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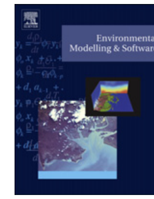

Improving evaluation criteria for monitoring networks of weak radioactive plumes after nuclear emergencies

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ABSTRACT

Networks of monitoring stations have been set up in many European countries to detect the passage of a radioactive cloud in the event of a large-scale nuclear emergency. The layout and spatial density of these networks differs according to the needs and criteria defined by national authorities. Germany and the Netherlands decided to set up relatively dense networks for the detection of weak radioactive plumes and, additionally, environmental radioactivity from deposited aerosols. Plausible evaluation criteria are presented here to assess important properties which determine the reliability and efficiency of sections of these networks. As a test case the existing sampling design of the Dutch and German networks with 193 sensors in an area of 200 km around the nuclear power plant near the city of Lingen (Emsland) in the German federal state of Lower Saxony has been selected. For a hypothetical accident scenario 292 radioactive plumes have been simulated which are shaped by recorded weather conditions of the year 2007. To quantify the network performance frequency distributions of the proposed evaluation parameters have been analyzed. Simulation results show that 95% of the plumes are detected within 4 h after the release. Maximal values of the γ-dose rate 1 m above the ground mostly occur near the source within a radius of 5 km. However, under certain weather conditions maximal ground values may also be found more than 50 km away from the source. Within a circle of radius 90 km 98% of the recorded maximal γ-dose rates of the plumes were found by 62% of the 193 sensors. But only in a joint network of German and Dutch sensors all simulated plumes triggered an alarm. This result encourages efforts of close international collaboration, e.g. between EU member states, in network design and operation. Test series which involved the removal of sensors either randomly or in a controlled way showed that the network configuration is fit for the intended purpose of detecting a large majority of plumes. But already a small reduction in the number of sensors would degrade the performance. Whereas the joint network triggers alarms reliably, it fails to detect the true plume maxima. The assessment criteria can be used for a revision of existing networks or for planning purposes in countries such as those applying for EU membership.

1. Introduction

Monitoring networks have been set up in many European countries to measure the γ-dose rates from aerosols and gases which are released into the environment after large-scale nuclear emergencies. The recorded data is used for different purposes such as early warning (Sombré and Lambotte, 2004), implementation of countermeasures (Genkel and Schnadt, 2010; Hopmeier et al., 2010) and mapping the extent of the release (Pebesma et al., 2011). After an accidental release the reliable detection of the radioactive plume and of the environmental radioactivity from deposited aerosols has the highest priority and is in the focus of this study.

The maintenance of networks with active radiation sensors consumes considerable financial resources, but is still justified by past events such as accidents at the facilities of Three Miles Island (U.S.A., 1979), Chernobyl (Ukraine, 1986) and Fukushima (Japan,

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2011). Often geographical, technical and budgetary restrictions impose limits to the size and technical capabilities of such networks. In the European Union (EU) the number of monitoring sensors varies between member states according to different monitoring goals which have been established in each country. Efforts to harmonize national networks are guided by a legal framework which is derived from Art. 35 and Art. 36 of the EURATOM Treaty (Engelbrecht and Schweighöfer, 2008). To serve the need for a cross-national representation of the radiological situation, the EURDEP system (de Cort et al., 1997) has been set up for the exchange of national monitoring data with a delay of some hours but a real-time connection of national networks is still not in place.

Within the EU research project of the 7th framework programme "Design of optimized systems for monitoring of radiation and radioactivity in case of a nuclear or radiological emergency in Europe" (acronym: DETECT) a web-based optimization tool is under development. The tool will provide guidance on the assessment of existing networks in EU member states and on network planning in EU candidate countries. Guidance is based on a number of performance criteria which have been obtained through a consultation process with national network operating bodies as stakeholders. Some of these criteria have been expressed in mathematical terms as assessment parameters which characterize the efficiency and reliability of a monitoring network. They have been applied here methodologically to a section of the existing networks in Germany and the Netherlands.

The design of these networks was conceived in the late 1980's and they have already been subject to major revisions (Doberkat et al., 2000). At the inception a rigorous performance appraisal was not possible due to limited computer capacity. This study partly makes up for the omission by testing the networks with a large number of simulated radioactive plumes for a typical accident scenario.

Within the DETECT project, optimizations of existing and planned networks have been carried out for Norway and the Balkans (Helle et al., 2011). For Norway both number and location of stations, that should be placed on its borders to detect plumes entering the country, have been calculated. For the Balkans it became clear that an integrated network stretched over several countries can be operated more efficiently than separate country-specific networks.

For monitoring networks of ambient radioactivity Melles et al. (2011) used the error variance from geo-statistical interpolation and the detection capability as two optimization criteria for a combined area of the Netherlands and two neighboring federal states of Germany which is similar to the present study area. They considered small and large accidents from a number of nuclear power plants (NPP's) inside and outside the study area and added malevolent attacks with radioactive explosive devices in major cities. Their optimal design pattern shows clusters of sensors around NPP's and in densely populated areas.

For France Abida and Bocquet (2009) showed that mobile sensors deployed along plume contours can significantly improve the performance of fixed sensors with respect to the estimation of radioactive contamination and the source term for a domain of 50 km around the Bugey NPP. A comprehensive optimization study for an automatic monitoring network of radioactive aerosols over France was carried out by Abida et al. (2008). They used mapping capability as the sole objective and considered 7300 accidents, 507 potential sensor locations and 3 nuclides. Plumes were followed up 10 days with a resolution of 1 h. The intention was to cover a large range of accident scenarios with a relatively coarse spatial resolution of some 40 km. The optimal design pattern was controlled by a single parameter in the cost function, concerning a trade-off between an adequate representation of either the near field or the far field around the accident. For sensor clusters around NPP's the near field was described well whereas a uniform distribution over France provided a satisfactory interpolation of the far field.

Optimization studies such as those reviewed above must be based on realistic evaluation criteria which facilitate a comparison of results. The goal of the present work is to develop such criteria of sensible performance and to demonstrate their usefulness with a case scenario for a hypothetical accident in a German NPP. Furthermore, the characterization of plumes which proved difficult to detect might be of potential interest for operators of existing networks.

2. Material and methods

2.1. Study area and monitoring network

The study area has a size of 200 km × 200 km and is centered on the Lingen NPP with a pressurized water reactor (PWR) in the Emsland region of the German federal state of Lower Saxony. Two thirds of the model domain belong to federal states Lower Saxony and North Rhine-Westphalia, one third lies in the Netherlands. Both German and Dutch monitoring networks are actively measuring radioactivity levels with in total 193 stations, of which 146 are run by the German Federal Office of Radiation Protection (BfS) (Bleher and Stölker, 2003) and 47 are run by the Dutch National Institute for Public Health and the Environment (RIVM) (Twenhöfel et al., 2005). Additionally, the federal state of Lower Saxony runs 20 monitoring stations in a separate network. The three monitoring networks are shown in Fig. 1, but only the networks of BfS and RIVM are considered here in detail.

A network of monitoring stations is called sampling design S. It usually consists of γ-dose rate detectors at 1 m height above ground which are permanently located in public areas. Depending on the country, the density of the sampling design varies significantly. In particular, Germany and the Netherlands maintain a high density compared to other EU countries. The German network is so constructed that a sensor is located in each square cell of length 12–14 km, leading to a density of 1 sensor per 150–200 km^2. Within each cell the location of the sensor has been chosen according to availability and suitability. Large lawns, which have little seasonal influence on the detector readings, have been chosen as preferred sites. Forests have been avoided because they lead to distorted signals due to high leaf area indices. The Dutch network has been set up with similar preferences.

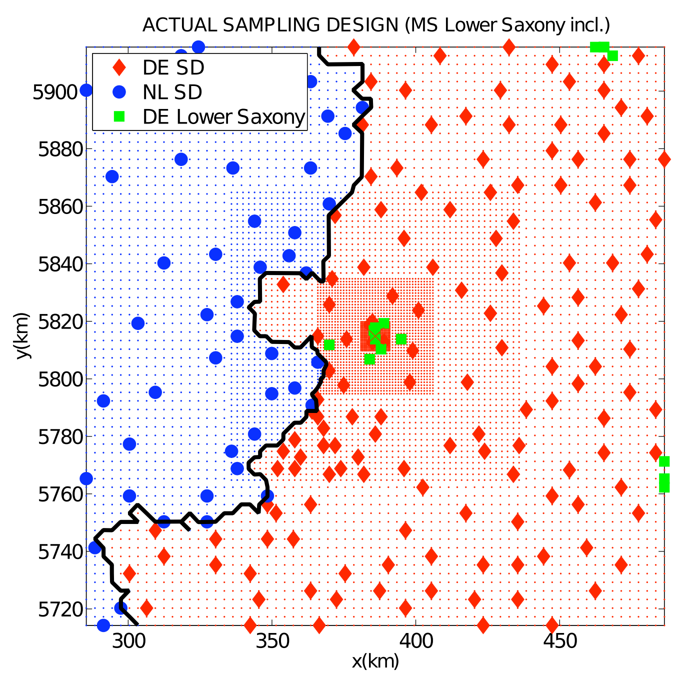

Fig. 1. Actual sampling designs of Germany run by federal authority BfS (146 diamonds), of the Netherlands run by national authority RIVM (47 circles) and of the German federal state of Lower Saxony (20 squares). The continuous thick line denotes the Dutch–German border.