Background

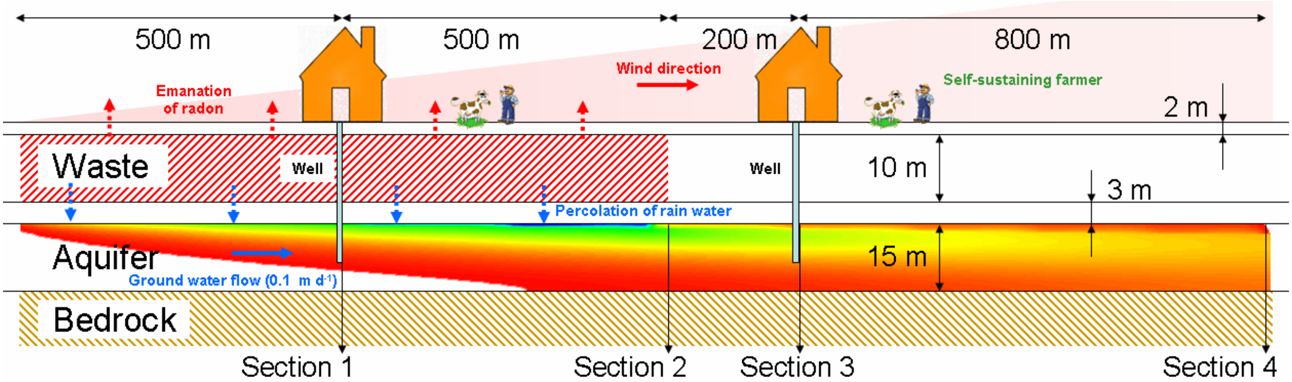
Remediation of sites contaminated by Naturally Occurring Radioactive Materials (NORM) is a current issue in many countries world wide. These materials could arise from many types of industries such as mining and milling of uranium, thorium and other metals, phosphate industry, coal mining and combustion, oil and gas industry, abandoned radium and thorium extraction facilities. Waste products originating from these industries need to be managed in a proper way. In recent years, new radiation protection legislation, growing awareness of radiation risks at some sites and public perception have created the necessity to develop remediation strategies for those sites. These strategies can be based on the exploration of hypothetical scenarios, where different exposure pathways are screened.

Objectives

SCK•CEN has been involved in an international comparison exercise under the IAEA EMRAS programme where the radiological impact of a hypothetical NORM waste dump site and the effect of corrective actions had to be assessed. The outcome of different radiological assessment models was compared. The waste dump (surface 1 km^2, 10 m deep, containing 1 Bq g^{-1} of ^{238}U in secular equilibrium with her daughters) is located above an aquifer which can be contaminated by the waste due to percolation of rain water. The waste dump is either uncovered or covered by a 2 m thick layer, with an erosion rate of 0.1 mm y^{-1} and an effective porosity of 0.2. The dose, resulting from living on top and at 200 m distance from the border of the waste dump was to be calculated.

Principal results

The SCK•CEN model DosDiM was used to assess the dispersion of the radionuclides in the biosphere and the resulting doses. The contaminant concentration in the aquifer was calculated by using the water and solute transport models HYDRUS 1D and 2D (see illustration). The highest concentration of ^{238}U was found at the border of the waste dump (*i.e.* Section 2) due to migration of contaminants from the waste following percolation with rainwater and taking into account ground water flow. From this point onwards, radionuclides

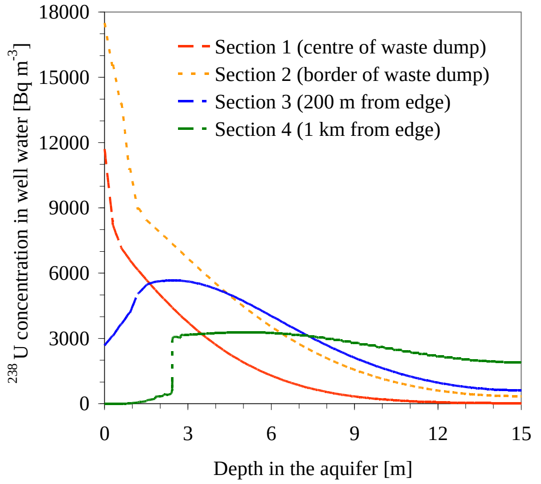


Graphical illustration of the conceptual model combined with an output file from HYDRUS 2D which determines the concentration of ^{238}U in the aquifer after 10000 year. Lowest concentrations in the aquifer are coloured red [150 Bq m^{-3}], highest concentrations are coloured blue [18000 Bq m^{-3}]

are being diluted. Dispersion of airborne contaminants (radon, dust) is calculated by using a multi source Gaussian dispersion model. External irradiation, inhalation from dust and radon, ingestion of contaminated drinking water (well) and consumption of contaminated food (self-sustaining farmer; food contamination by irrigation and watering of cattle) were the pathways considered.

Living on and consuming products from the uncovered waste area (Section 1) give without any doubt the highest dose. The total dose (12 mSv y^{-1}) remains unchanged with time. Inhalation is the most contributing pathway (61 % of which 56 % is due to radon inhalation). Ingestion of contaminated food accounts for 20 % of the total dose. Because no cover is applied, the external irradiation contributes to 19 % of the total dose.

Living outside the uncovered waste area (Section 3), reduces the doses considerably. Maximal dose observed after 10000 years is only 3.3 % of the maximal dose calculated for residence on the waste area. It comprises 0.2 mSv y^{-1} during the first 1000 years, from which 38 % is due to radon and 62 % due to dust inhalation. After 1000 years the well starts to be contaminated, resulting in an increase of the ingestion dose. The contribution of ingestion comprises 0.084 mSv y^{-1} (30%) of the total dose after 5000 years but reaches values up to 0.182 mSv y^{-1} (48%) after 10000 years. The influence of external irradiation is negligible in comparison to the other pathways.



^{238}U concentration in the well water [Bq m^{-3}] after 10000 years depending on the depth in the aquifer [m] and the section

For residents living on or in the vicinity of covered waste the total dose is a factor 100 lower than for the corresponding scenario with uncovered waste (Section 1 and 3). Notwithstanding the fact that the waste is covered, radon can emanate through this layer. During the first 100 years the inhalation pathway is responsible for all the annual dose contribution for residents living on the waste area (0.13 mSv y^{-1}) as well as those living outside the waste area (1.5 10^{-3} mSv y^{-1}). The inhalation dose increases progressively due to erosion of the cover. After 5000 years the ingestion pathway also starts to be important. For residents living on the waste, 22 % of the total dose is due to ingestion (mostly drinking water), whereas the total contribution for residents living outside the waste area is mainly due to ingestion. Food contamination is not direct because the waste is covered, but only indirect via irrigation with contaminated well water (adhesion and uptake from soil which becomes contaminated over time). Due to the application of a cover the exposure to external irradiation is negligible.

	Uncovered waste							
years after construction	*On the waste area*				*At 200 m from the edge of waste area*			
	Inhalation	Ingestion	External irradiation	Total dose [mSv y^{-1}]	Inhalation	Ingestion	External irradiation	Total dose [mSv y^{-1}]
1 - 1000	61%	20%	19%	12.0	100%	–	–	0.20
5000	61%	20%	19%	12.0	70%	30%	–	0.28
10000	61%	20%	19%	12.0	52%	48%	–	0.38
	Covered waste							
years after construction	*On the waste area*				*At 200 m from the edge of waste area*			
	Inhalation	Ingestion	External irradiation	Total dose [mSv y^{-1}]	Inhalation	Ingestion	External irradiation	Total dose [mSv y^{-1}]
1 - 100	100%	–	–	0.13	100%	–	–	1.5 10^{-03}
1000	>99.9%	<0.1%	–	0.14	>99.9%	<0.1%	–	1.6 10^{-03}
5000	78%	22%	–	0.23	2%	98%	–	0.09
10000	78%	22%	–	0.32	2%	98%	–	0.18

Overview of the relative contribution of inhalation, ingestion and external irradiation toward the total dose of residents living on and near the waste area in the uncovered and covered waste scenario for different time periods after the construction of the waste area

Both scenarios clearly illustrated the importance of the leaching process, the ground water pathway, and the beneficial effect of applying a cover when dealing with near-surface disposal of waste. A cover reduces the effect of radon emanation and eliminates the effect of resuspended contaminated dust. The NORM working group concluded that the scenario was complex and many choices, in terms of specification and choice of input data, had to be made. The exercise showed it is not always possible to specify a scenario without going through an iterative testing and modification process. Furthermore good communication between modellers is essential, to ensure that the same site specifications and environmental parameters are used.

Future developments

Though the general agreement between the different models was good, the DosDiM model will be further adjusted and improved by detailed benchmarking with other models. The availability or assembly of data sets from real sites is an important asset for further model testing and validation. Efforts will also be directed to the application of probabilistic calculations together with rigorous methods of estimating uncertainties in model predictions.

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Main reference

Environmental Modelling for Radiation Safety – Final report of the EMRAS Working Group on modelling of naturally occurring radioactive materials (NORM) releases and of the remediation benefits for sites contaminated by extractive industries, IAEA- TECDOC-… (2008). In preparation.