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Risks Due to Severe Accidents of Nuclear Power Plants in Europe – the Methodology of RISKMAP - Possible Extensions

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Abstract

The present study evaluates the geographical distribution of risks due to severe accidents of commercial nuclear power plants in Europe. The indicator for risk defined in RISKMAP is based on the deposition of the long-lived radionuclide Cs-137. RISKMAP is based on simulations assuming repeated severe accidents with large releases of radionuclides in every nuclear power plant in Europe which are dispersed and deposited over Europe according to historical weather conditions.

Favorable for the RISKMAP methodolgy is its modular design which allows scenario calculations and sensitivity analysis for the most sensitive assumptions and parameters. Possible extensions of the present RISKMAP approach including health and economic consequences are discussed

Subject key words: *severe accidents, nuclear risk, riskmap, source term, atmospheric dispersion, contamination, insurance policy, liability.*

1 Introduction

The transboundary character of risk due to severe nuclear accidents in Europe became visible by the accident in Chernobyl. Moreover, this accident has shown that the geographical distribution of contamination patterns after a severe accident is stochastic in the sense that it is the result of a coincidental combination of radioactive emissions and prevailing weather conditions. Nevertheless due to climatological features, such as wind distribution and precipitation patterns certain contamination patterns in Europe are more likely than others. The complex Cs-137 ground contamination distribution in Europe after the Chernobyl accident was evaluated by De Cort et al. (1996).

The present study has developed a methodology to map the risk due to severe accidents of nuclear power plants (NPPs) in Europe. Basis for the RISKMAP model are simulations assuming repeated severe accidents with large radionuclide releases in every NPP in Europe which were dispersed and deposited over Europe according to historical weather conditions.

RISKMAP could be used as risk management tool to identify NPPs which pose the highest risk to a specific region. The risk reduction of safety upgrading programs for specific NPPs or phase-outs could be evaluated. A second field of application for RISKMAP could be the support of a new discussion of international treaties on liability in the case of nuclear accidents by defining risk “exporters” and risk “importers” on a European level. International liability agreements, such as the Vienna and Paris conventions, set limits on the repair payments to be made by the operators of NPPs to countries adversely affected by nuclear fall-out independently of the actual risk caused or incurred by the individual countries.

The Evaluation of geographical aspects of environmental and technical risk by riskmaping has gained an increasing attention (Risk 1997). Regarding specifically risks due to severe NPP accidents Sinyak (1995) used empirical factors to describe the influences of geography resulting in normalized damage factors for the main cities of Europe. A map of risk of excess cancer deaths due to nuclear accidents was calculated by Slaper, Blaauboer and Eggink (1994). The applicability of the dispersion model used in their approach is restricted, especially in mountainous, high precipitation areas. An alternative statistical description for estimating the risk associated with a large accidental release of hazardous material at long range was developed by Smith (1998).

All parameters relevant to describe NPP accidents with large scale releases contain high uncertainties. Any useful tool must be flexible enough to calculate a large number of scenarios to define upper and lower bounds of risks and robust features of the geographical distribution of risk. Favorable for the RISKMAP methodolgy is its modular design which allows scenario calculations and sensitivity analysis for the most sensitive parameters without undue demand on computer resources.

2 Methodology

The risk posed by severe accidents in nuclear power plants is determined by the damage caused and the likelihood of occurrence. RISKMAP defines the frequency of exceedance of a chosen contamination threshold as indicator of risk.

Basically the present definition of risk indicators in the RISKMAP approach is restricted to long term and long distance effects by taking the most relevant nuclide, Cs-137, into account and excluding the close vicinity of the NPP. More comprehensive summaries of the methodology of RISKMAP can be found in contributions of Andreev et al. (1997; 1998).

Damage Indicators

At the present status of the study it was impossible to cover the wide range of direct and indirect consequences on health, environmental degradation, economic loss. The severity of these consequences is strongly influenced by mitigating measures and their timing. The damage indicator is defined in accordance with the accident management strategies at the Chernobyl accident (IAEA 1991) regarding a specific level of Cs-137 ground contamination necessitating measures for the improvement of the living conditions (185 kBq m^{-2}).

Source Terms and Release Parameters

The accidents of interest are severe accidents leading to large releases (with release fractions in the range of 40% of the Cs-137 inventory). The Cs-137 source terms and release parameters chosen were taken from different source term studies, such as Sdouz et al. (1993).

Frequencies of Severe Accidents

Results for frequencies of severe accidents with large off-site releases from different risk and safety studies have high uncertainties. Therefore different scenarios for the frequency of severe accidents were considered in the present study. One possible scenario evaluated attributes uniform frequencies to each reactor type (Sdouz et al. 1993; GRS 1989; Höhn et al. 1996). As second scenario the IAEA safety target for existing NPPs (IAEA 1988) was considered. The safety target requires that the frequency of large off-site releases should be below 10^{-5} reactor $year^{-1}$. The results have shown that the postulated release frequencies in different scenarios strongly influence the results.

Dispersion Simulation

The simulation of transport and deposition of the released Cs-137 allows to establish a causal relationship between the specific NPP accident and the ground contamination in a specific region in Europe. Transport and diffusion in the atmosphere are calculated with the Lagrangian particle model FLEXPART (Stohl et al. 1998) on the basis of analyzed fields from the European Center for Medium-Range Weather Forecasting (ECMWF) with some adaptations. The model domain covers Europe and the eastern Atlantic. The total period for simulations encompasses the year 1995, which was the most representative year of the period 1977-1996. Release intervals were chosen to assure sampling of all seasons and times of day.

Indicator for Risk

The indicator for the risk, the frequency of exceedance of the Cs-137 contamination threshold, has two contributors: the frequency of a severe accident in the specific reactor, and the percentage of the meteorological situations which lead to a sufficiently high deposition. This indicator for risk is calculated for all grid elements of a European grid. Finally, maps are plotted and evaluations by country are made by the use of a GIS software package.

3 Results

The geographical distribution of NPPs in Europe is very inhomogeneous. The density of NPPs is highest in western Europe.

The geographical distribution of the overall risk caused by these NPPs is strongly influenced by the assumptions made regarding the frequency of severe accidents with large radiological releases attributed to the individual NPPs. Nevertheless some scenario independent results could be derived. Some areas in Europe are generally favored because of their geography. It also turned out that by far more European countries are net importers than net exporters of risk.

Based on the geographical distribution of risk due to NPP accidents further evaluations and possible ways of presentation of the results could be found. Figures 1 and 2 show examples how the results can be presented.

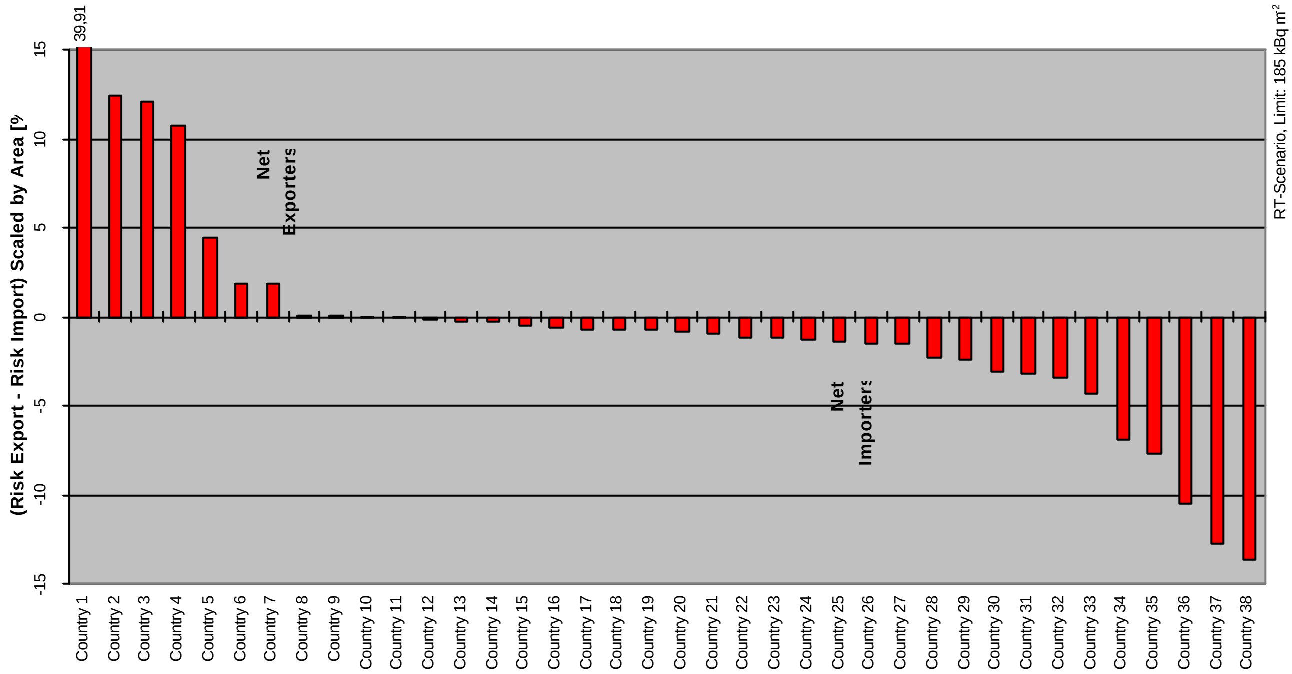

Figure 1: Presents net exporters and net importers of risk due to severe accidents in European NPPs

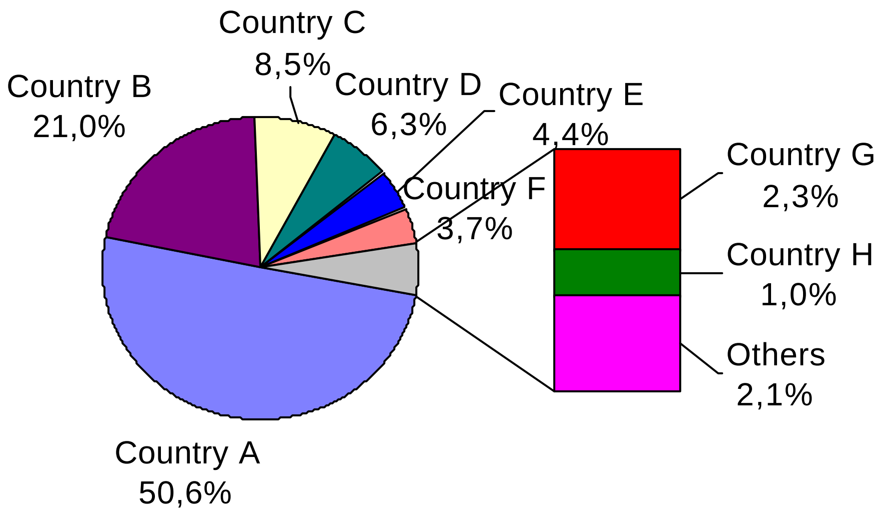

Figure 2: Shows the contributors (countries A, B, C, etc.) to the overall risk for a specific country.

4 Discussion and Outlook

The present results and sensitivity analysis of the parameters such as source terms, release parameters and release frequencies on which the results are based on show a very high dependency on the frequencies of accidental release attributed to the individual NPPs or NPP types. In this context the modular structure of RISKMAP, allowing for scenario calculations where uncertainties are especially high without undue demand on computer resources, turned out as one of the advantages of this approach.

Several options to reduce the uncertainty and limitations of RISKMAP are in discussion. Expert judgement, a methodology to handle uncertainties in risk assessment (Meyer et al. 1997), by inviting international experts could help to gain a higher acceptance for release frequencies for severe accidents in specific NPPs. Possible extension of the damage and risk indicators defined in RISKMAP could include:

- weighting by population density
- short time and short distance effects and other radionuclides (such as I-131, noble gases). Short time effects in the vicinity of the NPP could contribute considerably to the transboundary risk for NPPs sited close to the borderline such as Cattenom.
- health consequences taking into account different exposure pathways and countermeasures.
- material damages (such as infrastructure) and environmental consequences. For an assessment of these damages information about land-use, kind of settlements and economics in the specific regions are necessary.
- economical aspects of damage, such as costs of different countermeasures (evacuation, resettlement, foodbans, decontamination), medical costs (Rennings 1997).

For the presentation of the RISKMAP methodology and results a hypertext-based documentation was developed. Making the RISKMAP available in an interactive version on the internet could be the basis for the use of RISKMAP as a Risk Management Tool.

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