
Raskob, Wolfgang; Almahayni, Talal; Beresford, Nicholas A.. 2018.
Radioecology in CONFIDENCE: dealing with uncertainties relevant for decision making. *Journal of Environmental Radioactivity*, 192. 399-404.
https://doi.org/10.1016/j.jenvrad.2018.07.017

Radioecology in CONFIDENCE: Dealing with uncertainties relevant for decision making

Abstract

The CONFIDENCE project is performing research on uncertainties in emergency management and post-accident recovery. It concentrates on the early and transition phases of an emergency, but considers also longer-term decisions made during these phases. To ensure success, the project brings together expertise from four European Radiation Protection Research Platforms (NERIS, MELODI, ALLIANCE and EURADOS) and also from the area of social sciences and humanities.

This paper presents an overview of the CONFIDENCE project with a focus on CONFIDENCE's consideration of the radioecology required to support emergency management and post-accident recovery. For instance, operational decisions concerning land and foodchain management rely on radioecological models that are at present mostly based on simple, but highly uncertain, transfer ratios to predict contamination in foodstuffs. CONFIDENCE will investigate if process-based models are better suited to reducing uncertainties associated with empirical ratio based models. Model improvements and uncertainty reduction might be also possible by better evaluating past experience from Chernobyl and Fukushima.

Key words

Uncertainties, decision support, emergency, post-accident, radioecological modelling, transfer to human food, process-based models, countermeasure strategies, atmospheric ensembles

1. Introduction

In nuclear emergency management and subsequent long-term rehabilitation, dealing with uncertain information is an intrinsic problem for decision making. Uncertain information related to, for instance, incomplete data on the source term and the prevailing weather can result in dose assessments that differ dramatically from reality. In the presence of uncertainty, ineffective decisions are often taken (e.g. too conservative or optimistic predictions, and inadequately accounting for non-radiological risks), which may result in more overall harm than good due to secondary causalities as was observed following the Chernobyl and Fukushima accidents. As an example, simplistic radioecological models failed to predict areas of Western Europe where high radiocaesium transfer through the human foodchain would persist for decades following the Chernobyl accident. The reduction of uncertainty, and how to deal with (and effectively communicate) uncertain information, is essential to improve decision making for the protection of the affected population and to minimise disruption of normal living conditions.

Uncertainty is different at various stages of an emergency, which typically can be subdivided into a pre-release, release, and post-release phase, the latter dealing with long-term recovery issues. The CONFIDENCE (COping with uNcertainties For Improved modelling and DEcision making in Nuclear emergenCiEs) (https://resy5.iket.kit.edu/CONFIDENCE/) project focuses on reducing uncertainties in the release and the post-release phases, the latter including the transition between the short-term post-release and recovery phases (e.g. the first year(s)). However, decisions taken relatively early after an emergency affect long-term recovery and hence robust long-term predictions need to be made during these early phases. Therefore, with respect to contamination of the human foodchain CONFIDENCE's research programme includes the study of the long-term behaviour of radionuclides within the environment.

CONFIDENCE brings together expertise from all four European Radiation Protection Platforms and the social sciences and humanities field, such that we can address the scientific challenges associated with: model uncertainties and improve radioecological predictions and emergency management (NERIS, http://www.eu-neris.net/, ALLIANCE, http://www.er-alliance.eu/); situation awareness and monitoring strategies (EURADOS, http://www.eurados.org/); risk estimation in the early phase (MELODI, http://www.melodi-online.eu/); decision making and strategy development at local and national levels (NERIS) including social and ethical aspects (social sciences and humanities). Following an overview of the CONFIDENCE project, this paper will focus on our radioecological research.

2. General objectives of CONFIDENCE

Decision-making in a nuclear or radiological emergency has changed since the 1986 Chernobyl accident which affected large areas of Europe. The Chernobyl accident initiated many national and European level research activities to improve modelling in many areas with the aim of ultimately supporting decision making at all phases of such an event (see e.g. Cox et al., 2005, Geldermann et al., 2007, Gillett et al., 2001, Howard et al. 2005, Nisbet et al., 2005, Nisbet et al., 2010 and Papamichail & French, 2005). As a result, decision support systems (DSS) containing suites of simulation models emerged and are now used worldwide. One of these advanced DSS is the JRodos (Java based Real-time On-line Decision Support) system that is now used in about 20 different countries in Europe and beyond (see e.g. Ehrhardt, Weis, 2000 and Ievdin et al., 2010); JRodos is the DSS being evaluated and improved by CONFIDENCE. So far in JRodos only deterministic results ignoring uncertainty bands are provided to users. If the user wants to investigate uncertainties of e.g. the source term, multiple-model runs with different input have to be performed. In this way, uncertainty predictions are not an integral output associated with the prediction endpoints of these tools (French et al., 2016)

A first attempt to deal with uncertainties in JRodos was initiated (Raskob et al., 2009). The approach described in Gering (2005) uses the 'ensemble method', a form of the Monte Carlo analysis. Ensemble in this context means that a set of calculations, 100 in Gering (2005), were performed with input parameter variations. The input variations were generated by applying a distribution around the best estimate value of the parameter of interest. As source term and wind direction are the most uncertain ones in the release phase and hence they were selected as uncertain parameters. A log-normal distribution was assigned to the source term and a deviation of an order of magnitude is considered to be equally probable in both directions. A normal distribution was assigned to the mean wind direction with a standard deviation of 30°. The assumptions used were based on the results of unpublished work conducted in the frame of the EURANOS project (Raskob at al., 2010). As a consequence of this, 100 different input realisations were defined and three resultant individual realisations can be seen in Figure 1.

Figure 1: Three example predictions of total effective dose from inhalation, external irradiation from the passing cloud and seven days external exposure from the ground; this is used in Germany to define the need to initiate sheltering (from Raskob et al. 2009).

The colour coding of the results in Fig.1 can be interpreted as follows: as soon as the colour turns into yellow, the intervention criterion for sheltering is approached; if the colour is orange or reddish, intervention dose for sheltering is exceeded. A visualisation of the results was proposed in terms of areas where probabilities of exceeding a particular threshold were indicated (see Figure 2).

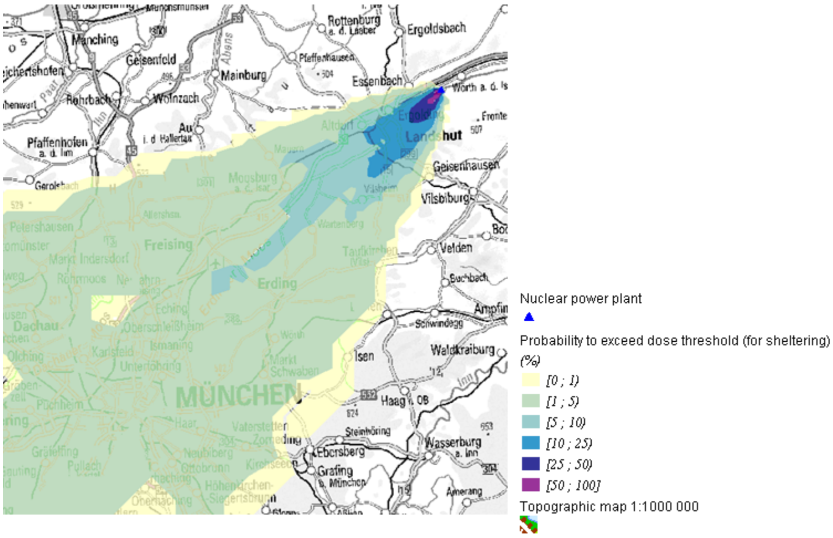

Figure 2: An example of the probability to exceed the 10 mSv threshold of the effective dose used for sheltering in Germany (Raskob et al. 2009).

However, the proposed approach was not realised in the operational version of the JRodos system. In CONFIDENCE we propose that the ensemble approach as used by Raskob et al. (2009) is the starting point for all assessments. This would allow the capturing of uncertainty bands of all the assessments in the pre-release and release phases.

Besides ensembles, model uncertainties and model improvements will be addressed in CONFIDENCE. Areas being focussed on are atmospheric dispersion and deposition, risk modelling to better estimate health effects and radioecological models. The focus of this paper is a discussion of our radioecological activities, the other activities within CONFIDENCE include:

- Identifying and ranking the main sources of uncertainties in the early phase, and characterising and quantifying their effect on simulation results

- Developing a prototype software for the quick and efficient assessment of cancer risk to affected populations to be used as an input in the overall decision making process
- Developing approaches and tools to integrate external and internal dosimetric monitoring data with simulation results to improve understanding of the radiological situation
- Improving the capabilities of radioecological models used to predict activity concentrations in foodstuffs and to better characterise, and where possible, reduce uncertainties (this element of our work programme being the focus of the next section)
- Improve the methodology to develop sensible countermeasure strategies in the transition phase by engaging national stakeholders and considering uncertainties when defining the strategies
- Identifying social and ethical issues related to uncertainty management in emergency and post-accident situations, and clarify how stakeholders at various levels deal with uncertainty in their decision making processes
- Support and improve communication of uncertainties and facilitate robust decision making taking into account the variability of the radiological situation
- Develop training courses and educational material for professionals and students related to the issues and activities addressed in CONFIDENCE

2.1 Radioecological modelling

There are considerable uncertainties associated with the radioecological simulation models used to predict the transfer of radionuclides along the foodchain. Initially after an accidental release the factors determining the contamination of foodstuffs will largely be defined by vegetation interception and the time of year. During the transition phase, factors controlling the uptake of radionuclides to vegetation from soil will become more important and these will dominate in the long-term rehabilitation phase. Predictions made using radioecological models will be used in the early part of the transition phase to make longer-term decisions, e.g., with regard to remediation strategies. Therefore, models must be sufficiently robust and fit for purpose with uncertainties reduced where practicable. Within CONFIDENCE there is a focus on understanding and reducing uncertainties in the prediction of the transfer of radionuclides to human foodstuffs. An aim of this work is to evaluate and ultimately improve the radioecology components of the JRodos DSS. We give an overview of this work below and highlight some of our activities.

2.1.1 Improving models

Radionuclide transfer parameters used in predictive models are often highly variable (e.g. see IAEA 2010). Furthermore, the parameterisation of the foodchain module (Müller & Gering 2003) of the JRodos system used in a number of European countries is based on the ECOSYS-87 model (Müller & Pröhl, 1993). This model predates the international compilation of radionuclide transfer parameter values (IAEA, 1994; 2010) which, for instance, incorporate the large amount of data obtained in post-Chernobyl studies. We will characterise and analyse the underlying probability distribution functions (PDFs) associated with transfer parameters to better enable uncertainty and sensitivity analyses comparing those parameters currently in the JRodos system and more recent recommendations (e.g. IAEA, 2010).

Whilst radioactive iodine ^{131}I may be the major health risk after a nuclear accident, its behaviour in the environment has been relatively poorly studied; likely the consequence of the comparatively short half-life of this radionuclide ($t_{1/2}$ ~ 8 days). We have studies on-going where ^{131}I is being applied to different crops in different areas of stable iodine status to enable time trends in ^{131}I activity concentrations to be determined and the key factors controlling these to be identified. The results of these studies will feed directly into improving the parameterisation of JRodos (note IAEA 2010 contains no data for the transfer of I to crops).

From personal contacts we were aware that Japanese scientists found that some radioecological information was lacking in the aftermath of the 2011 Fukushima accident. To determine if CONFIDENCE could learn from Japanese experiences, in July 2017 we circulated a questionnaire to approximately 60 Japanese scientists involved in radioecology and radiation protection. The aim of the questionnaire was to identify elements of human foodchain transfer for which knowledge was lacking, or where more information would have made assessments and predictions easier; at the time of writing we have received 21 responses. Issues with regard to radioecological knowledge of relevance to CONFIDENCE which have been raised are:

- The lack of transfer parameters for specific foodstuffs (including the transfer of intercepted radiocaesium to fruit)
- The need for transfer parameters appropriate to local conditions
- A need for an ability to predict changes in radionuclide activity concentrations in food products with time (including the need for biological half-life data)
- Variability (uncertainty) in transfer parameters and problems in communicating this to non-specialists/the public
- Need for guidance on selecting suitable models (note c. 40% of respondents were not involved in radiation protection or radioecology prior to the Fukushima accident)
- Need for pre-accident training in responding to nuclear emergencies
- Contamination of drinking water.

Some of the issues raised are already being addressed within the wider CONCERT research programme (e.g. communicating uncertainties). With respect to biological half-life, we have initiated a literature review and will publish the resultant database (JRodos utilising biological half-life values for animal derived foodstuffs). A number of the responders raised the need for transfer parameters for specific food products and which were also appropriate to local conditions. The process-based modelling studies within CONFICENCE, see below, aim to evaluate and develop models which take into account important site characteristics (i.e. soil parameters). It is unlikely that we will ever have data for all of the foodstuff-radionuclide combinations and, we therefore, need reliable extrapolation approaches. Extrapolation approaches for wildlife assessment have recently received some consideration (e.g. Beresford et al. 2016a). A number of papers (e.g. see Willey 2010) have suggested that models based on phylogeny (evolutionary history) could be used to make predictions of soil-to-plant radionuclide concentration ratios. However, to our knowledge such an approach has not been validated for crop plants. In CONFIDENCE, we will consider the practical applicability of this approach which, if validated, would provide a method of deriving concentration ratios for human foodchain species for which we have little or no data.

2.1.2 Process-based models

Models (including JRODOS) to predict the transfer of radionuclides to human foodstuffs typically use equilibrium concentration ratios to describe the transfer from soil to plants (i.e. crops and animal fodders) (e.g. Brown & Simmonds 1995; Müller & Pröhl 1993; Müller & Gering 2003) with international recommendations on parameter values for such models (IAEA 2010). These parameters are generic (i.e. one value being proposed for application, in-effect, anywhere) or at best categorised by simplified soil categories (e.g. sand, clay, loam or organic; IAEA 2010). The concentration ratio combines processes and parameters that vary both temporally and spatially. However, the transfer of radionuclides in the environment is highly variable being influenced predominantly by soil and land management characteristics.

Models which attempt to include processes controlling the transfer of radionuclides may be expected to give better predictions than those relying on generic concentration ratios. A simple example of a 'process-based' model is the inclusion of water potassium (K) concentration to estimate the radiocaesium activity concentration in fish (Smith & Beresford 2005). In the case of terrestrial foodchain, Wright et al. (2003) presented a spatially implemented model to predict the radiocaesium transfer to sheep which uses soil organic matter. The model predicted changes in the areas in England requiring restrictions on the movement and slaughter of sheep following the Chernobyl accident relatively well. As discussed below, in CONFIDENCE we are evaluating processed based model options for the two radionuclides which are likely to contribute most to dose in the long-term, caesium and strontium, in terrestrial (agricultural) systems. One element of our work will be to consider how such models can be incorporated into DSS, such as JRODOS; Cox et al. (2005) have already demonstrated that this is possible.

Radiocaesium

The model developed by Absalom et al. (1999) is a noteworthy example of process-based soil-to-plant transfer model for radiocaesium. It bridges the gap between simple empirical models and data-demanding mechanistic models. The model is practical and scientifically defensible, yet without too much need for highly specific and difficult-to-measure input data. The model capitalises on the mechanistic understanding of radiocaesium behaviour in soil-plant systems to simulate its soil-to-plant transfer. Specific sorption of radiocaesium on clay minerals, quantified in terms of the radiocaesium interception potential (RIP), and the competitive effect of K in soil solution on radiocaesium uptake into plants are among the key processes in the model. The model uses basic, often readily available parameters as inputs (e.g. clay content and exchangeable K) and can be readily incorporated into Geographical Information Systems to give spatial predictions and identify 'radioecologically sensitive' areas (Gillett et al. 2001). The initial model was expanded to cover a wider range of soils (i.e. organic) (Absalom et al., 2001). Tarsitano et al. (2011) refined the structure of the model to reduce redundancy in its parameterisation. The model has been widely used to estimate radiocaesium transfer to vegetation (food crops and grasses) under a wide range of European ecological conditions (e.g. Gillett et al., 2001; Van Der Perk et al., 2001). The model was also incorporated into a decision support system for identifying optimal countermeasure strategies (Cox et al. 2005).

However, recent application of the 'Absalom' model under ecological conditions found in Fukushima-affected areas in Japan highlighted some issues. Comparing grass concentration ratios calculated with the model, to values measured in several Fukushima-affected areas, Uematsu et al. (2016) noted that the calculated concentration ratio values deviated from the observed data. Whether the model over- or underestimated concentration ratios depended on the origin of the model parameters (i.e. directly measured or estimated) and the model version used (i.e. Absalom et al., 1999; Absalom et al., 2001; Tarsitano et al., 2011). Irrespective of version used, the model considerably underestimated the observed radiocaesium uptake into grass when using values of soil RIP and soil solution K concentration estimated from soil characteristics. The geometric mean (GM) of the model concentration ratio values was more than an order of magnitude lower than the GM of the observed values. In contrast, the GM of the model concentration ratio values was almost 10 times greater than that of the observed values when using the measured RIP and K concentration values.

The tendency of the models to underestimate radiocaesium transfer when using estimated parameter values was attributed to the overestimation of radiocaesium sorption and K mobility in the soils. The calculated RIP and K soil solution concentration values were greater than the measured values by factors of 10 and three, respectively. Overestimation of radiocaesium sorption could be ascribed to a number of factors. Firstly, the equation in the models used to calculate the RIP had been derived for European soils, whose mineralogical composition, and hence sorption characteristics, are markedly different from those of the soils in the Fukushima-affected areas of Japan (Uematsu et al. 2015). Agricultural soils from Fukushima-affected areas had three times lower RIP per unit clay than typical European soils. Additionally, unlike for European soils, the RIP did not correlate significantly to clay content in the Japanese soils.

Secondly, the concentration of NH_4^+, which is a strong competitor of radiocaesium for sorption on clay minerals (illites) and a model input, was not measured during the experiments of Uematsu et al. (2016). This parameter was instead assigned a generic value (0.56 mM) based on a literature study assumed to be representative of grassland soils in Japan. Concentrations of NH_4^+ in soil could vary with local agricultural practices (e.g. fertilisation) and field conditions. Hence, the effect of the uncertainty in this parameter on model performance cannot be ruled out.

Overestimation of K soil solution concentrations was also attributed to overestimation of other model parameters, namely, the concentration of calcium (Ca) and magnesium (Mg) in soil solution, which were four times higher than the measured values. The dependence of Ca and Mg concentration on soil pH, as assumed by the models, could not be demonstrated for the Japanese soils.

The fact that the model-calculated concentration ratio values still deviate from those observed in the field even when measured RIP and K concentrations are used likely indicates issues with other model parameters.

Therefore, whilst the Absalom model represents a trade-off between empirical and mechanistic radiocaesium soil-to-plant transfer models which should be able to reduce uncertainties in predictions, experience shows that its underlying assumptions need to be revisited. Notably, the correlation between soil RIP and clay content is not significant across all soils. To make it applicable world-wide (and ensure it is fit for purpose across all European conditions), additional experimental work is needed to parameterise, calibrate and validate it. In CONFIDENCE we have begun studies to test the Absalom model across a range of European soil types (from Mediterranean to Nordic systems).

Radiostrontium

Radiostrontium (^{90}Sr) can contribute significantly to foodchain dose following accidental releases (e.g. Chernobyl, Mayak). Despite its potential importance for the consideration of processed-based models for radiostrontium has received relatively little consideration with the possibly exception of the studies described in see Nordén et al. (2005). It is likely that a model using commonly available soil parameters (e.g. calcium status), similar to that described above for radiocaesium, could be derived for strontium and this is being investigated within the CONFIDENCE work programme.

The WHAM model was developed for predicting metal availability/binding in soils and aquatic environments (Lofts & Tipping (2011). The model has previously been applied in a limited manner to the prediction of strontium solid to liquid phase distribution coefficients (i.e. K_d values) in soils (Tipping et al. (1995); the application was not validated. This established model may provide a basis upon which we can develop a radiostrontium model based on commonly available soil parameters. However, the WHAM model is currently over parameterised for radioecological application (14 parameters are required to enable predictions of Sr). The first phase of our evaluation of the model is therefore, to conduct a sensitivity analyses to review (and reduce if possible) the number of model parameters before defining a laboratory/field testing and validation programme. Whilst the focus here will be on Sr, the WHAM model considers a number of elements which have radioisotopes potentially released following an accident (Tipping et al. 1995); if we can successfully adapt the WHAM model for ^{90}Sr modelling in a radioecological context then it is likely we will be able to adapt for other relevant radionuclides.

2.1.3 Including 'hot particles' in radioecological models

Subsequent to the Chernobyl accident there has been recognition of the potential importance of particulate deposition (commonly referred to as 'hot particles') (Beresford et al. 2016b). Such particles can add to uncertainty in transfer estimates, for instance, as evidenced after the Chernobyl accident. Weathering of the hot particles can cause increases in radionuclide availability with time (Kashparov et al. 2004). Consequently, there has been considerable efforts focussed on the behaviour of such particles in the environment, for instance weathering and leaching rates (Salbu et al in-press). However, to our knowledge there has been no consideration as to if, and how, radioactive particles should be incorporated into human foodchain models; this is being assessed within CONFIDENCE.

4. Conclusions and outlook

Research activities under CONFIDENCE started in January 2017 and will last three years. Radioecological studies focus on learning from past accidents and comparing process-based models with those using empirical concentration ratios to predict contamination in human foodstuffs. Activities will result in recommendations on the way forward in model improvements and models used for decision making.

CONFIDENCE is the first European project that addresses uncertainty handling and reduction in decision making in the area of emergency management and post-accident recovery. As the topic is extremely broad, CONFIDENCE will address many individual research points but will not investigate all these topics in depth. The consortium expects that at the end of the project, key uncertainties and ways to reduce these will be identified for the first time, but these will not necessarily be fully explored and addressed within CONFIDENCE.

In this respect, CONFIDENCE will identify those topics in uncertainty management that have to be considered in future research work. This has to be reflected in the strategic research agendas of all research platforms such as ALLIANCE, EURADOS, MELODI and NERIS. We believe that our approach that all research platforms in radiation protection are working together in the area of uncertainty handling and reduction is the way forward in dealing with key issues of interest in our community.

Acknowledgements

CONFIDENCE is funded by the European Atomic Energy Community Programme H2020 under grant agreement 662287. We would like to thank all other members of CONFIDENCE WP3 for their inputs to the proposal and our on-going work programme. Special thanks also go to Dr. Keiko Tagami (National Institute of Radiological Sciences, Japan) for helping to compile, translate and circulating the questionnaire to Japanese scientists.

References

Absalom, J.P., Young, S.D., Crout, N.M.J., Nisbet, A.F., Woodman, R.F.M., Smolders, E., Gillett, A.G., 1999, Predicting soil to plant transfer of radiocesium using soil characteristics. Environmental Science and Technology 33, 1218-1223.

Absalom, J.P., Young, S.D., Crout, N.M.J., Sanchez, A., Wright, S.M., Smolders, E., Nisbet, A.F., Gillett, A.G., 2001, Predicting the transfer of radiocaesium from organic soils to plants using soil characteristics. Journal of Environmental Radioactivity 52, 31-43.

Beresford, N.A., Wood, M.D., Vives i Batlle, J., Yankovich, T.L., Bradshaw, C., Willey, N. 2016a, Making the most of what we have: application of extrapolation approaches in radioecological wildlife transfer models. J. Environ. Radioact. 151, 373-386. http://dx.doi.org/10.1016/j.jenvrad.2015.03.022

Beresford, N.A., Fesenko, S., Konoplev, A., Smith, J.T., Skuterud, L., Voigt, G. 2016b, Thirty years after the Chernobyl accident: what lessons have we learnt? J. Environ. Radioact. 157, 77-89 http://dx.doi.org/10.1016/j.jenvrad.2016.02.003

Brown, J., Simmonds, J., 1995, FARMLAND. A dynamic model for the transfer of radionuclides through terrestrial foodstuffs. NRPB-R273. NRPB: Chilton.

Cox, G, Beresford, N.A., Alvarez, B., Oughton, D., Kis, Z., Eged, K., Thørring, H., Hunt, J., Wright, S., Barnett, C.L., Gil, J., Howard, B.J. & Crout, N.M.J., 2005, Identifying Optimal Agricultural Countermeasure Strategies for a Hypothetical contamination Scenario using the STRATEGY model. J. Environ. Radioact., 83, 383-397. http://dx.doi.org/10.1016/j.jenvrad.2004.05.021

Darrah, P.R., Staunton, S., 2000, A mathematical model of root uptake of cations incorporating root turnover, distribution within the plant, and recycling of absorbed species. European Journal of Soil Science 51, 643-653.

Ehrhardt, J., Weis, A., (eds.) 2000, RODOS: Decision Support System for Off-Site Nuclear Emergency Management in Europe, Final report of the RODOS project, European Commission, Brussels. Report EUR 19144, ISBN No. 92-828-9773-7, einschl. 2 CDs mit allen technischen Dokumenten des RODOS Systems

French, S., N. Argyris, H. Layton, J. Q. Smith, S. M. Haywood and M. Hort 2016, Presenting Uncertain Information in Radiological Emergencies. https://admlc.wordpress.com/publications/. UK Atmospheric Dispersion Modelling Liaison Committee.

Gering, F. 200,. Data assimilation methods for improving the prognoses of radionuclide deposition from radioecological models with measurements, Dissertation, Leopold-Franzen-Universität Innsbruck

Geldermann, J., Bertsch, V., Treitz, M., French, S., Papamichail, K.N, Hämäläinen, R.P., 2007, Multi-criteria decision support and evaluation of strategies for nuclear remediation management, Omega 37, 1, 238–251

Gillett, A.G., Crout, N.M.J., Absalom, J.P., Wright, S.M., Young, S.D., Howard, B.J., Barnett, C.L., McGrath, S.P., Beresford, N.A., Voigt, G., 2001, Temporal and spatial prediction of radiocaesium transfer to food products. Radiation and Environmental Biophysics 40, 227-235.

Howard, B.J., Beresford, N.A., Nisbet, A., Cox, G., Oughton, D.H., Hunt, J., Alvarez, B., Andersson, K.G., Liland, A. & Voigt, G., 2005. The STRATEGY project: decision tools to aid sustainable restoration and long-term management of contaminated agricultural ecosystems. J. Environ. Radioact., 83, 275-295. http://dx.doi.org/10.1016/j.jenvrad.2005.01.013

IAEA. 1994, Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments, Technical Reports Series No. 364, IAEA, Vienna

IAEA. 2010, Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Terrestrial and Freshwater Environment: Technical Reports Series No. 472. IAEA, Vienna. http://www-pub.iaea.org/MTCD/publications/PDF/trs472_web.pdf

Ievdin I., Trybushnyi D., Zheleznyak M., Raskob, W., 2010, RODOS re-engineering: aims and implementation details. In: Raskob W, Hugon M (eds) Enhancing nuclear and radiological emergency management and rehabilitation: Key results of the EURANOS European project. Radioprotection 45 (5 Supplément): S181-S189

Kashparov, V.A., Ahamdach, N., Zvarich, S.I., Yoschenko, V.I., Maloshtan, I.M., Dewiere, L., 2004, Kinetics of dissolution of Chernobyl fuel particles in soil in natural conditions, In Journal of Environmental Radioactivity, Volume 72, Issue 3, 2004, Pages 335-353, ISSN 0265-931X, https://doi.org/10.1016/j.jenvrad.2003.08.002.
(http://www.sciencedirect.com/science/article/pii/S0265931X03002340)

Lofts, S., & Tipping, E., 2011. Assessing WHAM/Model VII against field measurements of free metal ion concentrations: model performance and the role of uncertainty in parameters and inputs. Environ. Chem. 2011, 8, 501–516

Müller, H., & Gering, F., 2003. Documentation of the Terrestrial Food Chain and Dose Module FDMT in RODOS PV6.0. RODOS report RODOS(RA3)-TN(03)06, available via https://resy5.iket.kit.edu/RODOS/Documents/Public/HandbookV6/Volume3/FDM_Terra.pdf

Müller H., Pröhl G., 1993. ECOSYS-87: A Dynamic Model for Assessing Radiological Consequences of Nuclear Accidents. Health Physics 64(3), 232-252

Nisbet, A., Howard, B.J., Beresford, N.A., Voigt, G., 2005 Workshop to extend the involvement of stakeholders in decisions on restoration management. J. Environ. Radioact., 83, 259-261. http://dx.doi.org/10.1016/j.jenvrad.2005.01.012

Nisbet, A.F., Brown, J., Howard, B.J., Beresford, N.A., Ollagnon, H., Turcanu., C., Camps, J., Andersson, K., Rantavaara, A., Ikäheimonen, T., Duranova, T., Oughton, D., Kirchner, G., Papachristodoulou, C., Ioannides, K., Kwakman, P., 2010, Decision aiding handbooks for managing contaminated food production systems, drinking water and inhabited areas in Europe. Radioprotection., 45, S23-S37. http://dx.doi.org/10.1051/radiopro/2010014

Nordén, M., Avila, R., Gonze, M.A., and Tamponnet, C., 2005, Bioavailability in the BORIS assessment model, Radioprotection, Suppl. 1, vol. 40, S107-S111

Papamichail, K.N, French, S., 2005, Design and evaluation of an intelligent decision support system for nuclear emergencies, Decision Support Systems 41 (1), 84-111

Raskob, W., Gering, F., Bertsch, V., 2009, Approaches to visualisation of uncertainties to decision makers in an operational Decision Support System, in: Proceedings of the 6th International Conference on Information Systems for Crisis Response and Management, Gothenburg.

Raskob, W., Gering, F., Lochard, J, Nisbet, A., Starostova, V., Tomic, B., 2010, Overview and main achievements of the EURANOS project, In: Raskob, W., Hugon, M. (eds.): Enhancing nuclear and radiological emergency management and rehabilitation: Key results of the EURANOS European project, Radioprotection, Volume 45, Supplément 2010, 9-22

Brit Salbu, Valery Kashparov, Ole Christian Lind, Rafael Garcia-Tenorio, Mathew P. Johansen, David P. Child, Per Roos, Carlos Sancho, (in-press) Challenges associated with the behaviour of radioactive particles in the environment, In Journal of Environmental Radioactivity, ISSN 0265-931X, https://doi.org/10.1016/j.jenvrad.2017.09.001.
(http://www.sciencedirect.com/science/article/pii/S0265931X17303557)

Smith, J., Beresford, N.A., 2005, Chernobyl Catastrophe and Consequences. Chichester: Praxis Publishing/Springer.

Tarsitano, D., Young, S., Crout, N., 2011, Evaluating and reducing a model of radiocaesium soil-plant uptake. Journal of environmental radioactivity 102, 262-269.

Tipping, E., Woof, C., Kelly, M., Bradshaw K. & Rowe J.E., 1995, Solid-Solution Distributions of Radionuclides in Acid Soils: Application of the WHAM Chemical Speciation Model. Environ. Sci. Technol., 29, 1365-1372

Uematsu, S., Smolders, E., Sweeck, L., Wannijn, J., Van Hees, M., Vandenhove, H., 2015, Predicting radiocaesium sorption characteristics with soil chemical properties for Japanese soils. Science of the Total Environment 524, 148-156.

Uematsu, S., Vandenhove, H., Sweeck, L., Van Hees, M., Wannijn, J., Smolders, E., 2016, Variability of the soil-to-plant radiocaesium transfer factor for Japanese soils predicted with soil and plant properties. Journal of environmental radioactivity 153, 51-60.

Van Der Perk, M., Burema, J., Burrough, P.A., Gillett, A., Meer, M.V.D., 2001, A GIS-based environmental decision support system to assess the transfer of long-lived radiocaesium through food chains in areas contaminated by the Chernobyl accident. International Journal of Geographical Information Science 15, 43-64.

Wright, S.M., Smith, J.T., Beresford N.A. & Scott, W.A. 2003, Monte-Carlo prediction of changes in areas of west Cumbria requiring restrictions on sheep following the Chernobyl accident. Radiation and Environmental Biophysics 42, 41-47. http://dx.doi.org/10.1007/s00411-003-0187-6