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Review

Current practices for risk zoning around nuclear power plants in comparison to other industry sectors

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Abstract

This paper analyses the background and current status of the information basis leading to the definition of risk and emergency zones around nuclear power plants (NPPs) in different countries in Europe and beyond.

Although dependable plant-specific probabilistic safety assessment (PSA) of level 2 and/or level 3 could in principle provide sufficiently detailed input to define the geographical dimension of a NPP's risk and emergency zones, the analysis of the status in some European and other countries shows that other, "deterministic" approaches using a reference accident are actually used in practice. Regarding use of level 2 PSA for emergency planning, the approach so far has been to use the level 2 PSA information retrospectively to provide the justification for the choice of reference accident(s) used to define the emergency plans and emergency planning zones (EPZs). There are significant differences in the EPZs that are defined in different countries, ranging from a few up to 80 km.

There is a striking contrast in the extent of using probabilistic information to define emergency zones between the nuclear and other high risk industry sectors, such as the chemical process industry, and the reasons for these differences are not entirely clear, since the risk of chemical industry is similar as that of the nuclear sector. The differences seem to be more related to risk perception than to the actual risk potential. Therefore, there is a strong need to be able to communicate risk information to the Public both before and following an accident. In addition, there is a need to educate the Public so that they can understand risk information in a comparative sense.

Finally, based on the consensus discussions at a recent JRC/OECD International Seminar on Risk & Emergency Zoning around NPPs, a set of recommendations is given in the areas of

- a more comprehensive use of the available risk information for risk zoning purposes,
- risk communication;
- comparative (energy) risk assessment.

Keywords: PSA; Risk zoning; Energy risk assessment; Comparative risk assessment

Contents

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1. Background and overview

Within the Institute for Energy (IE) of the Joint Research Centre (JRC) of the European Commission (EC), located at Petten, The Netherlands, a project on *Benchmarking and Harmonising Strategic Planning Practices for Risk & Emergency Zoning around Nuclear Power Plants and Information to the Public* has recently been developed with the objectives to evaluate the corresponding status in Europe and beyond, and to determine whether it would be possible to move towards a higher level of international harmonisation.

The knowledge resulting from this project should help Regulatory Authorities, Civil Protection Institutions, European Institutions such as EC Policy Directorates General, the various PSA users and developers and, last but not least, the general Public to get a clear picture on the relevance of the issue in a comparative view (e.g. versus corresponding practices of the chemical process industries), on the consistency of current approaches and on related research and development needs.

Information has been collected and analysed in a first report [1] and later on distributed in a condensed version [2] to a large audience for review and comments. As a main conclusion, significant differences have been found in the definitions of EPZ of the NPPs in different Member States of the European Union (EU) and beyond.

The original idea for this project consisted in the view that PSA is currently already mature enough to be used also for NPP emergency and risk zoning (ERZ). However, at present it can be stated that not much is being done in EU Member States in application of level 2 or 3 probabilistic safety assessment (L2 or L3 PSA) results to emergency planning (EP). The approach to EP is, in general, strongly deterministic. The usual approach is that a reference accident is defined to be used as basis for drawing up the emergency plans. In EU Member States, the practical application of L2 PSA results for accident management is very limited and, effectively, very little risk-based information is used. In the course of this project, from the participating countries[1] only the Czech Republic and the UK informed about some cases where L2 PSA results were used in a formal way as an input to EP. The UK is the only EU Member State, which has been carrying out research on how L2 PSA outcomes could be used in a systematic way for EP purposes.

As a next step, JRC approached a large number of PSA experts on the one side and EP experts on the other side to ask whether incorporation of risk-informed support into NPP EP is currently a sufficiently relevant and mature topic to be treated by a seminar investigating prospects towards international harmonisation.

JRC received a large number of very positive responses, only a few ones being reserved or skeptical. While this is certainly not an exhaustive feedback, it was nevertheless reasonably found to organise together with OECD a *JRC Seminar on Emergency & Risk Zoning around NPPs*, which was held on 26–27 April 2005 at JRC's Institute for Energy in Petten, The Netherlands. The Seminar attracted a wide participation from EU and non-EU countries. More than 20 technical presentations in the area were given by participants from Europe, USA, South Africa and India.[2] The objectives of this seminar were:

- to provide a forum for presentation and discussion of status of EP and PSA, safety policies as well as current and possible future requirements for ERZ;
- to provide an opportunity for sharing of experience in the field on both good practice and identification of problem areas, including comparison to other major-hazardous industries, such as the chemical process industries, and thus;
- to help relevant stakeholders (i.e. regulatory authorities, utilities, emergency response organizations as well as PSA users and developers) on both national and international levels:
  - to decide on the relevance of this issue at this time;
  - to decide on related research and development needs;
  - to consider needs for international harmonisation.

2. Main conclusions and recommendations

2.1. Current approaches to emergency planning

It was clear from the ERZ Seminar's presentations and discussions that there are many similarities but also some significant differences in the way that EP is drawn up and EPZs are defined in different countries [4].

The "standard" approach to EP is mainly deterministic and uses a reference accident approach (consideration of design basis accident or selected reference scenarios) and almost no risk information is used. Sometimes a blend of deterministic and probabilistic approaches is used. The ERZ Seminar has gone some way to investigating these similarities and differences. However, it was clear that further work is required to provide a better understanding of the national approaches to EP and to

[1] The following countries were involved in the information collection exercise summarized in report [1]: Belgium, Czech Republic, Finland, Hungary, The Netherlands, Slovak Republic, Spain and the United Kingdom. In addition, some information was obtained from Japan and the USA.

[2] Further information on the Seminar can be found under http://www.energyrisks.jrc.nl and full proceedings are available from the authors on request.

determine whether it would be possible to move towards a higher level of harmonisation.

Especially, there is a large variety in approaches and data used for EPZ in different countries. As shown in Table 1, current EPZs range from less than 10 up to 80 km. The reasons for these differences need to be fully understood. In addition, the issue needs to be addressed on whether there is any advantage in defining larger EPZ or if there are any disbenefits from defining large EPZs. In many countries the relevant IAEA documents are used.[3]

Recommendation 1. It is recommended that further work be carried out towards understanding the reasons for differences in the EP in different countries.

Recommendation 2. It is recommended that further work be carried out on how the uncertainties inherent in the L2 PSA can be taken into account in defining EP and EPZs.

2.2. Current and future use of L2 PSA for emergency planning

It was agreed that the proper response to an emergency requires understanding of the underlying hazards. The results of L2 (and L3) PSAs provide important information in this area. The standard emerging worldwide is full scope L2 PSA to be carried out for all NPPs. Such analyses are of sufficiently mature nature to be used for a wide range of applications and could also be used as one of the inputs into EP as part of an overall risk-informed approach.

However, uncertainties in PSA are large and are likely to be greater in L2 PSA (derivation of the source terms) and greater still in L3 PSA (calculation of the off-site consequences of a release of radioactive material) as compared to L1 PSA. Further consideration needs to be given as to how these uncertainties are taken into account in proper EP.

A distinction should be made between full-scope L2 (and L3) PSA and restricted scope, when not all power levels or hazards are included (e.g. it may only address internal initiating events). Further consideration needs to be given as to how a restricted scope PSA could be used as an input to EP.

The approach used so far is to use L2 PSA information *retrospectively* in order to provide a justification for choice of reference accident(s) used to derive EP and EPZs. Where a reference accident approach is used based on L2 PSA information, consideration needs to be given to the number of reference accidents that need to be defined to characterise severe accident progression and release characteristics.

It was agreed that L2 PSA information could be used as a basis for EP and there is the potential to do this in a more *proactive* way. However, apart from the aspect of the above-mentioned uncertainties, consideration needs to be given on the methodology, i.e. how this is to be done in a risk-informed way that takes account of other factors so that it is not based

[3] For example, the October 2003 updated version of TECDOC-953 on "Methods for Developing Arrangement for Response to a Nuclear or Radiological Emergency" which gives guidance on EP and ERZ.

Table 1
Brief overview of emergency planning practices in different countries (based on Refs. [1,2] and presentations at the April 2005 JRC/OECD ERZ Seminar)

	Evacuation	Sheltering	Stable iodine intake/quick actions	Deterministic	Risk-informed	Internal zone[a]	EPZ
Belgium	10 km	10 km	20 km	√		?	?
Czech Republic	10 km Dukovany; 5 km Temelin	√	√	√, Dukovany	√, Temelin	10 km Dukovany; 5 km Temelin	20km Dukovany; 13 km Temelin
Finland[b]	5 km	20 km	20 km	√	√	5 km	20 km
France	5 km	10 km	10 km	√		?	?
Hungary	?	?	?	√		3 km	30 km (urgent); 80 km (long-term)
Japan	√	√	√	√	√	?	8–10 km
The Netherlands	5 km	20 km	10 km	√	√	?	?
Slovakia	√	√	√	√		3 km for Bohunice and Mochovce	30km Bohunice; 20 km Mochovce[c]
South Africa	√	√	√	√	√	5 km	5–16 km (urgent); 80 km (long-term)
Spain too specific to provide summary	?	?	?	√	√	?	?
Switzerland	?	?	?	√	√	3–5 km	20 km
UK too specific to provide summary	?	?	?	√	√	?	?
USA	√	√	16 km[d]	√	√	?	16 km (plume); 80 km (ingestion)

[a] Generally defined as the zone in which no (further) development is allowed.
[b] In Finland a NPP site is defined to extend to about 1 km from the facility.
[c] The EPZ for both Bohunice and Mochovce are divided into zones of 5 and 10 km.
[d] Since 2002 there is discussion to extend this to 32 km in view of possible terrorist threats.

on PSA information alone. L2 PSA provides an understanding of how a severe accident would occur, the accident management measures that could be used to mitigate the effects of the accident, and the resulting source terms and frequencies of releases from the plant. This provides the detailed information that would be required as input from PSA to definition of EP and EPZs.

One of the important issues is how to understand from the evolution of the accident which source term would happen. L2 PSA typically contributes to model accident management measures that can be carried out to mitigate the consequences of a severe accident. Severe accident management guidelines could effectively contribute to extending time for emergency response, i.e. this would extend the period of time available before a release of radioactivity would occur from the NPP and hence increase the time available to put the EP into action.

Recommendation 3. It is recommended that further work shall be carried out to determine how the L2 PSA information could be used in a systematic way as an input to defining EP and EPZs, taking into account the corresponding uncertainties. It is recommended that JRC should undertake a pilot study to produce a scheme for use of L2 and L3 PSA information for EP. This could be within the framework of or as a spin-off from JRC's involvement in the SARNET Network of Excellence.[4]

2.3. Full scope L3 PSA

Full scope L3 PSA is available only for very few NPPs in the EU. However, they are being developed in a number of countries (including The Netherlands, UK, USA, Japan, South Africa, India). One of the reasons could be one rather specific aspect of L3 PSA: while conducting L1 and partially also L2 PSA study is, or can be, in favour of nuclear operators/licensees due to their plant-internal character and related potential for improvement, they do not have any incentive to perform L3 PSA studies as these address exclusively plant-external effects. To have L3 PSA study available is, more or less, the concern of nuclear regulatory authorities and/or radiological protection authorities.

2.4. PSA quality requirements

To be useable as one of the inputs to EP, it is recognised that a high quality PSA is required that is suitable for this specific application. As mentioned, one particular aspect here is that the source terms need to be well defined in terms of the quantities of radioactive material released and the release profile (start of the release, duration, height, energy, etc.). The PSA that is used to provide an input to EP needs to be complete and address all the contributions to the risk in terms of the hazards considered and the operational modes addressed.

However, there was no agreement on the extent to which external hazards (such as severe seismic events) and security related events (such as terrorist attacks on the plant) should be taken into account in defining EP and EPZs. Further consideration is required of these topics.

Recommendation 4. To support the current IAEA activity on PSA quality for applications [3] and the Proposal for a Co-ordinated Research Project on PSA of nuclear facilities in relation to external events (into which the issue of security related events could be included).

2.5. Current legal requirements

There was a concern that the mandatory legal requirements in some countries may be over-restrictive and that the possibility of adopting a more risk-informed approach should be considered.

2.6. Future nuclear power plants

The trend is to improve the level of safety for future NPPs (so-called Generation III+, IV). This would significantly reduce the potential for severe accidents and releases of radioactive material from the plant to occur. In principle, this could be considered to reduce, or perhaps eliminate, the need for EP.

Recommendation 5. Further considerations needs to be given on how EP and the EPZs would be defined for future NPPs where the risk from the plant in terms of large off-site releases of radioactivity would be very much lower than for current plants. This needs to be reconciled with the expectations of the regulatory authorities and the Public. Consideration needs to be given on whether the moral obligation to provide an EP would outweigh the technical conclusion that this would not be required.

2.7. Risk communication

There is a need to be able to communicate risk information to the Public both before and following an accident. In addition, there is a need to educate the Public on that they can understand risk information. Further consideration needs to be given to how this can be done. Care must be exercised while *communicating risk-related information and insights on potential vulnerabilities* to the Public in the view of *security issues and prevention of malevolent acts. Education of the Public on risk considerations* is important for enhancing the general understanding of risk implications and better acceptance of risk from nuclear industry. *Comparative consideration* of emergency planning and associated risks for nuclear and other industries, as well comparison with general risks from daily life may be helpful in communicating risk information to the Public.

Recommendation 6. It is recommended that further work be carried out on risk communication and how this can be done in relation to EP.

2.8. European risk map

There was discussion of the long-term goal of developing a European risk map for all potentially major hazardous industries, which would include both nuclear and chemical installations.

[4] http://www.sar-net.org.

Nuclear and chemical safety have various different and various similar aspects (see Ref. [5]).

Regarding nuclear, NPPs are quite similar to each other in terms of:

- type of risk (risk of radioactive release through multiple barriers);
- steady state power production and outages;
- process system technology and supporting safety functions which are quite straightforward to analyse;
- all plant operators are used to safety and quality management systems.

Further, there are commonly accepted safety criteria, including de-facto international consensus on risk targets.

Chemical installations, on the other hand, are much larger in number and variety:

- different substances (chemical, fuels, explosives);
- different products and production technologies;
- process systems entities are often complex to analyse;
- not all plant operators are used to safety management systems nor thorough risk assessment methods (for event with very low frequencies and high consequences, in particular).

Regarding regulation, on an EU level, the so-called "Seveso Directive" 96/82/EC sets out basic safety management and risk analysis criteria, but there are considerable differences between different countries, branches (chemical, metal, refineries, mining, etc.) and operating companies. Further, there is some EU cooperation ongoing in the area of risk zoning (so-called "Land-Use Planning"), aiming at developing common databases for failure frequencies, scenarios, etc.

In summary, nuclear and chemical risks are basically similar in terms of involving a similar type and extent of consequences:

- direct consequences (fatalities, contamination, economics, etc.);
- latent consequences (cancer, genetics, etc.);
- indirect consequences (business impact, branch reputation, etc.).

Major differences between nuclear and chemical risks are:

- number and variety of facilities;
- plant technology and operational features;
- maturity of risk assessment and safety management practices;
- resources for regulatory surveillance throughout plant life cycle;
- systemic risk context (supply chains, infrastructure, clusters, etc.);
- "intangibles" (history, Public concerns, branch characteristics, etc.).

However, and this is reflected in many joint discussion fora[5] and emerging risk governance initiatives,[6] general views on risks are clearly converging between the nuclear and the chemical safety experts.

Recommendation 7. It is recommended to explore the possibilities as to how such an initiative could be linked to supporting implementation of some of the provisions of the EU Environmental Impact Assessment Directive or other international framework legislation in the area, such as the so-called "Aarhus Convention".[7] On an EU level, such a support activity would have to be conditional to the request of the corresponding EC Policy Directorate General.

2.9. International topical working group

It was agreed that the current EP practices for NPPs could be enhanced by moving towards a more risk-informed approach, where the process of defining the EP and EPZs takes account of the information provided by the L2 PSA. This would supplement the purely deterministic approach. However, the discussion showed that there is no guidance on how this should be done in general, though this has already been done in some countries where the source terms and frequencies produced by the L2 PSA have been used to check the choice of the reference accident(s) that have been used as the basis for EP. This is an example of a retrospective use of PSA.

Recommendation 8. It was recommended that JRC should set up an international topical working group to address risk-informed EP, incl. the above mentioned related topics of risk communication, risk mapping, etc. Not only EU Member States should be involved, but also wider international framework and co-operation would be desirable, such as together with IAEA or OECD.

3. Follow-up

Based on this summary report and the therein included recommendations, feedback is currently sought from interested institutions and EC Policy Directorates General in order to develop a possible follow-up initiative. More information on these ongoing discussions and developments will shortly be added to http://www.energyrisks.jrc.nl.

Acknowledgement

The very valuable comments of the reviewer shall be acknowledged.

[5] See e.g. [5] and http://www.energyrisks.jrc.nl/newspopuphtml.htm.

[6] See e.g. http://www.trustnetgovernance.com.

[7] UN/ECE Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters; see also: http://www.unece.org/env/pp/welcome.html.

References

[1] J. Kubanyi, C. Kirchsteiger, Risk-informed support of nuclear power plant emergency zoning, Report EUR 21580 EN, JRC Petten, 2005.
[2] J. Kubanyi, C. Kirchsteiger, Information basis to support NPP emergency zoning. Draft review of status and possible recommendations for discussion at the JRC-OECD seminar on emergency and risk zoning around NPPs, JRC Petten, April 26–27, 2005. Report EUR 21593 EN, JRC Petten, 2005.
[3] PSA Quality for Applications, Working Material, Draft, Rev.2.3, IAEA Vienna, February 2004.
[4] C. Shepherd, I. Kouzmina, Rapporteurs' Notes of the Seminar on Emergency and Risk Zoning around Nuclear Power Plants, JRC Petten, 2005.
[5] C. Kirchsteiger (Ed.), International Workshop on Promotion of Technical Harmonization on Risk-Based Decision-Making, Special Issue of Safety Science, vol. 40, nos. 1–4, 2002.