in the definition of E, and n any nuclide. By separating organ thyroid, t, from the other organs, o, and the iodine nuclides, iod, from the remaining nuclides, m, E and ER can be expressed by $E = \sum_o w_{o,n} D_{o,n} + w_t D_{t,m} + w_t D_{t,iod}$, and $ER = \sum_o w_{o,n} D_{o,n} + w_t D_{t,m} + w_t DR_{t,iod}$. Subtracting E from ER leads to Equation 2 which also correctly accounts for the two limiting cases, "no effect of thyroid blocking" *e.g.* for scenarios without radioiodine, and "complete thyroid blocking" *e.g.* for scenarios with only radioiodine and prophylactic intake.

5. Conclusions

The proposed model offers a consistent and holistic approach to identify action strategies for reducing the criterion dose in the first year below the reference level by a combination of sheltering, evacuation/relocation and food restrictions. Basically for research, thyroid blocking is included, but considered separately because it applies only to a fraction of the general population.

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