Environmental modelling of NORM

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INTRODUCTION

Many currently available environmental assessment models have the capability to predict the transport and behaviour of individual radionuclides as a single contaminant. When dealing with NORM, due to the radionuclide decay schemes present, a wider variety of radiological and chemical behaviour needs to be accommodated within modelling packages. The aim of this work, which is part of the Environmental Modelling for Radiation Safety (EMRAS) program set up by the International Atomic Energy Agency, is to enhance capability for assessing the environmental impact of NORM residues and wastes (and legacy sites) by developing scenarios for testing models, evaluating existing models, and developing new models where possible. Details of the program, together with working group reports and meeting reports can be found on the Internet.

MATERIALS AND METHODS

Hypothetical scenarios

Three hypothetical scenarios have been developed, for a point source, an area source and an area source plus a river. These scenarios assume ideal conditions, including simple geometry, homogeneity of the NORM residue (or a uniform discharge rate), and uniform groundwater flow. Application of models to these scenarios has helped to improve the scenario specifications and allowed comparison of the results from different models.

Point source scenario

This scenario is relatively simple, with a single stack 100 m in height, discharging radon-222, lead-210 and polonium-210 at a specified rate. Wind-rose, atmospheric stability, and other environmental data are specified. Modellers were asked to calculate the annual doses to occupants of two houses at given locations and with given land use, occupancy and dietary data.

Area source scenario

The source in this case is a waste pile 1 km square, and 10 m thick, with a cover layer of 2 m of clean soil. The waste is underlain by a 3 m thick layer consisting of 80% sand and 20% clay, immediately above a 15 m thick aquifer. The direction and speed of groundwater flow in the aquifer are specified, together with other relevant environmental data. Modellers are asked to estimate the annual doses to the occupants of three houses, one above the waste and two others at different distances from the waste in the direction of groundwater flow. Occupancy, dietary and water usage (drinking, irrigation) data are also given.

Area source + river scenario

The source in this scenario is the same as for the area source, but a river 300 m from the down-gradient edge (with respect to groundwater flow) of the waste is included. Most of the data for this scenario are the same as the data for the area source scenario. River flow parameters and the positions of houses at different distances downstream from the waste are specified, and modellers are asked to estimate the annual doses to occupants of these houses.

Real Scenarios

Development of real scenarios has proved difficult because of a lack of comprehensive data sets. However, four real scenarios have been examined, and are briefly described below.

Camden

This is a legacy site where a thorium processing facility and a gas mantle production facility were operated (USEPA, 1999). It is characterised by a highly heterogeneous distribution of contaminated material in a built up urban area near a large river. The available data indicate that there has been very little groundwater contamination even though there are several small creeks or streams in the area. This scenario has not been tested by the members of the working group.

Lignite power station

This site consists of two power stations, situated close together, with a total of 5 stacks with a city approximately 5 km to the south east. Values of radium-226 concentrations in dust and on the ground surface have been measured, and meteorological (wind rose) data are also available.

Phosphogypsum disposal – site 1

This site is a series of connected deposition areas under a lake, very close to the coastline. A series of monitoring wells is used to collect data on ^{226}Ra concentrations in surface water and groundwater. The results of measurements of groundwater flow are also available.

Phosphogypsum disposal – site 2

This site is a single large phosphogypsum stack which sits on top of a deep layer of clay. A concrete wall has been built surrounding the stack and inserted into the clay bed to retain the flow of contaminants leached into the groundwater. Leachate is extracted from a series of wells around the stack and pumped back to the top of the stack. A series of monitoring wells is used to measure radionuclide concentrations in the groundwater outside the stack wall.

RESULTS AND CONCLUSIONS

The hypothetical scenarios were tested by members of the working group. The results will be available in the working group final report (EMRAS: NORM, 2008). The models used in this work are summarised in Table 1). Other models or modelling packages (for example AMBER, FRAME) were described in the main report but not actually used by members of the working group for detailed testing of scenarios.

Table 1: The models used in this work, their type, and situations to which they were applied.

Model	Type	Usage
CROM (Robles et al., 2007)	Compliance	Point-source scenarios
COMPLY (USEPA, 1989)	Compliance	Point-source scenarios
CAP-88 (USEPA, 1992)		
PC-CREAM (Mayall *et al*., 1997)	Detailed	Point source scenarios
RESRAD v6. (Yu et al, 2001)	Detailed	Area source scenarios
RESRAD-OFFSITE (Yu *et al.*, 2007)	Detailed	Area source scenarios Area source + river
DOSDIM + HYDRUS (Zeevaert, 2005)	Detailed	Area source scenarios
PRESTO v4.2 (USEPA, 2007)	Simple	Area source scenarios

Both simple and complex models were used for testing the point source hypothetical scenario. In general, the radionuclide concentrations predicted by the simpler models were higher than those predicted by the complex model, PC-CREAM that was used for testing the scenario.

Four models were used for testing the area source scenario. RESRAD-OFFSITE and DOSDIM + HYDRUS use different approaches for modelling groundwater flow and contaminant transport, but the predictions of both models were similar. The RESRAD-OFFSITE model was 'calibrated' by estimating the natural background dose level. Although RESRAD v6 and PRESTO are designed for on-site calculations, the results indicated that PRESTO is not particularly appropriate for this type of detailed calculation.

RESRAD-OFFSITE was also used for testing the hypothetical area source + river scenario. Until predictions from other models are available, definitive conclusions cannot be drawn.

The lignite power station scenario was tested using PC-CREAM and CROM. Although the available meteorological data were not in a suitable form for use with PC-CREAM, and other assumptions had to be made to apply the model, the model predictions were in reasonable agreement with the measurement results.

Preliminary results of testing of the phosphogypsum disposal site no. 1 scenario have been published (Pérez Sánchez *et al*., 2007).

It is clear from this work that the ideal conditions specified in the area source and area source plus river scenarios, in particular simple geometry, source homogeneity, and uniformity of groundwater flow, do not apply to real situations. As most of the models used in this work are based on these simplifying assumptions, the interpretation of model predictions for the real scenarios can be much more complicated than for the hypothetical scenarios.

There are two obvious ways in which this work can be extended. The first is to examine other hypothetical scenarios and look at models that might be appropriate for these extra cases. One possibility would be a tailings dam scenario. The models used so far would not handle this scenario, so other models would need to be developed and/or tested.

It is also important to encourage the acquisition of good data sets (real scenarios) for testing models. Using hypothetical scenarios allows intercomparison of predictions from different models, but does not enable models to be validated. Validation requires comparison of model predictions with real data.

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