Revisiting the dose calculation methodologies in European decision support systems

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Revisiting the dose calculation methodologies in European decision support systems

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Abstract: The paper presents examples of current needs for improvement and extended applicability of the European decision support systems. The systems were originally created for prediction of the radiological consequences of accidents at nuclear installations. They could however also be of great value in connection with management of the consequences of other types of contaminating incidents, including 'dirty bomb' explosions. This would require a number of new modelling features and parametric changes. Also for nuclear power plant preparedness a number of revisions of the decision support systems are called for, to introduce new knowledge and thereby improve prognoses.

Key Words: Decision support, radioactivity, dose estimation, atmospheric dispersion, dirty bomb.

1. INTRODUCTION

In order to avoid repeating the mistakes and failures encountered in the aftermath of the Chernobyl accident, where countermeasures were implemented on a hit-and-miss basis, it is essential to use the best possible supporting instruments in reaching decisions on justification and optimisation of intervention. The European ARGOS and RODOS standard systems are developed for this purpose, and offer excellent overview options for studying conceivable contaminating incidents before they happen, and developing a targeted and effective operational preparedness across Europe. They are also ideally equipped to enable best estimates of the consequences during and after the occurrence of an incident, helping to secure the best possible use of perhaps limited resources available within given timeframes, and to avoid wrong, and sometimes irreversible, decisions from being made. It should however also be noted that the dose calculation methodologies applied in some of the modules of the decision support systems are still based on the knowledge platform that was available several decades ago and only relate to the types of threats that were of concern at that time. Terrorist attacks involving dispersion of radioactive contaminants (e.g., 'dirty bombs') may lead to contaminants with characteristics that can not be adequately represented by the current dose estimation methodologies in the European decision support systems. In relation to nuclear power plant accidents, for instance a revision of the parameterisation in the ingestion dose calculation module is recommended on the basis of recent investigations, and in general a better representation of physicochemical forms of contaminants would lead to much more reliable dose estimates.

2. METHODS AND RESULTS

2.1 Preparedness for terror attacks

Malicious airborne dispersion could occur in a number of different types of scenarios, which would generally involve plume propagation at a much lower altitude than implicitly assumed in the original ARGOS and RODOS systems. Means of dispersion might include generating a haze of small radioactive particles employing a nebuliser arrangement from some elevated place in the city, such as a rooftop. However, to inflict real harm on an exposed population, the source would need to have considerable strength, wherefore its placement and set-up would be far from trivial, and the release height might well still not be sufficient to cause widespread contamination over a city area. Alternatively, the contamination could be spread by aircraft. However, such an arrangement would pose considerable difficulties to terrorists, both due to the recent increasing air traffic security and in relation to adequately shielding the pilot from the contamination so that he would live long enough to be able to carry out the attack. A third possibility could be to disperse the contamination using a 'dirty bomb' device. We will here focus on this latter type of means for dispersion.

Doses from any atmospheric contamination event may occur through a number of pathways, including inhalation during the plume passage, inhalation of resuspended contaminants, external exposure from a passing contaminated plume, external exposure from contaminated indoor and outdoor surfaces, external and internal exposure following contamination of human skin, eyes, hair and clothing, and exposure from ingestion of contaminated food. If the contaminating incident were a 'dirty bomb' explosion, it would be impossible to say that one dose contribution would generally be likely to be greater than another. A 'dirty bomb' attack could for instance involve a single pure alpha emitter, like ^{238}Pu or ^{252}Cf. In that case all external dose contributions can be ignored, as the radiation will not penetrate the human stratum corneum, and thus not cause a dose to living cells via this route. Here exposure pathways involving the intake of radionuclides via inhalation or ingestion will be of interest. Liquid droplet and particularly vapour condensation particles that may under some circumstances be produced in a 'dirty bomb' explosion if sufficiently high pressure is generated would be small and certainly inhalable, whereas the physical fractionation of for instance some metals would lead to negligible inhalable particle concentrations (Harper et al., 2007). Inhalation doses could thus have highly varying importance according to the specific scenario. Inhalation dose modelling would need to adequately represent the actual likely physicochemical forms, e.g., with respect to particle size and solubility. This is currently not possible in the European decision support systems.

The different particle size distributions that would arise from different types of ‘dirty bomb’ attacks would lead to very different atmospheric dispersion and deposition pattern in a city area. The current versions of the European decision support systems, ARGOS and RODOS, only operate with two different particle size categories, which is clearly inadequate in relation to ‘dirty bomb scenarios. Currently, particles larger than 5 μm can not be modelled in the decision support systems, yet many conceivable ‘dirty bomb’ scenarios will disperse larger particles over a quite large area (Harper et al., 2007, Andersson et al., 2009). Also, the plume originating from a ‘dirty bomb’ would be likely to at least partially be dispersed at such low altitude that interactions with obstacles like buildings and trees could have an important bearing on the dispersion and deposition pattern. Parts of the plume can be entrained and delayed behind obstacles in the landscape, which adds to the complexity of the spatial contaminant distribution. The introduction of a recently created high-resolution dispersion model, URD, in ARGOS has enabled modelling of such effects, following the trajectories of both primary puffs and secondary puff sections representing different parts of the contaminated air mass. This model also takes into account the increased small scale turbulence and limitations on horizontal eddy movements due to the comparatively low plume altitude. As has been demonstrated (Astrup et al., 2005), these factors can affect the contamination pattern, wherefore the original larger scale dispersion models in ARGOS and RODOS are not well suited for ‘dirty bomb’ scenario estimation. It should be noted that ARGOS and RODOS are currently not equipped with models that can predict the airborne dispersion of contaminants in large indoor and semi-confined spaces like underground train stations and airports.

Contaminant deposition will be strongly influenced by precipitation during the plume passage, as plume rainout and washout are powerful deposition processes. Both dry and wet deposition will very much depend on particle size. This type of dependencies have only recently been considered in the ARGOS and RODOS decision support systems, where a library of deposition velocities has been introduced to distinguish between the small (slightly less than one micron) particles likely to be formed in a large nuclear power plant accident by volatile radiocontaminants like caesium, tellurium and molybdenum and the somewhat larger (typically 2-4 μm) particles of more refractory contaminants (e.g., strontium, zirconium and cerium) that were for instance observed at considerable distance after the Chernobyl accident. However, the size spectra of particles that could contaminate an inhabited area in a ‘dirty bomb’ scenario are much more complex, and here it is also here essential to distinguish between different types of particle formation processes. Whereas a well constructed liquid source bomb detonation may produce large amounts of submicron particles with low deposition velocity (thus having potential to disperse over a very large area), much of the aerosol produced in a bomb detonation involving a ceramic contaminant will have sizes exceeding 10 µm, and thus due to gravitational settling have dry deposition velocities exceeding that of a 0.5 µm particle by orders of magnitude. If these differences are not taken into account in a decision support model, both absolute contamination level and dose estimates and the size and location of the contaminated areas will be completely wrongly predicted.

In modelling doses that would be received over time with and without intervention, it is essential to estimate the natural migration and weathering of contaminants deposited on the different surfaces in the environment. A problem is here that the parameters governing the estimates of natural migration of contaminants in ARGOS and RODOS are practically exclusively based on measurements of the behaviour of Chernobyl radiocaesium (i.e. caesium in readily soluble form). The caesium cation has the feature that it binds very strongly and selectively in minerals that are highly abundant in most common construction materials, as well as in soil and street dust (Andersson, 2009). As the Chernobyl accident demonstrated, radiocaesium contamination levels on construction materials only very slowly declined (often with a half-life of many years), whereas contaminants embedded in larger and less soluble particles were much easier removed from impermeable surfaces near the Chernobyl NPP. Literally no other perceivable contaminant ion would be nearly as strongly fixed on urban surfaces and in soil as the caesium cation. This may not be of critical importance in connection with modelling of the long-term radiological consequences of large nuclear power plant accidents, where radiocaesium would anyway play a dominant role, but in connection with a ‘dirty bomb’ dispersion scenario, which could involve a single and very different contaminant, long term doses could be overestimated by many orders of magnitude if the caesium cation weathering parameters, which are currently the only available ones in the ARGOS and RODOS systems, are applied. Obviously also the efficiency factors for countermeasures involving contaminant removal, which are in the European decision support systems also based on Chernobyl experience, should be re-evaluated to provide reliable estimates for other contaminants than caesium.

2.2 Preparedness for nuclear power plant accidents

A few examples of current shortcomings of the European decision support systems in relation to accidents at nuclear installations are outlined in the following.

The ECOSYS model is the ingestion dose model integrated in the ARGOS and RODOS decision support systems for nuclear emergency management. The parameters used in this model have however not been updated in recent years, where the level of knowledge on various environmental processes has increased considerably. A Nordic work group has carried out a series of evaluations of the validity of current default parameters in ECOSYS (Nielsen & Andersson, 2008). Model input that has been reviewed and improved include a number of parameters relating to location specific conditions (consumption rates, imported foodstuffs, animal feeding regimes, seasonal crop development) as well as a number of generic parameters (parameterisation for deposition to crops, soil and snow, parameterisation for natural weathering of contaminants from crops, parameter values for leaching rates, fixation rates, desorption rates and resuspension enrichment factors for contaminants in soils, soil-to-plant transfer factor parameterisation in relation to soil classification, and animal metabolism parameterisation).

For instance with respect to dry deposition velocity, it is clear that the current approach in the European decision support systems, where all aerosols are represented by a single value, is inadequate. Within the rather narrow range of aerosols from the Chernobyl accident that could be dispersed by wind over distances of hundreds or even thousands of kilometres, typical deposition velocities to crops vary by about a factor of 5 and are governed by different mechanisms (Brownian diffusion for the smaller aerosols, and gravitational settling for the larger). Different release processes will result in different aerosol size distributions, and only the smallest particles will be transported as far away by wind as thousands of kilometres. However, the risk of strong contamination of rather big food-producing areas with larger particles should not be ignored. Crop deposition velocity values currently applied in ECOSYS for aerosols in the size groups recorded at long distances after the Chernobyl accident are up to an order of magnitude different from those that should typically be expected for this type of scenario on the basis of state-of-the-art information (Andersson et al., 2011). Since initial concentrations on soil or crops of airborne contamination have a linear dependence on the relevant deposition velocities, a change in the assumed deposition velocity values by a given factor will generally lead to a change in ingestion dose estimate by the same factor. Deposition velocities are therefore in general very important to model correctly, and depending on the scenario type.

There is in general a need to consider the release *process* also in connection with nuclear power plant accidents, when defining the released contaminants. Traditionally, the ‘source term’ is in decision support models simply a radionuclide vector, but the physicochemical forms of the released contaminants are crucial to consider. For instance, in connection with the Chernobyl accident, the strontium particles released in the explosion and the subsequent fires had very different environmental solubility/mobility due to differences in oxidation during the release process. Currently, food dose models in the decision support systems will assume that all contaminants in soil are in solution and ready for uptake. However, the Chernobyl accident showed that, e.g., the environmental strontium particle dissolution was a process lasting years, depending on soil pH.

3. CONCLUSIONS

The European computerised decision support systems for nuclear emergencies have many useful computation features, user interfaces and graphic representation possibilities that would be invaluable in the establishment of a state-of-the-art European based consequence estimation tool for malicious contaminant dispersion scenarios. However, it should be stressed that model and parameter refinements are urgently needed to provide reliable consequence estimation for this particular category of scenarios. Also for use in connection with accidents at nuclear power plants a number of improvements of the models should be made employing new knowledge to improve the quality of dose prognoses.

References

K.G. Andersson, in Airborne radioactive contamination in inhabited areas: Radioactivity in the Environment vol. 15, edited by K.G. Andersson (Elsevier, Amsterdam, Netherlands, 107 (2009).

K.G. Andersson, T. Mikkelsen, P. Astrup, S. Thykier-Nielsen, L.H. Jacobsen, S.C. Hoe, S.P. Nielsen, J. Environ. Radioactivity **100**, 1005 (2009).

K.G. Andersson, S.P. Nielsen, H. Thørring, H.S. Hansen, H.P. Joensen, M. Isaksson, E. Kostiainen, V. Suolanen & S.E. Pálsson. J. Environmental Radioactivity **102**, 1024 (2011).

P. Astrup, S. Thykier-Nielsen, T. Mikkelsen, Risø-R-1539(EN), Risø, Roskilde, Denmark (2005).

F.T. Harper, S.V. Musolino, W.B. Wente, Health Phys. **93**(1), 1 (2007).

S.P. Nielsen, K.G. Andersson (eds.), NKS report NKS-174, Nordic Nuclear Safety Research (NKS), Roskilde, Denmark, (2008).