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A probabilistic risk assessment for accidental releases from nuclear power plants in Europe

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Abstract

The 1986 accident with the nuclear power plant in Chernobyl has shown that severe accidents with a nuclear power plant can lead to a large scale contamination of Europe. At present, over 200 nuclear power reactors for commercial electricity production are operational in Europe. An integrated assessment of probabilistic cancer mortality risks due to possible accidental releases from the European nuclear power plants is provided. Location specific risks are presented in maps of Europe. The excess mortality risk due to the combined operation of the European nuclear power plants is estimated to be about 10×10^{-8} per year in western Europe. Going East the risks increase gradually to over 1000×10^{-8} per year in regions of the former Soviet Union, where reactors of the Chernobyl type are located. The nuclear power plants in eastern Europe dominate the estimated risk pattern and contribute at least 40–50% to the average risk in western Europe.

Keywords: Nuclear power plants; Nuclear accidents; Risk assessment; Probabilistic risks

1. Introduction

The safety of nuclear power plants is an important issue in the discussion regarding future scenarios for power generation. Risks are related to regular emissions of radionuclides, the disposal of radioactive waste and possible accidental releases. Risks related to regular releases and waste disposal have been addressed elsewhere [1]. Estimates of risks related to large scale accidents with the reactor core are performed on a local scale by means of probability safety analyses. The accident with the nuclear power plant in

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Chernobyl in 1986 has shown that large scale accidents with nuclear power plants can lead to the contamination of an entire continent. This study is aimed at an integrated risk assessment for possible large scale accidental releases to air from nuclear power plants in Europe. We developed and applied a method which provides a probabilistic evaluation of the chain: sources–dispersion–exposure–risk (see Refs. [2–4] for details). The results of the evaluation are risk maps, providing an estimated location dependent probabilistic death-risk due to accidents with nuclear power plants. The risk maps do in no way reflect the situation following a specific accident. They provide a probabilistic view of the risks involved, and the major areas at risk.

2. Evaluation of the source–effect chain

The estimation of possible accidental releases requires an evaluation of accident probabilities and subsequent release scenarios for all nuclear power plants. Accidents can lead to large scale environmental emissions if in addition to severe damage to the reactor core a failure of the security systems occurs. Such accident scenarios are related to the construction and maintenance of the plant and its safety systems, in relation to the seismic activity in the area, the materials used, and the operational and safety procedures applied. Furthermore, societal instabilities could lead to an increase in accident risks, when accompanied by negligence of maintenance and safety procedures, and/or the lack of well trained personnel. Also acts of terrorism and war could increase risks. An estimate of the risks related to societal and political disruption is in our view highly speculative, and the fact that no such provoked accidents have occurred in the previous decades cannot be regarded as a guarantee for the future. Nevertheless, we will not include these risks.

Detailed safety analyses are not available for many of the 217 European power plants, that were operational in 1992 [5]. Therefore, a generalization was made to estimate accident probabilities and probabilistic releases.

Reactor design and redundancy of safety features led to estimated probabilities of severe damage to the reactor core [6]. The nuclear power reactors were classified in four accident probability classes: 10^{-3} per year (29 plants), 10^{-4} per year (146 plants), 10^{-5} per year (39 plants), and 10^{-6} per year (3 plants). Four accident scenarios were estimated based on NUREG-1150 [6]. The average probability for an accident with severe damage to the reactor core equals 2×10^{-4} per year, which is comparable to the 2.5×10^{-4} per year that could be estimated looking at the history of major accidents with the reactor core (2 accidents in approximately 8000 reactor years of worldwide experience (with reactors at Three Miles Island and Chernobyl). Only in the Chernobyl case this lead to a large scale contamination. Using binomial statistics, we can estimate maximum and minimal values for the probability of severe damage to the reactor core [3]. For all reactors in the world taken together, the average risk could be at most 4–5 times higher than estimated here (at 5% level), or a similar factor lower. For the reactor types that are in the highest risk category a history of 500 reactor years and 1 large scale accident, leading to an overall range for the accident probabilities which is a factor of 10 higher or lower than the 10^{-3} per year used here.

Atmospheric dispersion and deposition is calculated applying a probabilistic air dispersion model. Uncertainties are estimated to be a factor of 4 [3]. Radiation exposure of the population can occur through inhalation, external exposure and ingestion of contaminated food products. The uncertainty in the dose estimates is determined based on comparison with various other models and assessments, and amounts to a factor 4. A full description of the model is given in Ref. [3].

The exposure is calculated for a lifetime follow up period of 70 years and excess risks are expressed in terms of excess cancer mortality due to excess radiation doses received. Short term deaths in the direct vicinity of the power plants are not included. Baseline risk estimates are provided for an adult rural population, eating fresh products with a food consumption which is regarded at the high end of the consumption range. The group considered is assumed to spent 30% of the time outdoors. Countermeasures are not considered.

For 8000 receptor locations in Europe, the excess cancer death risks due to possible accidental releases from the 217 operational nuclear power reactors are calculated, using a dose–death risk conversion coefficient of 2.5% per sievert.

3. Results

Ingestion is the major dose contributing pathway ($\pm$50% of the total dose). External exposure contributes around 33% (primarily due to Cs-137), inhalation around 10% and external exposure from the cloud 3% or less. Thus, deposition related contributions amount to around 85% of the total dose. For the adult population 70% of the 70 years follow up dose will be received in the first year. Following an accident countermeasures can lead to a reduction of risks. Most effective risk reduction could be expected from avoiding the use of contaminated food products, especially in the first year. The maximum risk reduction from this could be around 40–50% of the presented risks [3].

The major two dose contributing nuclides in the various source terms are I-131 and Cs-137, together contributing 60–75% of the total dose by all 57 nuclides considered. In addition, Cs-134 contributes approximately 15%, and all other nuclides less than 5% each, and no more than maximally 25% in total.

The risk estimates are plotted on a map of Europe. Two risk maps are obtained: one (Fig. 1) representing the present situation (i.e. for 1992) and a second (Fig. 2) presenting a situation where it is assumed that eastern European reactor types have a safety level which is comparable to that of western European reactors.

The estimated excess death risk provided for Europe shows a large variation (see Fig. 1). This risk is less than 10^{-8} per year in Iceland and southwestern parts of Spain and Portugal. It increases from west to east: 2×10^{-8} per year in Ireland, 3×10^{-8}–10×10^{-8} per year in England and large parts of France, Italy and Norway, around 10×10^{-8}–30×10^{-8} per year in the Netherlands, Belgium, Germany and large parts of central Europe. A risk over 100×10^{-8} per year is found in large areas of the former Soviet Union, including the Baltic states, Belarus, Russia and Ukraine. In these countries, a risk of 1000×10^{-8} per year is exceeded in the smaller regions around the nuclear reactors.

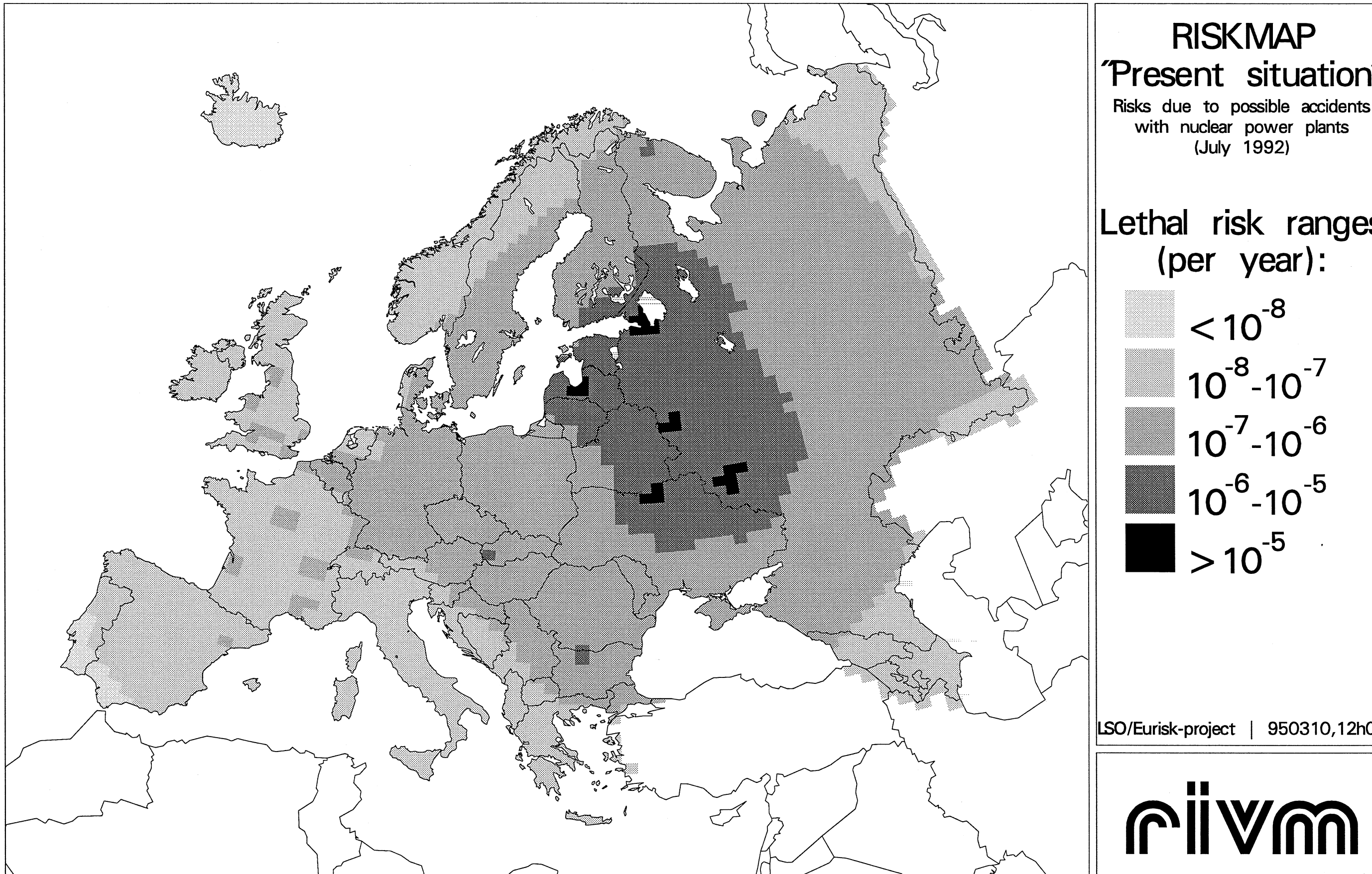

Fig. 1. Estimated mortality risk due to possible accidental releases from nuclear power plants in Europe: the situation for 1992.

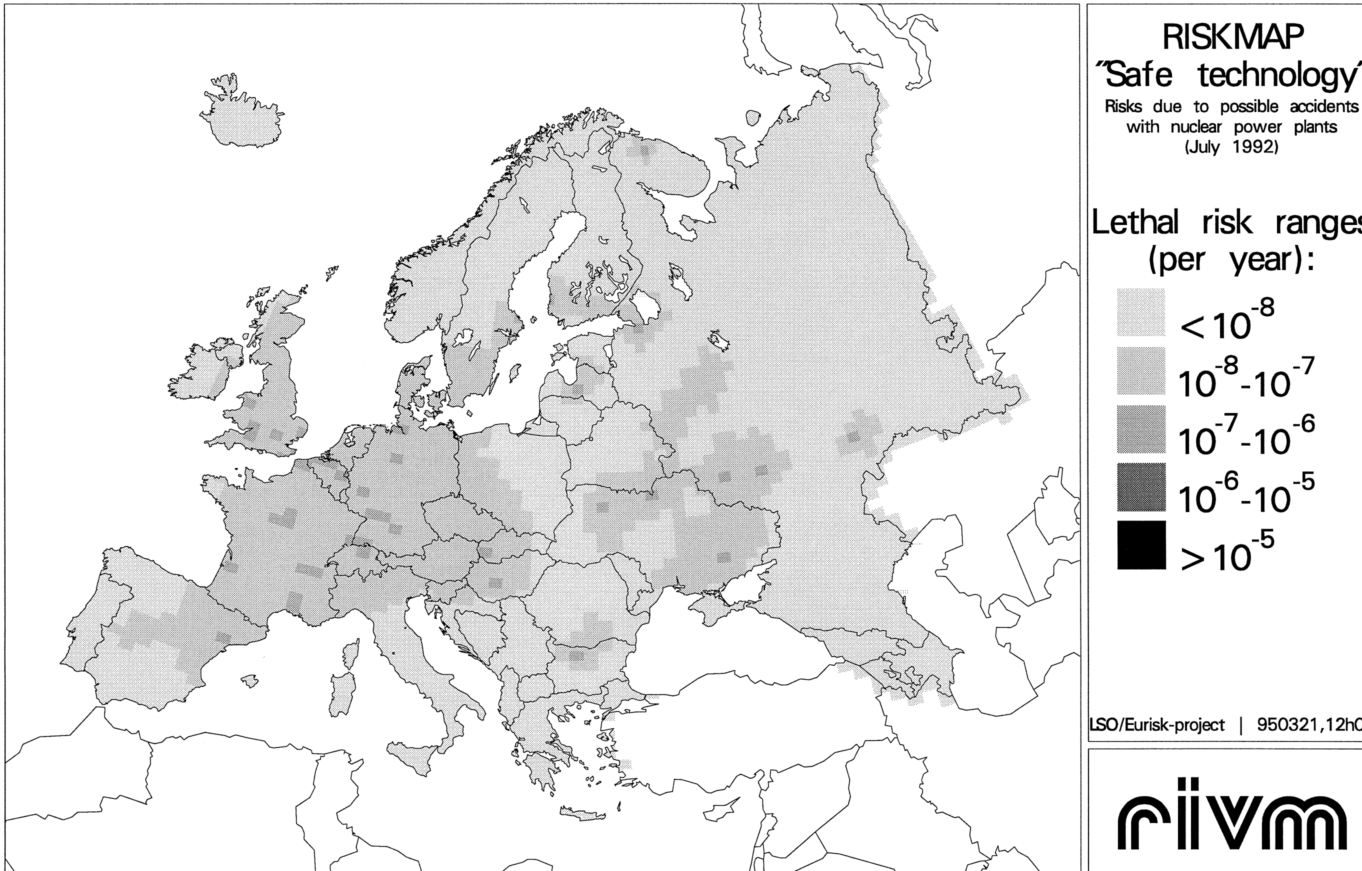

Fig. 2. Estimated mortality risk due to possible accidental releases from nuclear power plants in Europe: assuming that the safety of eastern European reactors becomes comparable to that of western European reactors.

Nuclear power reactors in the eastern European countries dominate the estimated risk pattern and contribute at least 40–50% to the average risk in the western European countries. Improving the reactor safety in eastern European countries leads to considerable reductions in the estimated risk (Fig. 2). These results show that largest risk reductions can occur in eastern Europe (more than a factor 100), whereas reductions of approximately 50% are found in western Europe, where the density of nuclear plants is highest.

Completely accounting for the ICRP-60 [7] changes overall risk is increased with a factor of 2.5. Another source of variation in the risk assessment can be due to the definition of the risk-group under consideration. Small children at the time of an accident are estimated to have 3- to 4-fold higher risks than the risk-group considered here. On the other hand taking a mixed rural and urban population and 20% outdoor occupancy would lead to 50% lower exposure doses than calculated here.

4. Uncertainties and discussion

Largest uncertainties are due to the estimation of accident probabilities, accident scenarios and nuclide releases. No detailed safety studies are available for many of the European reactors. This holds in particular for many of the reactors in eastern Europe, where risks are considered higher because many of the reactors lack a redundancy in safety features. Some indications of the uncertainties involved can emerge from the history of major accidents that involved the reactor core. Improvements to the safety precautions could lower the risks over time, however, an increase in economic and social instability could increase risks. An indication of the overall uncertainty involved, is obtained by assuming that various errors in the chain are independent, and lognormally distributed [3]. The overall risk is composed of a multiplication of the various components in the chain. The overall estimate of the uncertainty factor (at 95% significance) is 15 in western Europe and 20–25 in eastern Europe (up as well as down). These estimates must be seen as first indications of overall uncertainty. Near specific reactors risks could deviate more, and also local weather conditions (for instance in mountainous areas) could show larger deviations than the overall indications.

5. Implications and conclusions

The aim of environmental policies is the reduction of man-made environmental risk, both for regular releases and for accidental releases. This study provides a probabilistic evaluation of individual death risks due to possible accidents with nuclear power plants in Europe. The risks evaluated in this study are restricted to radiation induced cancer deaths, thus, acute radiation victims, which can occur in the close vicinity of the reactor (< 5–10 km), are not included. Acute radiation victims can mainly be expected among personnel involved in controlling the accident. An other aspect not covered in the present evaluation is the fact that a large scale accident, when occurring, could lead to a disruption of the society.

Although the risk evaluation does not cover all aspects of risks involved in accidental situations, it serves the purpose that risks can be put in perspective and made comparable to risks from regular emissions. The overall average uncertainty is considerable. The main contributor to the uncertainty is the lack of knowledge on accident probabilities and releases, especially for the eastern European reactors.

The eastern European reactors are presently dominating the calculated risks in Europe, and substantial lowering of the overall risks could be achieved if the safety measures and procedures which apply to western European reactors are also implemented for eastern European reactors. In that case the average risk in western Europe is reduced nearly twofold, and in eastern Europe the risk reduction can amount to more than a factor of 100. Thus, quality of safety design can reduce risks considerably. In view of the uncertainties in the calculated risks, quantitative probability safety assessments, especially for eastern European reactor types, are important. These studies could also be used as a basis to improve the safety measures for the reactors. The achievement of a safety level fully in line with western technology will possibly require the dismantling and replacement of the most dangerous reactor types. This shortens the productive lifetime of the reactors and has major economical consequences, which should be weighted against the achieved risk reduction.

References

[1] UNSCEAR, United Nations Scientific Committee on the effects of atomic radiation, sources and effects of ionizing radiation, Report to the general Assembly, 1993.
[2] H. Slaper, R.O. Blaauboer, Probabilistic risk assessment for accidental releases from nuclear power plants in Europe, Methods and results. Proceedings of an International Symposium on Environmental Impact of Radioactive Releases Organized by the IAEA and Held in Vienna, 8–12 May 1995, IAEA-SM-339, 1995.
[3] H. Slaper, R.O. Blaauboer, G.J. Eggink, A risk assessment method for accidental releases from nuclear power plants in Europe, RIVM report 743030002, Bilthoven, Netherlands, 1994.
[4] H. Slaper, G.J. Eggink, R.O. Blaauboer, Risks of potential accidents of nuclear power plants in Europe, RIVM report 743030001, Bilthoven, Netherlands, 1993.
[5] Kernkraftwerke in Europa 1992, Atomwirtschaft, August/September 1992.
[6] B.Th. Eendebak, C. Bakker, W.A.G. van der Mheen, Brontermen voor Europese kernenergiecentrales, KEMA, Arnhem, Netherlands, 1992.
[7] ICRP publication 60, Ann. ICRP, vol. 21, no. 1–3, Pergamon Press, Oxford, UK, 1991.