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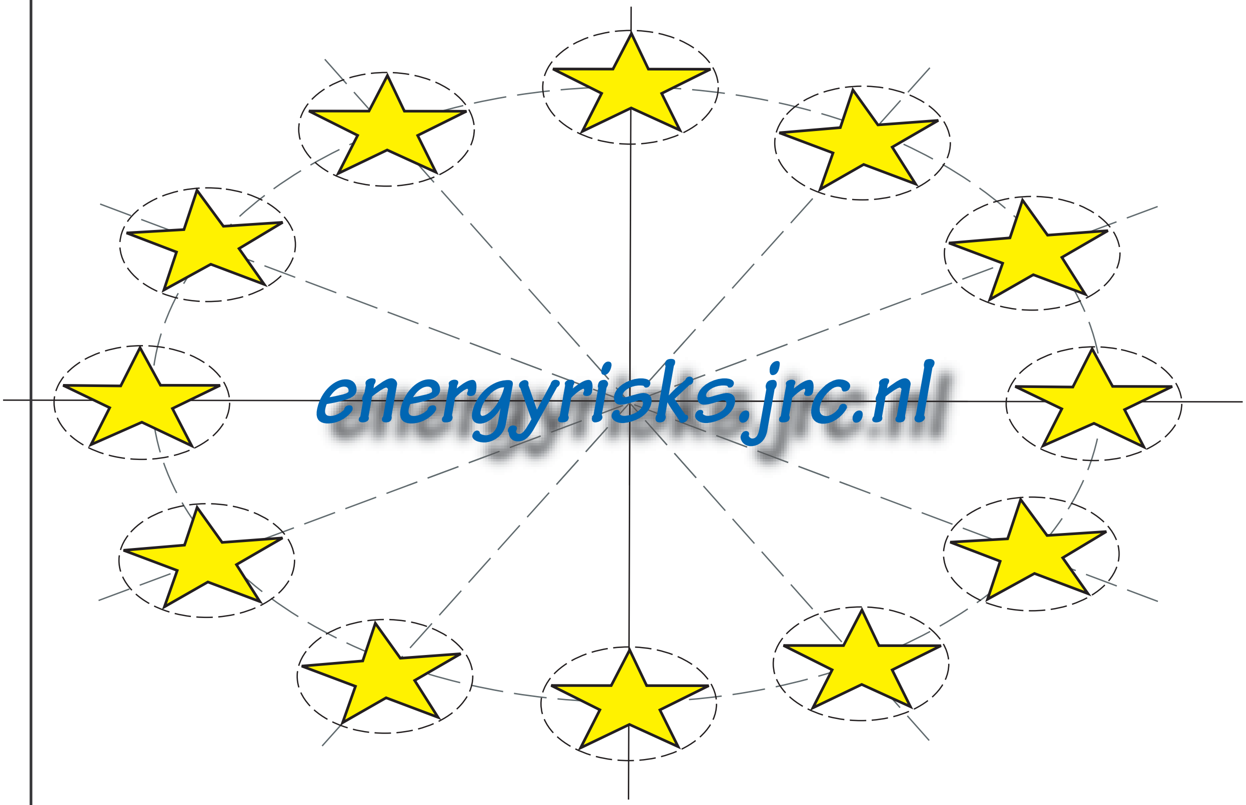
Risk-informed Support of Nuclear Power Plant Emergency Zoning

Benchmarking and Harmonising Strategic Practises for NPP Emergency Zoning and Information to the Public



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EUROPEAN COMMISSION
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Joint Research Centre

EUR 21580 EN

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http://www.energyrisks.jrc.nl/

http://www.jrc.cec.eu.int/

http://ie.jrc.cec.eu.int/

Luxembourg: Office for Official Publications of the European Communities, 2005

EUR 21580 EN

Printed in The Netherlands, Institute for Energy – JRC IE, PR & Communication

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Preface

With the advent of improved understanding and increased characterisation of severe accidents, management of them should be analysed as an integrated complex process. The interrelationship of emergency operating procedures, severe accident management guidelines, and nuclear power plant (NPP) emergency off-site actions should be planned and organized to minimize the consequences of such accidents, considered over the whole spectrum of their possibilities and probabilities, within the limits of practicality. A deterministic approach, coupled with both probabilistic safety assessment (PSA) methodology and PSA results, can play significant roles in the development of relevant utility, regulatory and all stakeholders policies.

This document describes the background, objectives and current state of a corresponding activity within JRC-IE's Analysis and Management of Nuclear Accidents (AMA) Action on benchmarking and harmonising strategic planning practices for emergency zoning and disseminating information to the public, based on a **risk-informed decision making approach.**

This activity is expected to complement - in terms of probabilistic aspects - current JRC-IE activities on traditional deterministic safety assessment of NPPs and other energy systems.

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LIST OF ABBREVIATIONS

AGR	Advanced Gas Reactor
ALARA	As Low As Reasonably Achievable
ALARP	Low As Reasonably Practicable
ALWRA	Advanced Light Water Reactor
AM	Accident Management
ANPA	Agenzia Nazionale per la Protezione dell Ámbiente
ANSI	American National Standards Institute
APWR	Advanced Pressurised Water Reactor
ASME	American Society of Mechanical Engineers
ATWS	Anticipated Transient Without Scram
AVN	AIB-Vinçotte Nuclear
BDBA	Beyond Design Basis Accident
BMU	Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit
BWR	Boiling Water Reactor
CCF	Common Cause Failure
CDF	Core Damage Frequency
CEA	Commissariat à l'Energie Atomique
CIEMAT	Centro de Investigaciones Energeticas, MedioAmbientales y Technologicas
CRAC	Calculation of Reactor Accident Consequences
DBA	Design Basis Accident
DEPZ	Detailed Emergency Planning Zone
DG	Directorate-General
DNB	Departure from Nucleate Boiling
EC	European Commission
ECCS	Emergency Core Cooling System
EDF	Electricité de France
EPR	European Pressurised water Reactor
EPRI	Electric Power Research Institute
EPZ	Emergency Planning Zone
EU	European Union
FSAR	Final Safety Analysis Report
GIS	Geographical Information System
GPR	Groupe Permanent chargé des Reacteurs nucléaires
GRS	Gesellschaft für Anlagen-und Reaktorsicherheit
HNP	Hatch Nuclear Plant (in the USA)
HSE	Health and Safety Executive
I&C	Instrumentation and Control
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IE	Initiating Event
INSAG	International Nuclear Safety Advisory Group
IPSN	Institut de Protection et de Sûreté Nucleaire
JRC	Joint Research Centre
KWU	Kraftwerk Union (Siemens AG)

LERF	Large Early Release Frequency
LOCA	Loss Of Coolant Accident
LWR	Light Water Reactor
MAAP	Modular Accident Analysis Program
NII	Her Majesty’s Nuclear Installations Inspectorate
NPP	Nuclear Power Plant
NRC	Nuclear Regulatory Commission
NRWG	Nuclear Regulators Working Group
OECD	Organisation for Economic Co-operation and Development
PIE	Postulated Initiating Event
PORV	Power (Pilot) Operated Relief Valve
PRA	Probabilistic Risk Assessment
PSA	Probabilistic Safety Assessment
PWR	Pressurised Water Reactor
RCS	Reactor Coolant System
R&D	Research and Development
RIDM	Risk-informed Decision-Making
RSS	Reactor Safety Study (WASH-1400)
RV	Relief Valve
Ry	Reactor.year
SAP	Safety Assessment Principle
SAR	Safety Analysis Report
SA	Severe Accident
SFC	Single Failure Criterion
SG	Steam Generator
SGTR	Steam Generator Tube Rupture
TECDOC	Technical Document (of the IAEA)
TMI	Three Mile Island
TSO	Technical Support Organisation
UK	United Kingdom
US, USA	United States of America
USNRC	United States Nuclear Regulatory Commission
WWER	Water-Water Energy Reactor

EXECUTIVE SUMMARY

Within the Institute for Energy (IE) of the Joint Research Centre (JRC) of the European Commission (EC), located at Petten, The Netherlands, an activity on ***Benchmarking and Harmonising Strategic Planning Practices for Emergency Zoning and Information to the Public*** is in progress within the framework of the JRC FP-6 Action Nr. 3131 "Analysis and Management of Nuclear Accidents" (AMA).

The objective of this project is to identify the corresponding relevant information currently used on the basis of either Probabilistic Safety Assessment (PSA) or other sources, to document the current status of defining NPP risk zones and to specify relevant information to the public from as many different European and other countries as possible. Another, rather long-term objective related to this JRC project is to agree - together with the developers and owners of this information - on a harmonised template to publish corresponding results to different stakeholders, including the public, at a European level.

Level 3 PSA methodology can, in principle, be used to estimate the offsite consequences of severe accidents and could provide an acceptable basis for implementation of the probabilistic approach to emergency planning. Besides, the outcomes could be used as information source for European NPP risk mapping. For these purposes, examples of the most relevant data would be:

- Evacuation notification time[1];
- Total early fatalities;
- Total late fatalities;
- The amount of radiation the individuals receive depending on the distance from the plant;
- The most frequent wind direction;
- Economic losses, etc.

Considerable experience has been gained during the past years regarding severe accident risk assessment and mitigation, mainly in the USA. Prediction of environmental impacts of severe accidents (in the form of probability-weighted consequences) was performed for all NPPs and the risk reduction potential was identified using severe accident mitigation alternatives. These activities are being performed mainly within the license renewal process of the plants. In addition, the future risk is calculated for the extended lifetimes.

Based on the information obtained, significant differences have been found in the definitions of Emergency Planning Zones (EPZ) of the NPPs in different

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[1] Two of the three fission product boundaries have failed and the failure of the third boundary is likely; the time depends on the initiating event and the PSA can predict it.

countries within the EU and beyond. The approach to emergency planning is, in general, very strongly deterministic. The usual approach is that a reference accident has been defined (usually Design Basis Accident) to be used as basis for drawing up the emergency plans.

In EU Member States, the practical application of Level 2 PSA results for the accident management is very limited and, effectively, very little risk-based information is used. In the course of this project, only the Czech Republic and the UK informed about some cases where Level 2 PSA results were used in a formal way as an input to emergency arrangements. The UK is the only Member State of the EU, which has been carrying out research to consider how Level 2 PSA outcomes could be used in a systematic way for emergency planning purposes.

The **benefits from this project** are:

1) a better understanding of important issues in PSA applications to risk-informed supporting of emergency zoning in relation to NPP accident management,

2) a better knowledge on the actual use of various current approaches and methods in the area, and

3) information on the efforts undertaken by utilities, regulatory authorities and other stakeholders to explore possibilities and means of using probabilistic approaches for this topic.

The resulting knowledge should help regulatory authorities, civil protection institutions, European institutions such as EC services, various PSA users and developers and, last but not least, the general public to get a clear picture on the relevance of the issue, the consistency of current approaches and on related research and development (R&D) needs.

The original hypothesis for this project consisted in the view that PSA is currently already mature enough to be used also for NPP emergency risk zoning. However, at present it can be stated that not much is being done in application of Level 2-3 PSA results for emergency planning in EU Member States. As a next step, JRC approached a large number of PSA experts on the one side and emergency planning/radiation protection experts on the other side to ask whether incorporation of risk-informed support into NPP emergency planning is currently a relevant enough topic to be treated by a technical seminar with a view of international harmonisation or is the topic somewhat premature at the present stage.

JRC-IE received a large number of very positive responses, only a few ones being reserved or sceptical. While this is certainly not an exhaustive feedback, it was nevertheless found reasonable to organise a JRC seminar on "Emergency & Risk Zoning around NPPs", which will be held on 26–27 April 2005 in Petten, The Netherlands (see Appendix C). The seminar will provide an opportunity for sharing of experience in the field on both good practice and identification of problem areas, incl. comparison to other major-hazardous industries, such as the chemical process industries. Based on the outcome of this seminar, possible follow-up R&D actions, e.g. in the form of an international Working Group could be envisaged.

ACKNOWLEDGEMENT

This report is largely based on information collected by RELKO Ltd, Engineering and Consulting Services, Bratislava, Slovak Republic, and summarised in report RELKO/1R1204, December 2004 [1]. JRC would like to acknowledge the very good co-operation with RELKO in the course of this project.

1. INTRODUCTION

Emergency planning zones (EPZs) around NPPs are, in general, defined on a deterministic basis. They help to plan a strategy for protective actions during an emergency. The exact size and shape of each EPZ is a result of detailed planning which includes consideration of the specific conditions at each site, unique geographical features of the area and demographic information.

Predetermined protection action plans are in place for an EPZ and designed to avoid or reduce doses from potential ingestion of radioactive materials. These actions include sheltering, evacuation, use of stabile iodine tablets in the short term, food bans, relocation and decontamination in the longer term.

There are significant differences in EU Member States in the way how emergency plans have been drawn up and how EPZs have been defined. Usually simplified deterministic approaches are used.

Based on the state-of-the-art developments and achievements in application of PSA technology, the original hypothesis that triggered this project consisted in the view that PSA is currently already mature enough to be used also for NPP emergency risk zoning. This resulted in the long term objective of this JRC project to agree - together with the developers and owners of this information - on a harmonised template to publish corresponding results to different stakeholders, including the public, at a European level.

2. BACKGROUND: CURRENT NUCLEAR SAFETY ISSUES & RELEVANCE OF THE ISSUE

The 1995-2000 activity programs of the Nuclear Regulators Working Group (NRWG) and the Reactor Safety Working Group (RSWG) of the EC were carried out within the framework of the 1975 and 1992 resolutions of the Council of Ministers on the technological problems of nuclear safety [2].

The 1975 resolution called for *”... progressive harmonisation of safety requirements and criteria in order to provide for an equivalent and satisfactory degree of protection of the population and of the environment against the risk of radiation resulting from nuclear activities …”*. The 1995 Consensus Document on the safety of European Light Water Reactors (LWR) noted that *”... harmonisation begins with the identification of convergences and the assessment of divergences based on synthesis studies resulting from an intensive exchange of information of the actual practices in the different Member States”.*

In 1993, the EC established a contract with a Consortium of European Technical Support Organisations (TSOs) in order to arrive at common views on technical safety issues related to large evolutionary Pressurised Water Reactors (PWR) in Europe, which could be ready for operation during the next decade. The TSOs involved were: AVN (Belgium) (Technical project leader), AEA Technology (United Kingdom), ANPA (Italy), CIEMAT (Spain), GRS (Germany) and IPSN (France). The general objective of the European TSO Study Project on Development of a Common Safety Approach in the EU for Large Evolutionary Pressurised Water Reactors [2] was to develop, through a collaboration of EU TSOs, a common safety approach to issues related to large evolutionary PWRs in Europe, which could be ready for operation during the next decade. The TSO study represented an important step forward in the development of a common approach of the TSOs to the safety of advanced evolutionary PWRs. This goal was mainly achieved by an in-depth analysis of the **key safety issues**, taking into account new developments in the national technical safety objectives.

After careful considerations, and on the basis of the survey of advanced PWR concepts in preparation for the consolidated analysis, a list of 12 key issues was finally prepared and selected for in-depth analysis. These selected key issues, listed below (those key issues of the list, which are in close relation to the report in hand, are printed in **bold**), were judged to have the greatest safety significance:

- **Use of PSA in design and licensing;**
- **Reduced environmental source term and emergency plan;**

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[2] http://europa.eu.int/comm/energy/nuclear/safety/index_en.htm

- Identification of postulated initiating events (PIEs) and associated acceptance criteria;

- Instrumentation and control systems important for safety (hardware and software aspects);

- System architecture;

- Passive systems behaviour;

- Practical elimination of core melt in shutdown states with open containment;

- Practical elimination of high pressure core melt;

- Practical elimination of core melt with containment bypass;

- **Practical elimination of large early releases resulting from containment failure;**

- Mitigation of low pressure core melt and vessel melt-through;

- Identification of severe accidents: methodology and acceptance criteria.

For all the key issues considered in the European TSO Study, conclusions have been developed covering the state of knowledge, safety approaches, and the approaches taken in selected reactor designs. In addition, TSO group positions have been formulated regarding the development of a **common approach** for each key safety issue, highlighting any studies still to be done in order to reach the required common understanding and consensus. These common positions formed the major achievement of the TSO study project. Areas in which further work was felt to be needed include [2]:

- **PSA methods and use;**

- **In-containment source term and radiological releases;**

- Application of the Single Failure Criterion (SFC) and maintenance; consideration;

- Reliability of passive systems;

- Containment by-pass;

- Hydrogen risk, no occurrence of deflagration to detonation transition;

- Strategies for corium coolability;

- Demonstration of practical elimination of selected sequences;

- Qualification of systems for severe accidents.

In summary, an important step forward has been made in the development of a common safety approach of the TSOs. This was mainly achieved by an in-depth analysis of the key safety issues. The above lists of key issues and of areas for further work clearly indicate that risk-informed support of emergency zoning for NPPs, harmonisation of strategic planning practices and information to the public are of high relevance.

A further argument for moving towards more risk-informed approaches comes from the common practices in another high-risk industrial sector, the chemical process industry: Although in the process industry the probabilistic approach to risk assessment is certainly less complete and consistent as compared to the nuclear industry, risk-informed results are nevertheless used in many countries for land use planning (risk / emergency zoning) purposes. Land use planning is a legal requirement in the EU under the so-called Seveso II Directive ("Directive 96/82/EC on the control of major-accident hazards")[3] and risk-informed methods are encouraged in the practical implementation of the Directive. Then why is current practice in the nuclear sector with its large number of high-quality PSAs seemingly quite different? Is it entirely due to the uncertainties that are still related to PSAs? Is it necessary to first proceed towards more PSA harmonisation, e.g. by development of PSA standards and quality templates, before more risk-informed approaches are used for risk and emergency zoning? Or is there the danger of loss of trust and credibility when being reluctant to compare current practices with more risk-informed approaches?

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[3] http://europa.eu.int/comm/environment/seveso/index.htm

3. OBJECTIVES OF THE PROJECT

Plant-specific PSA can provide together with other information resources relevant information for strategic planning purposes in the area of emergency zoning (risk zones) around a NPP and information to the public on the geographical component of its risk.

The general objectives of this project are:

- to identify what is the corresponding relevant information currently used on the basis of either PSA or other information sources,
- to document the current status together with concrete examples of NPP risk zones, and
- to specify information to the public from as many different European and other countries as possible which could be published at a European level (preparatory steps towards development of corresponding consensus).

The more detailed objectives are:

- To analyse how information from plant-specific PSA studies is currently used in different countries / NPPs for providing a decision-making basis for emergency / risk zoning around a NPP and how information is disseminated to the public.
- To collect and document corresponding examples from as many different European and other countries as possible.
- To agree together with the developers and owners of this information on a harmonised template to publish corresponding results to different stakeholders, including the public, at a European level. Where consensus on publication of information at a European level cannot be achieved, it is essential to clearly document the "sensitivities" of individual countries / stakeholders in terms of data confidentiality. Criteria to come to a corresponding European consensus are the relevance of the information (sufficient level of detail), its easily understandable character and the acceptability for publication by the national authorities in terms of different national legislation, values and habits. The mechanism to come to this consensus is consultation of experts from designated contact points in the participating countries and analysis of related legislation as well as of plant-specific PSAs and other information resources used.

4. RISK-INFORMED DECISION-MAKING

One of the key challenges in truly risk-informed decision-making (RIDM) is the reconciliation of PSA results and insights with traditional deterministic safety analysis. This is particularly true when it comes to defense in depth and safety margins. PSA results often conflict with deterministic insights. If a method of reconciling these conflicts is not defined, then RIDM can become deterministic assessment, along with PSA. This results in PSAs being an additional layer of requirements rather than a tool for optimised decision-making. Alternatively, if PSA information is always used to override deterministic considerations, then this is a ‘risk-based’ approach, not a 'risk-informed' one [3].

There is a general agreement that RIDM has the potential [4] to contribute towards maintaining and improving nuclear safety. It can complement the deterministic approach to nuclear safety and maintain the concepts of defence in depth and adequate safety margins. However, risk-informed decision-making is a broader concept than just the use of PSA [5]. RIDM uses the results of PSA as one input to the decision-making process, but allows for consideration of other factors, in particular aspects of safety management and safety culture. At present these aspects are included in PSA only to the extent that they are reflected in the plant-specific data used, but they are not explicitly modelled in PSAs. RIDM is a process, which can be used by the utility and the regulator, and provides the framework for risk-informed regulation. The objective is to enhance regulatory effectiveness, using risk information to optimise nuclear safety regulations by eliminating regulatory requirements that are shown to be unnecessary in the light of this information, and thus to reduce regulatory burdens.

Whether risk-informed regulation is of benefit to utilities depends to a large extent on the common understanding developed with the regulatory authorities. Since the preparation of a PSA imposes a considerable burden, in terms of the human and financial resources that need to be expended, it is of utmost importance to define clearly what is expected from the utility and how the results will be used. This common understanding can be developed in a dialogue that includes all stakeholders. RIDM will strengthen the perception that the operator is assuming the primary responsibility for safe operation.

RIDM in areas that affect licensee requirements necessitates review (and, ultimately, approval) of PSAs and supporting information by the regulatory body. A suitable regulatory framework and regulatory staff with considerable technical capabilities in the areas of PSA and risk-informed decision-making are prerequisites for such review and approval. This constitutes a considerable burden for countries with small nuclear programmes and limited numbers of regulatory staff.

It is necessary to ensure the availability of high quality PSAs to support RIDM. The meaning of ‘high quality’ in this context can vary and is defined as being commensurate with the intended use. Several IAEA as well as EU Member States have developed national PSA guidelines, and the IAEA has prepared guidance on "PSA Quality for Applications" at the international level [6]. An American Society of Mechanical Engineers (ASME) has developed standard on PSA [7, 8]. Additional efforts to promote the production of high quality PSAs include peer reviews, establishment of user groups for similar type of plants, pooling of data and preparation of reference PSAs.

RIDM can be successful only if all stakeholders understand the process and the results obtained. The general public is an important stakeholder and it is necessary to find ways of communicating the results of RIDM to them.

In addition to the main nuclear regulatory body, a licensee has to deal with several other regulatory organizations, e.g. those responsible for environmental protection. If the concept of RIDM is not shared by these other authorities, this might complicate the decision-making process. Thus, consistency between the approaches followed by different authorities will be beneficial.

Although there are ongoing developments of systems to help support decision-making in emergency situations and for emergency planning (especially for emergency zoning around NPP) and some of these tools may use data obtained from the PSA, it is expected that the PSA itself would not be consulted to support the emergency response during an accident. With the accident in progress, the probabilistic nature of the PSA is not readily applicable and the data and methods are not in a rapidly accessible format. For efficiency and usefulness, the understanding of the range of outcomes from various events and actions and the impact of the different countermeasures should be or should already have been taken into consideration in the development of the pre-established NPP emergency plan [9].

5. PSA to SUPPORT EMERGENCY PLANNING

PSA of a NPP provides a comprehensive, structured approach to identifying failure scenarios and deriving numerical estimates of the risks to plant staff and members of the public as well. PSAs are normally performed at the following three levels [10]:

Level 1 PSA, which identifies the sequences of events that can lead to core damage, estimates core damage frequency (CDF) and provides insights into the strengths and weaknesses of the safety systems and procedures provided to prevent core damage.

Level 2 PSA, which identifies the ways in which radioactive releases from NPP can occur and estimates their magnitudes and frequencies. This analysis provides additional insights into the relative importance of accident prevention and mitigation measures such as reactor containment.

Level 3 PSA, which estimates public health and other societal risks such as contamination of land or food.

PSA provides a systematic approach to determining whether safety systems are adequate, the plant design balanced, the defence in depth requirement have been realized and the risk as low as reasonably achievable. These are characteristics of the probabilistic approach, which distinguish it from the deterministic approach. To date, PSA have been performed for more than 200 NPPs worldwide and are under various stages of development for most of the remaining NPPs. All of them have been done to Level 1 to provide an estimate of the core damage frequency for initiating events occurring during full power operation. Many of them also estimate the contribution to the risk, which would arise during low power and shutdown conditions. In some cases, the analysis has been extended to consider how the sequences would progress after core damage has occurred. This is often termed a Level 1+ (Level 1 plus) PSA, although the exact meaning of this varies from country to country.

However, the emerging standard in the past few years is for Level 2 PSAs to be carried out. A review of the use and development of PSA in OECD NEA member countries carried out by the OECD Committee on the Safety of Nuclear Installations (CSNI) and Working Group on Risk Assessment (WGRisk) in 2002 [11] provided details of the current status of PSA programmes including guidelines, various PSA applications, major results in recent studies and research and development topics.

The above-mentioned PSAs have been conceived for a wide variety of reasons, which include the following fully or partly relevant ones in terms of the present document:

- To provide insights from risk analyses to supplement those obtained from deterministic safety assessments;

- To estimate the risk from plants for comparison with the risk criteria;

- To address the phenomena that would occur during core damage and provide insights into how a plant would behave during a severe accident;

- To identify weaknesses in the level of protection provided for severe accidents;

- To identify additional safety systems and accident management measures that would provide further protection against severe accidents;

- To provide an input into emergency preparedness.

The state-of-the-art is to have a full scope Level 2 PSA (including external events and low power and shutdown) that is maintained as a 'living PSA' with regular updating. Modern computer technology allows frequent recalculations of the PSA to evaluate the impact of changes in operation or design and allows use of the PSA in various applications. There is a general agreement, as documented in various IAEA Safety Standards, that the deterministic approach to nuclear safety should be complemented by a probabilistic approach.

Though PSAs have been used extensively in the past, their use was usually limited to a variety of applications on a case-by-case basis as deemed necessary or useful. There is now a recent development, led by the USA and followed by several other countries, to move to a much expanded use of PSA in what is termed 'risk-informed decision-making' (see chapter 3). The main driving force behind this movement is the expectation that the use of risk insights can result in both improved safety and a reduction in unnecessary regulatory requirements, hence leading to a more efficient use of resources for NPP operators and the regulatory authority.

Historically, the use of probabilistic approaches for nuclear safety has always been more common in countries such as Argentina, Canada, The Netherlands, South Africa, UK and the USA as well as in some Scandinavian countries. Probabilistic considerations are also part of the IAEA international safety standards, e.g. the General Nuclear Safety Objective is defined in [12] as: *"to protect individuals, society and the environment from harm by establishing and maintaining in nuclear installations effective defence against radiological hazards."* This is supplemented by two complementary Safety Objectives related to radiation protection and technical aspects. The Technical Safety Objective requires one *"to take all reasonably practical measures to prevent accidents in nuclear installations and to mitigate their consequences should they occur; to ensure with a high level of confidence that, for all possible accidents taken into account in the design of the installation, including those of very low probability, any radiological consequences would* *be minor and below prescribed limits; and to ensure that the likelihood of accidents with serious radiological consequences is extremely low"*. It is specified that *"a safety analysis of the plant design shall be conducted in which methods of both deterministic and probabilistic analysis shall be applied"*.

The International Electrotechnical Commission (IEC) issued, in its International Standards No. 61508 [13] and No. 300-3-9 [14], dealing with the requirements for risk analysis and functional safety analysis of technological systems and specifying the scope of the analysis in general. They intend to provide guidelines for selecting and implementing techniques for risk assessment of technological systems. The objective of these standards is to ensure quality and consistency in the planning and execution of risk analyses and the presentation of results and conclusions.

There is international consensus that application of PSA can provide an in-depth understanding of the level of safety (mitigation of initiating events, prevention of core melt accidents and mitigation of severe accidents) achieved in design. It should be viewed as a complementary, additional tool in safety analysis that improves safety-related decision-making. PSA is not and cannot be a wholesale replacement of traditional safety methods or philosophies. From this document point of view, PSA has been found useful, among other recognised reasons because it provides a common understanding of the problem, thus facilitating communication among various stakeholder groups, and is an integrated approach, thus identifying the needs for contributions from diverse disciplines such as the engineering and the social and behavioural sciences [15].

The publication of the Reactor Safety Study WASH-1400 and subsequent conducted NPP PSAs had a tremendous impact on the thinking of nuclear safety experts. Two major insights from WASH-1400 were [16]:

- Prior thinking was that (no quantified) frequency of severe core damage was extremely low and the consequences of such damage would be catastrophic. The WASH-1400 calculated a Core Damage Frequency (CDF) in the order of 10^{-4} to 10^{-5} per reactor-year, a much higher number than anticipated, and showed that the consequences would not always be catastrophic.

- A significant failure path for radioactivity release that bypasses the containment building was identified. Traditional safety analysis methods had failed to do so.

This application of PSAs to operating plants has provided modelling techniques and quantification tools that are sufficiently proven and allow use of PSA for plant-specific decision-making (e.g. use of PSA in design and licensing for future PWRs, [2]).

There is an international consensus on a qualitative safety objective, which is to reduce the risk of accidental releases of radioactivity as compared to existing reactors, including severe accidents. To achieve this objective, in establishing additional requirements, even for Design Basis Accidents (DBA), Beyond Design Basis Accidents (BDBA) and other multiple failure situations, the PSA results should be used as a design input. Implementation of this approach should lead to the achievement, as stated in INSAG-3 [15], of a CDF less than 10^{-5} per reactor operating year to be considered for future reactors as a reference value. This value, as well as in some cases an objective for large early release frequency (LERF) of less than 10^{-6} per reactor operating year is in common use currently.

The scope of the design stage PSA should cover sequences leading to core melt (Level 1) and include a probabilistic assessment of the containment performance for core damage situations (Level 2). Besides, all operating states, including low power level and shutdown states should be analysed. Further, to overcome the generally known weaknesses in the use of PSA as a decision-making tool, it is advisable to use, among other, the following principles:

- Maintain deterministic criteria for design of safety systems in case of DBAs, supplemented by probabilistic requirements. In this case the PSA can help in achieving a balanced design and in evaluation of the different modes of operation, such as low power level/shutdown states.

- Establish requirements for BDBAs using a realistic approach and PSA insights, to identify the need for additional system requirements including redundancy and diversity in safety-related systems. Nevertheless, deterministic criteria should be applied where there would be uncertainties in the phenomenology of these situations or of operating conditions, such as for the containment design to cope with core melt sequences. These criteria should be established to ensure a safety margin to cover uncertain phenomena. The results of R&D programmes could help to rationalize the requirements, progressively adjusting the design in light of the results of the validated calculations, so eliminating safety margins shown to be unnecessary. That is why the report [1] supports the continuation of R&D programmes with the objective of obtaining better knowledge of severe accident phenomena.

- Define a coherent and harmonised methodology and acceptance criteria for the use of PSA for various relevant applications.

It shall be mentioned that the development of a common approach for application of PSA during the licensing process is much more difficult than for the design process. This results from the current differing balances between probabilistic and deterministic approaches within existing national regulatory environments. Some countries have a largely deterministic framework, where PSA is used mostly as a method to check and evaluate the design. Others base their regulation ultimately on demonstrating tolerable risk to society, where probabilistic criteria have to play significant part in demonstrating the justification of a plant’s acceptability, although these are underpinned by the need to demonstrate that some deterministic engineering principles are being followed in the design. These positions are not mutually exclusive, however, they are difficult to accommodate within a single methodology.

In conclusion, the common international approach to the further improvement of NPP safety is a well-balanced combination of the deterministic approach and the use of PSA as a complementary tool.

5.1 NPP Safety Management

Safety management of the NPPs is a relatively new concept that builds on the experience gained from the Three Mile Island and Chernobyl accidents. It incorporates insights derived from severe accidents research programs now at various levels of completion. Fortunately, serious nuclear accidents are very rare. As a result, there is very little practical experience with emergency response to a reactor accident.

Basically, safety management is divided into three parts:

- Accident management;
- Emergency management;
- Risk management.

Accident management combines elements of plant design and operating configuration with operator guidelines and procedures to optimize the capabilities of preventing, arresting the progress, or mitigating the consequences of potentially severe accidents.

Emergency management has to protect the public from the effects of actual release of radioactive material from a NPP. Successful accident-management strategies reduce the need to implement emergency plans. Emergency planning generally refers to the development of plans to keep the radiological consequences of an accident below specified limits. For NPPs, both onsite and offsite emergency response plans are required. This is because a severe accident at NPP could impact individuals located some distance away from the power plant. Planning encompasses organization, notification procedures, emergency facilities and equipment, and training. Emergency preparedness generally refers to readiness of a nuclear plant staff and government authorities to implement the plan when needed. Accident management interfaces with emergency management in the NPP control room. The operating crew keeps the plant under control. However, the same crew initiates the execution of emergency plans.

Regarding *risk management*, risk is a quantitative measure of accident loss potential in terms of both the event likelihood and consequences. Likelihood is determined in terms of either frequency (how often can this happen) or probability (what are the chances this will happen). Consequences are expected effects from the accident, usually measured in terms of health impact, property damage and environmental impact.

Fig. 5.1 shows the relationships among accident management, emergency management and risk management [17]. Although there are some obvious overlaps and multiple interfaces, distinctions are reasonably clear.

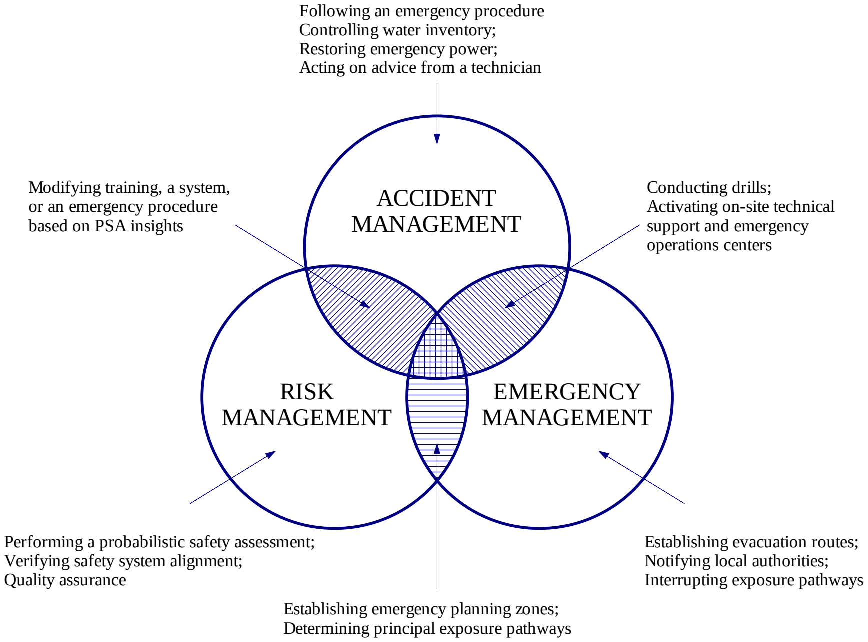

Fig. 5.1 Relationship among accident management, emergency management and risk management.

Risk management comprises the analyses, decisions and actions that are designed to minimize risk. Documented risk analysis forms the technical basis for risk-management decisions and actions. Risk management focuses on the possibilities of an accident; accident management deals primarily with the realities of the moment. Risk management is successful if it reduces the need for both accident management and emergency management.

In the next part of this chapter, a more detailed description is given for all three parts of safety management.

5.2 Radioactive Release Management within Accident Management

Management of radioactive releases is, together with management of pressure vessel and containment, a part of accident management. Once the containment has failed, the safety objective is to mitigate the fission product release. This objective can be achieved by controlling dispersed fission products, suspended fission products in the containment atmosphere, and fission products residing in water and by increasing retention time. Explicit mechanisms have been identified that contribute to the transport of fission products to the containment. These include flow-through power operated relief valves (PORVs) or safety relief valves, primary system piping boundary failure, and vessel bottom head failure. There is not a great deal that can be done in the case of dispersion due to primary boundary failure. A possible measure, feasible for small breaks, is to direct some of the primary coolant through the PORVs to the quench tank. Adverse consequences, such as possible acceleration of core damage, would have to be assessed before initiating this measure.

The release of fission products outside the containment can be caused by isolation failure, steam generator tube rupture (SGTR), and interfacing loss of coolant accidents (LOCA) outside the containment. If the re-isolation attempts failed as a result of equipment failure or the inability to isolate the leak, depressurization of the containment would result in a reduction of driving forces across the leak. Further measures to consider include containment spray systems and strategies to ensure that fission products in the containment water remain inside.

Control of fission products in the containment atmosphere means managing aerosol and gaseous dispersion. A range of measures have been considered: spray systems, chemical additives, filters, chemically reactive materials such as charcoal beds, or increased surface areas or cold surfaces to promote plate-out and condensation. Conservative assessments indicate, for instance, that the aerosol concentration in the containment atmosphere will decline by four to five orders of magnitude within a 5-day period.

Nuclear installations are sited, designed, constructed, commissioned, operated, and decommissioned according to strict requirements and regulations. They have been developed to protect the health and safety of plant personnel and the public. Despite these precautions, the possibility of an accident leading to a nuclear emergency cannot be excluded entirely. Such emergency might result in the release of radioactive material to the environment and the exposure of plant personnel. The release of radioactive material might also have potential consequences for the general public and for property outside the nuclear installation. Therefore, the on-site and off-site emergency actions have to be planned in advance that might be necessary to mitigate such consequences.

No operating license for a NPP will be issued unless a finding is made by the nuclear regulatory authority that there is reasonable assurance that adequate protective measures can and will be taken in the event of a radiological emergency. In other words, an operating license will be granted only if adequate emergency plans have been developed.

The proper response to an emergency requires an understanding of the hazards. A plan can provide the right people with the information they need to respond properly during an emergency. When available, the results of the Level 2 and Level 3 PSA would provide the most important information in this area.

To develop an emergency plan, several bases of knowledge are required. The three principal bases of knowledge are knowledge of phenomena, plant knowledge, and human factors knowledge. Understanding of degraded core behaviour, containment phenomena, and fission product behaviour have particular importance in emergency plans to manage severe accidents. Such knowledge is available from studies and evaluations of severe accident sequences. The plant-specific PSA studies are important source of information. They indicate how the plant would respond physically to accident-initiating events and to subsequent automatic and manual actions.

Plant knowledge refers the existence and status of plant systems, their associated controls, and their accessibility and operability under design-basis and severe accident conditions. Plant knowledge information represents the means by which operators respond to accidents. This information can be given in the form of a systems analysis or a set of plant drawings and descriptions, or it may exist only in the minds of plant personnel.

Human-factors knowledge provides ways to identify the steps that have to be performed and the decisions that have to be made. It has impact on probability of success and how those steps can be put to the form of written procedures or other appropriate guidance in the best way.

Emergency planning consists of the development of strategies to protect the public in situations of severe reactor accident. The reason for developing these strategies is that during the first hours of an accident at an NPP, critical decisions may be necessary for actions to protect the public; moreover, balanced protective actions will be required in the long term.

During the first few hours of an accident at a NPP, plant conditions are major determining factors in developing early protective action recommendations. The plant operator is responsible for mitigating the consequences of an accident and for recommending to off-site authorities protective actions that are commensurate with the severity of the accident. These public officials are responsible for making decisions on the actions necessary to protect the public and for transmitting these decisions to the public.

The regulatory body responsible for the plant shall monitor the actions of the plant operations staff and may provide guidance, recommendations and advice concerning the protective actions to both the operators and public officials. The plant operator and public officials would use such guidance in developing their emergency plans and implementing procedures.

The basic premise in emergency planning, and this is supported by PSA results, is that in the unlikely event of a severe core damage accident, plant operators cannot predict with certainty the occurrence of a radiological release, the magnitude and duration of any such release, or the radiological consequences of the release. The protective actions must be taken in light of these uncertainties, i.e. knowing the possible range of risks. As stated in IAEA-TECDOC-1200 Applications of PSA for NPPs [10], most emergency plans in IAEA Member States were originally developed on the basis of release and dispersal calculations for a selected set of postulated accidents. This obviously applies also for EU Member States.

A major effort has been undertaken for about 25 years to obtain a better understanding of fission product transport and release mechanisms in LWRs under accident conditions, including severe accidents. The state of knowledge today is such that conservative and rather conservative assumptions can be abandoned in favour of best estimate assumptions and models, coupled with sensitivity analysis. Current practices for DBAs still make large use of deterministic assumptions and models. Nevertheless, a general trend is application of realistic assumptions and methods, similarly to what is generally applied in the field of severe accidents. For DBAs appropriate margins must be included in the assumptions and models to account for the uncertainties in the predictions [2].

A main safety objective for the next generation of NPPs is to significantly reduce the possibility of significant radioactive releases to the environment, even in the case of core melt accidents, so that only very limited protective actions are required in area and time [2]. This is also in agreement with GPR/RSK proposal [18], the reference to that is taken from the European TSO Study [2].

To achieve the general safety objective described above, the main strategy, as proposed by GPR/RSK and follow-up formally approved by the safety authorities of France and Germany for next generation of plants, is to "practically eliminate" severe accident sequences which could lead to large early releases and to substantially improve the containment function for all other severe accident sequences, so that the off-site release objectives are met. A situation is considered practically eliminated if it is physically impossible or if proper design provisions are taken to make it extremely unlikely with a high degree of confidence. "Practical elimination” of severe accident sequences which could lead to large early releases means that, concerning these sequences, when they cannot be considered as physically impossible, sufficient design and operation provisions have been taken so that these sequences can be considered as extremely unlikely with a high degree of confidence. The demonstration would be provided through deterministic and/or probabilistic means.

The European TSO study [2] also made use of the requirements developed by the European utilities and takes advantage of the recommendations made by the French and German nuclear safety advisory groups: “Groupe Permanent chargé des Réacteurs nucléaires” and "Reaktorsicherheitskommission" (GPR/RSK). The study agrees with the GPR/RSK position, concerning the radiological consequences of low pressure core melt accidents (the sequences leading to early containment failure having been "practically eliminated”), that *”… the associated maximum conceivable release would necessitate only very limited protection measures in area and in time. These would be expressed by no permanent relocation, no need for emergency evacuation outside the immediate vicinity of the plant, limited sheltering, and no long term restrictions in consumption of food. Calculations of potential radiological consequences shall take into account realistic assumptions and parameters. … due to the wide range of potential accident conditions in severe accident situations, the achievement of this objective has to be demonstrated by the calculation of the radiological consequences of different representative accident sequences which have to be precisely defined, depending on the design of the plant”.*

Regarding the subject of radiological consequences for DBAs, which is complementary to the ones covered in the key issue of reduced environmental source term and emergency plan, the "1995 Consensus Document" of the RSWG [19] concludes as follows:

There is currently a lack of consensus on both the methodology and data that are used for licensing calculations for both the faults considered (large LOCA and steam generator tube rupture (SGTR)) and the sequences considered for SGTR faults. It is therefore recommended that there is an endeavour to increase the level of harmonisation in the licensing process. It is also recommended that future harmonisation on calculations of radioactive releases and environmental consequences be based on realistic assumptions. As mentioned in [2], the European TSOs agreed that this trend should be encouraged.

Regarding severe accidents and future plants, it is recognised that *"further reduction of environmental impact and simplification of emergency planning are sought as important targets in some countries".* The TSOs pointed out that the possible simplification of emergency planning should remain a matter of national concern.

As stated in the European TSO study [2], an ideal framework for new NPPs in Europe would be a harmonised set of European safety objectives and related calculation methodologies, so that the different results obtained in different countries for similar plants and scenarios could be explained mainly in terms of plant-specific features and site conditions rather than in terms of different (often arbitrary) assumptions or calculation tools.

Based on the previous considerations, at least two objectives for further work can be formulated:

- Harmonisation of requirements concerning the radiological consequences of any postulated event (within or beyond DBAs):

The internationally accepted common approach is that the recommendations given in ICRP Publication 63 "Principles for Intervention for Protection of the Public in a Radiological Emergency" [20] and the IAEA Safety Series No. 109 "Intervention Criteria in a Nuclear or Radiation Emergency" [21] can be regarded as widely agreed references concerning the initiation of protective actions. The ICRP recommendations provide relatively high intervention levels for the "nearly always justified" protective actions (e.g. 500 mSv for evacuation), while it provides a rather wide range of values for the so-called "optimised values" (50-500 mSv for evacuation). The above cited IAEA document [21] provides relatively low "generic intervention levels" (for example 50 mSv for evacuation), which may be lowered or increased based on local conditions as, for example, population density, adequate transportation, weather conditions, etc. These levels were formally approved by the IAEA International Basis Safety Standards for Protection Against Ionising Radiation and for the Safety of Radiation Sources, Safety series 115 [22]. It seems to be consensus that new NPPs should be designed in a way taking into account ICRP document [20] as well as other relevant documents, such as the two above-mentioned IAEA documents [21, 22] and of course the ALARA approach. In this way it would be possible to claim minimal protective actions, as suggested by the GPR/RSK recommendations, and provide the technical bases for a simplification of the emergency planning for those countries where this is sought as an important safety objective.

- Harmonisation of the assumptions and methodologies for the quantification of the radiological consequences of representative postulated accident sequences (within or beyond DBA conditions) at a NPP in Europe:

It is necessary to mention that fairly large and noticeable differences currently exist in different countries regarding the radiological consequences of DBAs. These differences are mainly due to the use of deterministic rather than risk-informed assumptions. Development and use of harmonised assumptions and methodologies, at least in Europe, is also recommended in the European TSO study [2], so that different results in different countries could clearly be justified mainly due to different plant features and/or specific site conditions.

5.3 *Emergency Response within Emergency Management*

The overall objective of emergency response is to reduce radioactive release for a spectrum of accidents that could produce excessive off-site doses. In the event of an accident, the plant is required to classify the initiating conditions. Example is provided from [23], describing the US approaches. The four emergency action levels are defined as follows: unusual event, alert, site area emergency, and general emergency (see Fig. 6.2).

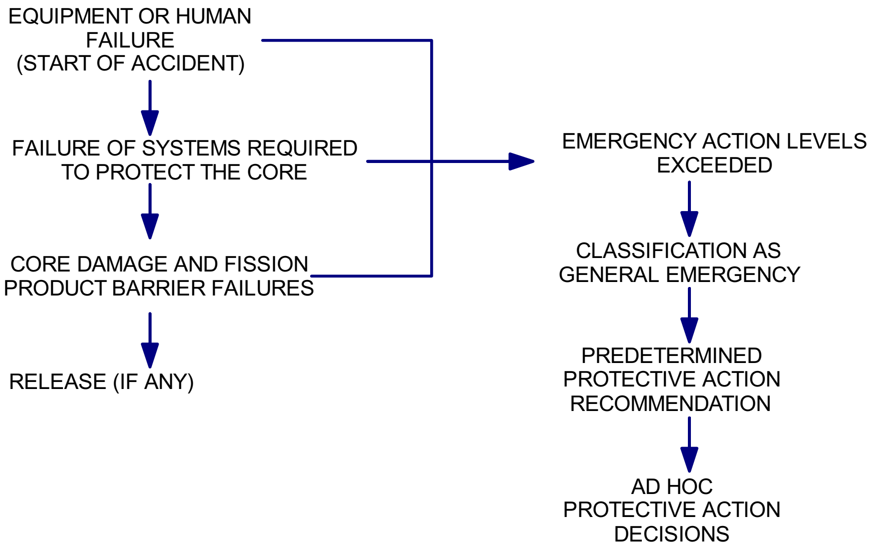

Fig. 5.2 Emergency action levels to classify accidents and recommend actions

Radiation exposure from a nuclear accident can produce two different types of health consequences, each of which has very different implications for emergency planning. First, severe radiation exposures (greater than 0.5 - 1.0 Sv), within a short period of time such as a day, can lead to destruction of cells in the body and produce a variety of injuries and sicknesses. For more extreme exposures greater than 2.0 - 3.0 Sv, such injuries can be fatal and, for exposures greater than 5.0 Sv, death is the most likely outcome [23]. Second, radiation exposures of any severity may damage generic material in cells. Thus, one objective of emergency response is to keep everyone, or as many people as possible, well below exposures great enough to produce early injuries or death.

5.4 Exposure Protective Options

The exposure protective options represent the consequence mitigation part. The main options for preventing and limiting exposures are:

Evacuation. The best strategy for preventing serious exposures, if feasible, is to evacuate people from the area before the radioactive materials arrive.

Sheltering. Placing barriers between the radioactive materials and people is effective for some releases. The most commonly available and suitable barrier is a building, the walls and roof of which attenuate to some extent the gamma radiation. The heavier the construction, the more effective the shielding; basements are particularly advantageous locations.

Respiratory protection. Breathing through any of a variety of materials – facemasks, tissues, towels, or other cloth – offers significant protection against the inhalation of particles.

Relocation. If large amounts of radioactivity persist in the area, sheltering is not a sufficient protective measure, and people must be moved from the area until it is decontaminated.

Potassium iodide (KI) prophylaxis. Iodine uptake by the body can be blocked by the ingestion of stable iodine prior to, or immediately after, exposure. If taken properly, potassium iodide will help reduce the dose of radiation to the thyroid gland from radioactive iodine, and reduce the risk of thyroid cancer.

Decontamination of people. Apart from removing people from the vicinity of radioactivity or using barriers, it is, in some situations, desirable to remove radioactive materials from the immediate vicinity of people. Decontamination includes removing contaminated clothing and washing off external contamination.

Decontamination of land and buildings. This is not generally considered an emergency response; however, it is important to remember that the significant off-site economic costs of a major accident will be for attempted decontamination and for property that is unusable because it cannot be sufficiently decontaminated.

Protection of the food chain. Ingestion of contaminated food and water can account for nearly half of the aggregate population's exposure to radioactivity. Food-chain interventions are thus crucial to emergency response efforts directed toward delayed health effects.

Medical treatment. Finally, there is a need for medical efforts to alleviate consequences. Medical care entails screening and follow-up capabilities and the possibility of deploying a significant medical infrastructure.

6. CURRENT APPROACHES TO EMERGENCY PLANNING IN SELECTED COUNTRIES

One of the first steps of this project consisted in the collection of relevant information about current practices in different countries on defining the emergency plans and the associated emergency planning zones and on implementation of Level 2 and Level 3 PSA results into emergency planning. This chapter presents the collected information.

Besides some relevant general information, information from the following areas has been collected:

- Basis for the emergency planning;
- Definition of emergency planning zones (EPZ);
- Status of the Level 2 PSA for the NPPs;
- Requirement to provide information for the public living in the EPZ in the event of radiological emergency;
- Future activities for implementation of Level 2 PSA results into emergency planning.

The following EU countries were involved in this information collection exercise: 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.

The obtained information is presented in detail in Appendix A. In the next part of this chapter the information is evaluated.

6.1 Information Sources

The main sources of information were:

- National Reports under the Convention on Nuclear Safety [24-28], prepared by the nuclear regulatory authorities (information provided from Czech Republic, Hungary, The Netherlands, Slovak Republic and UK).
- Personal discussions of the authors of the RELKO report [1] with representatives of the nuclear regulatory authorities and relevant research institutes of the participating countries (information provided from Czech Republic, Hungary, The Netherlands, Slovak Republic and UK) [29-33].

- The first interim report on ”Use of Level 2 PSA information as a basis for emergency planning” [34], prepared by Ch. Shepherd, HSE NII, UK, within OECD-NEA WGRisk task group (information provided in a form of questionnaire from Belgium, Finland, Hungary, Japan, Slovak Republic, Spain and the United Kingdom).

- Generic Environmental Impact Statement for License Renewal of Nuclear Plants [35, 36], US NRC Radiation Protection and Emergency Preparedness home page. Obtained from the USA by e-mail communication [37].

6.2 Emergency Preparedness in Selected Countries

Emergency preparedness means to be ready for emergencies before they happen. It is a prudent defence-in-depth measure regardless how small the probability of a serious reactor accident is. The objective is to mitigate public health consequences in the unlikely case of a reactor accident.

The combined efforts of the nuclear regulatory authorities, the government officials and the NPP operators have produced comprehensive emergency preparedness programs in each country that assure the adequate protection of the public in the event of a radiological emergency. The emergency preparedness process incorporates the means to rapidly identify, evaluate and react to a wide spectrum of emergency conditions. Emergency plans are dynamic and are routinely reviewed and updated in order to reflect an ever-changing environment.

The nuclear regulatory authority issues reactor operating licenses, which require an acceptable, integrated emergency plan (i.e., both on-site and off-site planning) that provides reasonable assurance that adequate protective measures will be taken in the event of a radiological emergency.

The government officials have the overall responsibility of deciding and implementing the appropriate protective actions for the public during a NPP radiological emergency. They are responsible for notifying the public to take protective actions, such as evacuation, sheltering or taking of potassium iodide pills. The officials base their decisions on the protective action recommendations provided by the NPP and their own radiological or health organization. The nuclear regulatory authority provides oversight and guidance of the protective action decided by the government officials. However, neither the NPP operator nor the regulatory authority can order the public to take protective actions.

In each of the countries participating in this project, the appropriate measures have been taken to ensure that there are on-site and off-site emergency plans that are routinely tested for nuclear installations and cover the activities to be carried out in the event of an emergency.

During the licensing of a NPP not only DBAs but also BDBAs (which are normally not covered by the Safety Analysis Report and other licensing documentation) are taken into consideration in each country. BDBAs are used to define the EPZs. The consequences of such events could lead to releases into the environment and subsequently to an radiological impact exceeding the impact of releases occurring as a result of DBA.

The population within the EPZ closest to the plant is at greatest risk of exposure to radiation and radioactive materials. The purpose of radiological emergency preparedness is to protect people from the effects of radiation exposure after an accident at a NPP. Evacuation is the most effective protective measure in the event of a radiological emergency because it protects the whole body (including the thyroid gland and other organs) from all radionuclides and all exposure pathways. However, in situations when evacuation is not feasible, in-place sheltering is substituted as an effective protective action. In addition, administering potassium iodide is a reasonable, prudent, and inexpensive supplement to both evacuation and sheltering. When the population is evacuated out of the area, and potentially contaminated foodstuffs are prohibited, the risk from further radioactive iodine exposure to the thyroid gland is essentially eliminated.

The above-described principles of emergency planning apply to each country participating with information in this project. As described in the next subchapter, differences are in the definitions of EPZs.

6.3 Basis for Emergency Preparedness

Generally, accidents are categorized as DBA (i.e., the plant is designed specifically to accommodate them) or BDBAs. The likelihood of a BDBA is generally lower than a DBA but the consequences may be higher. To determine the response to accidents, both deterministic design basis and probabilistic beyond design basis accident analyses are performed.

There are two basic approaches to emergency planning: a deterministic approach based on DBAs and a probabilistic approach based on the probabilistic assessment of BDBAs.

6.3.1 Deterministic Emergency Planning

As already mentioned, the approach to emergency planning in EU Member States is strongly deterministic. The usual approach is that a reference accident has been defined (usually the DBA) which is then used as the basis for developing and setting up the emergency plans. From the EU Member States, only the Czech Republic and the UK informed about using Level 2 PSA results in a formal way as input into their emergency arrangements (see Appendix A).

The main disadvantage of the deterministic approach is that it analyzes only the DBA, e.g. the worst credible accident. However, evaluation of hazards should never be limited to the selected reference accident but should always include the complete spectrum of potential occurrences. Each accident occurs differently and produces different consequences.

6.3.2 Risk-informed Emergency Planning

The proper response to an emergency requires understanding of the underlying hazards. Understanding of degraded core behaviour, containment phenomena and fission product behaviour is extremely important in emergency plans used to manage BDBAs. Such knowledge can be distilled from plant-specific Level 2 and 3 PSA studies.

PSA addresses a broad spectrum of initiating events by assessing the event frequency and consequences. Mitigating systems reliabilities are assessed, including the potential for multiple and common cause failures. The treatment therefore goes beyond the single failure requirements of the deterministic approach. As already concluded in WASH-1400 [42], PSA studies so far have shown that the CDFs are greater than what the industry had generally believed possible before the development of PSA methodology. This was attributed mainly to two safety-related principles that had governed early reactor design:

- The reactor was considered safe if it was designed for the DBA;
- Chances of accidents would be reduced tremendously if redundancy in safety-related components was employed.

The large LOCA is defined as the DBA against which the emergency core coolant system is designed. Similarly, the single failure criteria were applied to incorporate redundancy and diversity into the safety systems. The design criteria based on these concepts have traditionally been called deterministic design criteria. What these criteria had failed to demonstrate in the past and what PSAs successfully showed were accident scenarios involving multiple failures with significantly higher core damage frequency than expected.

The results of Level 2 and Level 3 PSAs also pointed to certain rare accidents, beyond the traditional design basis accidents that could dominate a plant's risk spectrum (for example steam generator tube ruptures bypassing the containment). Furthermore, the common cause failure issues raised in the PSA community have pointed out that redundancy does not improve the system reliability to the degree that reactor designers thought it did [38].

As can be seen from Appendix A, Level 2 PSAs are currently being carried out or are already available for the NPPs in all of the EU Member States analysed in this report. These PSAs give the radiological source terms and frequencies for the range of accident sequences that could occur. This information could be used in future as basis for preparing emergency plans.

The UK is the only Member State which has been carrying out research to consider how the Level 2 PSA information could be used in a systematic way for emergency planning purposes.

Based on the Level 2 PSA results for the Temelín NPP in the Czech Republic, it was found that no sequences identified in the PSA have more serious consequences than those sequences used as a basis for the (deterministic) determination of the EPZ size. This confirms that these accident sequences have been selected correctly [39].

Use of PSA results for this purpose in Japan is also limited [11, 34].

The practical application of the Level 2 PSA results for accident management is very limited. Furthermore, there is no Level 2 application for emergency management. Many NPPs do not have access to the technologies, which facilitate full-scope Level 2 or 3 PSAs that treat power operations, low power and shutdown operating modes, as well as accidents initiated by external events. Common internationally accepted standards for such extensive, in-depth analyses do not exist.

In summary, it would certainly be desirable that the overall emergency management was supported by Level 2 and Level 3 PSA results. The following two options could be offered:

- In the short term, a full-scope plant-specific Level 2 PSA with fission product transport capability would be needed for each NPP in the EU. Their results coupled with engineering and medical judgements would provide an acceptable basis for risk-informed emergency planning.
- In the longer term, it would be desirable that full-scope Level 3 PSAs for all NPPs should be available.

The USA is the only country, which has very extensive application of the Level 3 PSA methodology to emergency planning. The USA approach to the application of Level 3 PSA methodology is described in Appendix B, where the main results are presented for all US NPP sites.

6.4 Emergency Planning Zones

The following definitions of the emergency planning zones are given in the different countries [24-28, 34]:

Belgium: The general EPZs are associated with the following protective actions: evacuation (10 km), sheltering (10 km), stable iodine intake (20 km) and food chain (whole country). The size of these zones has been defined taking into account a rough (presumably largely deterministic) estimation of the associated risks.

Czech Republic: The predetermined evacuation of people is performed within 5 km internal zone around Temelín NPP and within 10 km internal zone around Dukovany NPP. The emergency planning zone is a territory of 20 km around Dukovany NPP and 13 km around Temelín NPP. The predetermined actions are sheltering and taking iodine tablets. The difference between the EPZ for Temelín NPP and for Dukovany NPP is due to different population densities, meteorological and evacuation conditions.

Finland: Rescue service plan (by rescue service authorities) for emergency preparedness zone (20+ km); advance iodine pellets and quick actions for 5 km zone.

Hungary: There are three planning zones: the smallest in radius of 3 km is the "precautionary protective action-planning zone" in which the measures are introduced without delay. This zone is surrounded by the next 30 km circle within which the "urgent protective action planning zone" can be found; and then the largest zone of 80 km is located. That is the "long term protective action planning zone". Concerning the latter two zones, special laws determine the intervention levels.

Japan: The EPZ is about 8 to 10 km for the facilities of commercial plants and research reactors with power levels greater than 50 MWt. The standard of EPZ is the zone which boundary (distance from the nuclear facilities) is defined so as to keep less than the lower limit of radiation exposure at the boundary, 10 mSv to whole body dose and 100 mSv to thyroid with sufficient margins supposing hypothetical accidents that cannot happen technically. Outside this range, there is no necessity of emergency actions such as sheltering and evacuation.

The Netherlands: The various zones for direct measures are defined geographically as follows: 1) Evacuation zone circle with a radius of 5 km, 2) Iodine prophylaxis circle with a radius of 10 km, 3) Sheltering zone: circle with a radius of 20 km. The measures in cases of nuclear emergencies are coordinated at the national level.

Slovak Republic: The EPZ is defined in relation to the maximum size of any radiation emergency that can be reasonably foreseen. The hazard area represents a circle with centre in the nuclear facility and radius 30 km for Bohunice site, and 20 km for Mochovce site. In case that the boundary demarcating the hazard area interferes with an inhabited area, then the whole inhabited area is considered as a hazard area. The difference in the EPZ for Bohunice NPP and Mochovce NPP is due to different population density, meteorology and evacuation conditions.

Spain: The definition is included in the Basic Nuclear Emergency Plan and it is common to all NPPs. These zones are predefined in function of the distance at the nuclear site (concentric zones) and of the wind direction (sector zones). The required different actions depend on each zone and the emergency situation. This is related to the emergency category, established in the Internal Emergency Plan and according to the Final Safety Assessment Report.

UK: For each nuclear licensed site in the UK there is a defined zone round the site – the Detailed Emergency Planning Zone (DEPZ) within which the arrangements to protect the public are planned in detail. The boundary of this zone is defined in relation to the maximum size of any radiation emergency that can be reasonably foreseen and ranges from 1 to 5 km. It is also recognised that radiation emergencies could occur that would have consequences beyond the DEPZ. The nature of the response required is more difficult to predict and will depend on a number of factors such as the characteristics of the release that has occurred and the prevailing weather conditions. To deal with this, there is a requirement that the emergency plans incorporate arrangements for “extendibility” beyond the DEPZ.

USA: To facilitate a preplanned strategy for protective actions during an emergency, there are two emergency planning zones (EPZs) around each NPP: 1) The plume exposure pathway EPZ has a radius of about 10 miles (16 km) from the reactor. Predetermined protection actions include sheltering, evacuation, and the use of potassium iodide where appropriate. 2) Ingestion Exposure Pathway EPZ. It has a radius of about 50 miles (80 km) from the reactor. Predetermined protection actions include a ban of contaminated food and water.

6.5 Information to the Public

The approach regarding the requirement to provide information for the public living in the EPZ in the event of radiological emergency is the same or similar in all countries evaluated in this project.

Immediately after becoming aware that an incident has occurred that may result in a radiation dose that exceeds the government protective action limits, responsible NPP personnel evaluate plant conditions and then make protective action recommendations to the government offices on how to protect the population. Neither the NPP operator nor the nuclear regulatory authority can order the public to take protective actions. The plant operator recommends to the appropriate government offices which protective actions (such as evacuation, sheltering, or taking potassium iodide pills) to take while the regulatory body provides oversight and guidance from its incident response centers.

The government response organizations are responsible for deciding which of the recommended actions are necessary to protect the public and for communicating these decisions to the public within a short time. Once the local emergency response organization has been activated, it will establish a local emergency operations centre to coordinate decisions and implementation of protective actions with other government organizations.

A prompt alert and notification system is in place to notify the public within the EPZ of a NPP. This system will be activated within a short time after the decision by government agencies of a need to take protective actions. This system typically uses sirens, tone-alert radios or a combination of these methods. After receiving the alert the radio or television stations identified in emergency information materials will provide information and emergency instructions to follow. Citizens living near a NPP receive emergency information annually on how they will be notified given a problem at a facility and what actions to take.

More detailed information for individual countries is provided in Appendix A.

7. INFORMATION TEMPLATE FOR EUROPEAN NPP RISK MAPPING

In recent years, particular attention has focused on Geographical Information Systems (GIS) which allow the merging of geographical, spatial or location data at the scale and extent of an accident with information on settlement patterns, infrastructure and characteristics of the affected population. Therefore, GIS can be used not only for pre-event vulnerability assessment but also for improving preparedness, mitigation and response plan activities.

Within this project, it is intended to ultimately arrive at a consensus on an information template for European NPP risk mapping, which could be integrated in a GIS for public information purposes. A proposal for such a template as well as for possible future activities in this area are given in this chapter.

7.1 The Required Parameters

Collection and access to information and data, as well as their most accurate evaluation are of paramount importance in the identification, assessment and prevention of risk. However, they are equally important to deal with emergencies before accident occurs, i.e. for identification of potential sources of accident, accurate appraisal of scale and impacts and knowledge of the human, technical and economic environment in which they occur. Quality information of this kind, especially when it embodies lessons learned from similar accidents serves various purposes: it helps to speed up the emergency response, it reduces the likelihood of unpleasant surprises and it contributes to ensuring the adequacy of the emergency response measures taken.

Nevertheless, the problem becomes much more complex when an accident affects more than one country, necessitating co-ordination of information and data to ensure that the emergency response can proceed effectively. For the purpose of the European NPP risk mapping it is necessary to map out possible parameters for describing the effects of nuclear accident on the community and for highlighting its vulnerabilities. Such parameters comprise health effects, damage to private property and environmental damage. The Level 3 PSA provides the required parameters for the NPPs.

However, the risk can be changed. Many factors could potentially increase the consequences to the general public resulting from a severe-accident release. A comprehensive listing and description of factors that influence consequences are provided for example in the NUREG/CR-2300 PRA Procedures Guide [40]. The primary assumption is that regulatory controls will ensure that the physical plant condition (i.e., the predicted probability of radioactive releases from an accident) will be maintained at a constant level during the plant lifetime. Therefore, the frequency and magnitude of a release will remain relatively constant. In other words, significant changes in consequences will result only from changes in the NPP external environment. Such factors include e.g. population density, meteorology, and evacuation. Studies have shown that some factors have a greater degree of influence than others; for example, population has a very strong influence over risk, e.g. NUREG-1150 [41]). Evacuation can have a significant influence on early fatality risk but a much more limited impact on latent fatality risk. Interdiction primarily reduces latent fatality risk. While particular aspects of meteorology, such as rainfall, can have a significant impact on peak risk values, mean health effect values are relatively insensitive to meteorology.

To illustrate these considerations, data for the Millstone NPP provide a good example of the process by which the risk can be influenced by external impact. The early fatality of 0.025 fatalities/y is predicted for 2050. This value is higher than that reported in the Millstone for the year 2010 (0.0008 fatalities/y) and represents the increase in early fatalities that could occur as a result of increased population around the Millstone site [35].

When the basic reasons for the risk influence of each factor are examined, these factors can generally be reduced to the following three issues:

- The number of people exposed to the severe accident release;
- The likelihood that any given individual receives an exposure;
- The amount of radiation the individual receives.

Consequently, site population (which reflects the number of people potentially at risk to severe accident exposure) and wind direction frequency (which reflects the likelihood of exposure) have been chosen as the primary factors affecting risks.

Two types of information sets are recommended to be involved in the information template for European NPP risk mapping for each NPP:

1) Generic information about the risk:

- Total expected early fatalities;
- Total expected late fatalities;
- Expected economic impacts;
- Expected amount of radiation the individuals receive depending on the distance from the plant.

2) Information about changes in the plant external environment (factors, which change the risk):

- Site population;
- Wind direction frequency.

If there are changes in the plant external environment, the risk would have to be recalculated.

7.2 Recommendations for the Future Activities

Before starting development of this project, JRC-IE conducted a basic preliminary search. Based on OECD NEA report entitled “The Use and Development of Probabilistic Safety Assessment in NEA Member States”, published in July 2002 [11] and the Working material of IAEA/US NRC Technical Committee Meeting on “Risk-informed Decision Making”, which was held in Washington DC, USA, in November 2001 [45], the following essential information and conclusions on relevant using PSA was found:

1. The proposed project Benchmarking and Harmonising Strategic Planning Practices for Emergency Zoning and Information to the Public sounded feasible and realistic. It might be useful to make a rather detailed search, including possibly interviews with some well-known PSA and emergency planning experts.

2. The most relevant experience/know-how might be found in Japan, The Netherlands, South Africa, UK and USA.

Further development of the project continued in close technical co-operation with RELKO Ltd, Engineering and Consulting Services, Bratislava, Slovak Republic. The present report is largely based on the report RELKO/1R1204 Benchmarking and Harmonising Strategic Planning Practices for Emergency Zoning and Information to the Public (Report prepared for JRC), December 2004, Bratislava [1].

Based on the state-of-the-art of developments and achievements in application of PSA technology, the original hypothesis to this project consisted in the view that it is currently already mature enough to be used also for NPP emergency risk zoning. However, at present it can be stated that there is still a need to build significant momentum towards the application of Level 3 PSA results for emergency planning in EU Member States. Therefore, a decision was made to approach some PSA experts on one side and emergency planning/radiation protection experts on the other, with the question: *Is incorporation of risk-informed support into NPP emergency planning currently a relevant enough topic to be treated by a technical seminar with a view to international harmonisation, or is the topic somewhat premature at the present stage*.

JRC-IE received a great many positive and even very positive responses with only very few rather reserved ones. That is why the organising of this seminar is one of the outcomes of the project as well (see Appendix C). After discussing the topical issues within the seminar, a follow-up decision should be made to effectively continue in relevant research and development (R&D) activities.

Regarding recommendations for future activities, from the review performed, it could be proposed to carry out a series of reviews of the NPP safety management in several countries, which could involve accident, emergency and risk management. The reviews would focus on the consistency of the related policies, on their ability to deal with the new challenges and on identifying opportunities for improvement and best practices. Such a project would have to show the applicability of the results for emergency managements and their limitations.

Preparation of full-scope Level 2 PSAs with fission product transport capability as well as of full-scope Level 3 PSA studies for each NPP in EU Member States should be encouraged.

To fulfill these objectives, the following steps could be considered:

- Identify sources of hazard and develop accident scenarios;
- Quantify the uncertainty of factors and parameters and evaluate the probability of scenarios;
- Evaluate consequences by determining the pathway to exposure (exposure assessment) and the response to exposure (dose-response assessment);
- Combine evaluated consequences and probabilities and compare them with risk limits;
- Evaluate sensitivity of results to changes in parameters;
- Summarize various elements of risk assessment to facilitate communication with relevant stakeholders, incl. general public;
- Perform risk reduction analysis, where the needs, options and their costs are compared;
- Make safety management decisions based on risk assessment results.

Finally, the development of a European NPP risk map based on plant-specific PSA results is considered an important task to present the risk from the use of nuclear power in a consistent and objective way to relevant stakeholders. The basis of such a mapping would have to be a harmonised "risk information template" at European level, based on the consensus of the developers and owners of this information.

Where consensus on publication of information at a European level cannot be achieved, it would be essential to clearly document the “sensitivities” of individual countries / stakeholders in terms of data confidentiality etc. Criteria to come to a corresponding European consensus are the relevance of information (sufficient level of detail), its easily understandable character and the acceptability for publication by national authorities in terms of different national legislation, values and habits. The mechanism to reach this consensus is consultation of experts from designated contact points in the participating countries and analysis of related legislation, as well as of plant-specific PSAs and other information resources used.

As a long term perspective, the development of a European risk map for all major hazardous industries (energy sector, process industries, transport etc.) could be put in place for discussion.

8. CONCLUSIONS AND RECOMMENDATIONS

The evaluation of a first set of information collected from different countries in the course of this project leads to the following **conclusions**:

1. There are significant differences in the way Member States have drawn up the emergency plans and have defined emergency planning zones.
2. The approach to emergency planning is strongly deterministic and almost no risk-based information is used.
3. The proper response to an emergency requires an understanding of the underlying hazards. The results of Level 2 and 3 PSAs provide important information in this area.
4. Level 2 PSAs are currently available for many NPPs in the EU. However, the results are practically not used in emergency planning.
5. Full scope Level 3 PSA is available only for very few NPPs in the EU.
6. There is a way of improving the existing approach to emergency planning in EU Member States: In addition to the deterministic approach, risk-based aspects to emergency preparedness should be implemented. Such an approach would also facilitate the development of a European NPP risk map in the future.

Recommendations for future activities are:

1. To enhance current NPP emergency planning practices by risk-informed aspects, Level 2 and 3 PSA results should be considered.
2. Full-scope Level 2 PSA covering fission product transport capability should be prepared for each NPP.
3. Full-scope Level 3 PSA should be developed in the longer term.
4. Regarding possible future activities of JRC, it could be proposed to prepare a Level 2 – 3 Pilot Project Study with the aim to show the applicability of the generic results for emergency management and risk zoning purposes.
5. Development of the European NPP risk map based on PSA results. As a first step, international consensus should be achieved together with the developers and owners of the "risk information" on a harmonised information template to publish corresponding results to different stakeholders, including the public, at a European level.
6. Long-term development of a European risk map for all potentially major hazardous industries.

7. For all these purposes, the creation of an international topical Working Group would be necessary.

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LIST OF APPENDICES

A: Essential Information on Emergency Planning in Selected Countries

B: The USA Approach to Emergency Planning

C: Call for Papers to Seminar on Emergency & Risk Zoning around NPP
26 – 27 April 2005, EC DG - JRC/IE Petten, The Netherlands

APPENDIX A

Essential Information on Emergency Planning in Selected Countries

Country	Definition of emergency planning zones (EPZ)	Requirement to provide information for the public living in the EPZ in the event of radiological emergency	Basis for the emergency planning	Status of Level 2 PSA for the NPPs	Future activities for implementation of Level 2 PSA results into emergency planning
Belgium	The general emergency planning zones associated with the following protective actions: evacuation (10 km), sheltering (10 km), stable iodine intake (20 km) and food chain (whole country). The size of these zones has been defined taking into account a rough estimation of the associated risks.	This requirement is also explicitly included in the general nuclear emergency plan and is based on the European Directive 89/618/Euratom. This includes information on: - Basic concepts of radiation and health effects - Types of emergencies and associated consequences - Emergency arrangements to alert, protect and assist the population during emergencies - Adequate expected response actions in case of an emergency.	The basis of the existing on-site NPP emergency plans is the general nuclear emergency plan giving a general structure of such plan and the post-TMI actions.	Level 2 PSAs have been made for Doel 1 and 2 and Tihange 1. These Level 2 PSAs are limited to a probabilistic analysis of containment failure modes, do not cover shutdown states and do not include source term analysis.	There are no plans in this area for the future.

Country	Definition of emergency planning zones (EPZ)	Requirement to provide information for the public living in the EPZ in the event of radiological emergency	Basis for the emergency planning	Status of Level 2 PSA for the NPPs	Future activities for implementation of Level 2 PSA results into emergency planning
Czech Republic	The predetermined evacuation of people is performed within 5 km internal zone around Temelín NPP and within 10 km internal zone around Dukovany NPP. Emergency planning zone is formed by a territory of 20 km around the Dukovany NPP and 13 km around the Temelín NPP. The predetermined actions are sheltering and taking KI tablets. The difference in the EPZ for Dukovany NPP and Temelín NPP is due to different population density, meteorology and evacuation conditions.	The off-site emergency plans set down targets and methods of ensuring the individual types of protective countermeasures: • Notification of government bodies and organizations, • Warning of people, • Sheltering people, • Evacuation of people, including dosimetric checks and decontamination at the exits from the endangered territory, • Regulation of persons movements within the endangered territory, • Health care. Public protection manual for the case of a radiation accident is distributed. The manuals contain information on the procedure the public shall follow after the warning signal within the emergency planning zone.	Reference accidents have been defined for each of the sites. This is considered to be the bounding accident for all units of nuclear power plant on the site. For the Temelín plant it was stated based on the Level 2 PSA results, that no sequences identified in Level 2 PSA have more serious consequences than those sequences used as a basis for determination of the EPZ size. It confirms that these base accident sequences have been selected correctly.	Level 2 PSA study is prepared for both Dukovany and Temelín NPP for full power and shutdown operating modes.	There are no plans in this area for the future.

Country	Definition of emergency planning zones (EPZ)	Requirement to provide information for the public living in the EPZ in the event of radiological emergency	Basis for the emergency planning	Status of Level 2 PSA for the NPPs	Future activities for implementation of Level 2 PSA results into emergency planning
Finland	Rescue service plan (by rescue service authorities) for emergency preparedness zone (20+ km); advance iodine pellets and fast actions for 5 km zone); no population centres or other activities that are difficult to evacuate.	By the government authorities the public is notified to take protective actions in case of emergency. Information manuals on radiation accidents are distributed every three years to every household in EPZ.	The legal basis to have a rescue service plan for emergency planning zone. No special accident sequence has been used as design basis.	A Level 2 PSA for Loviisa power plant has been made for full power, internal initiating events. Emergency plan is not based on probabilities or improbabilities. However, PSA has produced extensive information on accident sequences and releases to the environment; “typical” accident sequences with large releases, the release timing, magnitude and content, are listed in the plant emergency plan.	The accident sequences in PSA are going to be completed for external and area events, also for shutdown states. Also it is planned, but not yet decided – to make in advance some rough scenarios with accident sequences, source terms and recommendations concerning protective actions. Nevertheless, the information from PSA Level 2 is utilised when creating sequence descriptions for accident preparedness drills. The risk importances of different accident sequences have been changed in the past because of plant modifications done almost annually. This will continue some time, and has some effect on how specifically PSA results are used for emergency planning.

Country	Definition of emergency planning zones (EPZ)	Requirement to provide information for the public living in the EPZ in the event of radiological emergency	Basis for the emergency planning	Status of Level 2 PSA for the NPPs	Future activities for implementation of Level 2 PSA results into emergency planning
Hungary	Among the planning zones, the smallest in radius of 3 km, is the “precautionary protective action planning zone”, in which the measures to be introduced shall be implemented without undue delay with the necessary preliminary arrangements. This circle is surrounded by the next, 30 km, circle within which the “urgent protective action-planning zone” can be found; and then the largest one, of 80 km, the “long-term protective action planning zone” is located. Concerning the latter two, special laws determine the intervention levels, the taking into account of which shall be provided for determining the protective actions to be introduced.	In the frame of present Hungarian legislation the protection of the public is the task of the authorities (State Emergency Response Organisation), but in the early stages of an emergency the operator of nuclear facility must support the work of authorities. The public is warned by installed sirens (around nuclear power plant) or through radio and television. The operator of nuclear facility may also issue press statements and statements through radio, television and press after a discussion with Public Information Group. This group is a part of State Emergency Response Organisation.	The Emergency Plans of Paks NPP take into account emergencies with different releases and exposure pathways. A bounding accident is not defined, however, the detailed analyses of a serious accident sequence were considered during emergency planning.	Although the current Nuclear Safety Codes attached to the Decree of Government do not require Level 2 PSA studies to be performed for NPPs in Hungary, the Hungarian Atomic Energy Authority has requested this study from the NPP. The study devoted to the point estimation of radioactivity release and its conditions was completed last year and passed to the Authority for evaluation. Currently its uncertainty assessment is being performed.	Yes, during the preparation of serious accident management guides.

Country	**Definition of emergency planning zones (EPZ)**	**Requirement to provide information for the public living in the EPZ in the event of radiological emergency**	**Basis for the emergency planning**	**Status of Level 2 PSA for the NPPs**	**Future activities for implementation of Level 2 PSA results into emergency planning**
Japan	The EPZ is about 8 to 10 km for the facilities of commercial plants and research reactors with power levels greater than 50 MWt. The standard of EPZ is the zone which boundary (distance from the nuclear facilities) is defined so as to keep less than the lower limit of radiation exposure at the boundary, 10 mSv to whole body dose and 100 mSv to thyroid with sufficient margins supposing hypothetical accidents that cannot happen technically. Outside this range, there is no necessity of emergency actions such as sheltering and evacuation.	Upon the declaration of the emergency by national government, local public body shall immediately provide information to the members of the public who live in the vicinity of the nuclear facility.	The tentative distance for Emergency Planning Zone to nuclear power plant is proposed at 8~10 km in Japanese Guideline of nuclear radiation hazard prevention. This value is set that no sheltering would be needed for the people being beyond this distance.	Level 2 PSA results regarding severe accident sequences, radiological source terms, and frequencies for the range of accident sequences that could occur are used as the basis for developing the nuclear emergency plans and the severe accident management of LWR plants. The developed analytical models of Level 2 PSA can contribute to the advancement of the emergency planning as well as to the periodical PSA and the safety goal study.	There are no plans in the near future. First the future of Level 2 PSA will have to be discussed.

Country	Definition of emergency planning zones (EPZ)	Requirement to provide information for the public living in the EPZ in the event of radiological emergency	Basis for the emergency planning	Status of Level 2 PSA for the NPPs	Future activities for implementation of Level 2 PSA results into emergency planning
The Netherlands	The various zones for direct measures are defined geographically as follows: • Evacuation zone: circle with radius of 5 km; • Iodine prophylaxis: circle with radius of 10 km; • Sheltering zone: circle with radius of 20 km. It should be noted, however, that measures in cases of nuclear emergencies are coordinated at the national level.	The central government is responsible for informing the population. It does this in conjunction with the local authorities in question.	The Borssele NPP has established the levels from the IAEA system in its Emergency Plan: 1) Emergency standby; 2) Plant emergency; 3) Site emergency; 4) Off-site emergency	In the early 1990s the Level 1+ PSAs were expanded to full-scope Level 3 PSAs, including internal and external events, power and non-power plant operating states, human errors of omission and commission. The PSAs were expanded partly to comply with the requirement that the studies should be “state-of-the-art” (i.e. non-power plant operating states and human errors of commission), and partly because of the licensing requirement associated with the ongoing modification programmes (i.e. an Environmental Impact Assessment had to include a Level 3 PSA).	No.

Country	Definition of emergency planning zones (EPZ)	Requirement to provide information for the public living in the EPZ in the event of radiological emergency	Basis for the emergency planning	Status of Level 2 PSA for the NPPs	Future activities for implementation of Level 2 PSA results into emergency planning
Slovak Republic	The EPZ is defined in relation to the maximum size of any radiation emergency that can be reasonably foreseen. The hazard area represents a circle with centre in the nuclear facility and radius of 30 km for Bohunice site, and 20 km for Mochovce site. In case that the boundary demarcating the hazard area shall interfere with an inhabited area then the whole inhabited area is considered as a hazard area. The difference in the EPZ for Bohunice NPP and Mochovce NPP is due to different population density, meteorology and evacuation conditions.	Based on the national legislation, operator of nuclear facility shall take such measures and steps as will create preconditions for the prevention, overcoming or mitigation of the consequences of accidents, and inform the public of such steps and measures. Operator has prime responsibility for preparation of on-site emergency plan; local authorities have prime responsibility for preparation of off-site emergency plan within regions, districts, and communities, including public information.	A reference accident has been defined for nuclear facilities on the site bounding for each type of facilities on the site. For example, for the WWER440/V213 nuclear power plants, the accident sequence is defined as a large loss of coolant accident (large LOCA). It leads to rapid depressurisation of the primary circuit with core damage and reactor pressure vessel failure. The radioactive release from this event has been translated into quantities of specific radioactive isotopes.	The full power and shutdown Level 2 PSA is completed for unit 1 of the Bohunice V-1 NPP (2xWWER440/V230) and for the unit 3 of the Bohunice V-2 NPP (2xWWER440/V213). The Level 2 PSA for the Mochovce NPP (2xWWER440/V213) is under preparation. Level 3 PSA study has not been prepared yet, but particular supportive deterministic radiological analyses are available and documented in separate reports (distribution of radioactive materials in the environment and food chains, and calculation of offsite doses in the areas of nuclear facilities.	A harmonisation process of emergency preparedness and planning between the national nuclear installations is going on in Slovakia. This process takes into account changes in legislation (EU directives, IAEA recommendations, international good practice, accident management, state-of-the-art methodology) as well as significant safety improvements done in last years. Results of Level 2 PSA will be used in identification of the most risky scenarios and consequences to be applied in the emergency plans.

Country	Definition of emergency planning zones (EPZ)	Requirement to provide information for the public living in the EPZ in the event of radiological emergency	Basis for the emergency planning	Status of Level 2 PSA for the NPPs	Future activities for implementation of Level 2 PSA results into emergency planning
Spain	The definition is included in the Basic Nuclear Emergency Plan and it is common to all nuclear power plants. These zones are predefined in function of the distance at the nuclear site (concentric zones) and of the wind direction (sector zones). The required different actions depend on each zone and the emergency situation. This is related to the emergency category, established in the Internal Emergency Plan and according to the Final Safety Assessment Report.	Basically, this requirement is the same that included in the 89/618/EURATOM Directive and, transferred to the Spanish Regulations by the “Acuerdo del Consejo de Ministros relativo a la información del público sobre medidas de protección sanitaria aplicables y sobre el comportamiento a seguir en caso de emergencia radiologica”. This Regulation contains the minimum information to be supplied to all members of the public, before and during an Emergency. The public institutions are responsible for implementation of these actions.	According with the FSAR, the Internal Emergency Plan of each nuclear plant includes the starting events categorized for the possible effects over the members of the public (in four enveloped groups). For each category, it sets out the possible radiological consequences, and it predefines the actions to carry out. The External Emergency Plan establish “a priori” radiological levels for actuations, but in the beginning of the emergency, the procedures to carry out can be related to the emergency category defined in the internal emergency plan.	Level 2 PSA has been carrying out for all the Spanish NPPs (2 BWR GE-design, 6 PWR W-design and 1 PWR KWU-design). The analyses include release categories grouped by percentage and time and using the LERF concept as the main result for others PSA applications. For the most relevant categories there are representative source terms obtained from specific analyses. There is no Level 2 PSA for shutdown states yet. A pilot project for two reference Plants is planned to be done. External events are not analysed in the Level 2 PSA.	No, there are not at present.

Country	Definition of emergency planning zones (EPZ)	Requirement to provide information for the public living in the EPZ in the event of radiological emergency	Basis for the emergency planning	Status of Level 2 PSA for the NPPs	Future activities for implementation of Level 2 PSA results into emergency planning
UK	For each nuclear licensed site in the UK there is a defined zone around the site, the Detailed Emergency Planning Zone (DEPZ), in which the arrangements to protect the public are planned in detail. The boundary of this zone is defined in relation to the maximum size of any radiation emergency that can reasonably be foreseen and ranges from 1 to 5 km. It is also recognised that radiation emergencies could occur that would have consequences beyond the DEPZ. The nature of the response required is more difficult to predict and will depend on a number of factors such as characteristics of the release that occurred and prevailing weather conditions. To deal with this, there is a requirement that the emergency plans incorporate arrangements for "extendibility" beyond the DEPZ.	If a radiation emergency is reasonably foreseeable, the plant operator is required to provide members of the public in that area with information on the actions that they may need to take. A radiation emergency is defined as an event that is likely to result in any member of the public receiving a dose in excess of the specified levels – given as an effective dose of 5 mSv, or an equivalent dose of 15 mSv for the lens of the eye or 50 mSv for the skin. There are the effective doses that would be accrued within one year following the radiation emergency with no credit being taken for health protection countermeasures such as stable iodine tablets during the first 24 h following the radiation emergency. For UK sites, information is supplied to all the members of the public inside the DEPZ.	A reference accident has been defined for each of the sites in the UK. This is considered to be the bounding accident for the type of nuclear power plant on the site. For example, for an Advanced Gas Reactor (AGR), the accident sequence is defined as a major failure of the coolant circuit leading to a rapid depressurisation of the primary circuit with one of the channels of the reactor overheating and catching fire. The release from this has been translated into quantities of specific radioactive isotopes. One licensee has used Level 2 PSA information to optimise the emergency planning arrangements using a probabilistic approach.	A full scope Level 3 PSA has been carried out for the PWR at Sizewell B and this includes a detailed Level 2 PSA. Level 2 PSAs have also been carried out for all the gas cooled reactors. However, the aim of the analysis has been to address the accident frequency criteria given in the Safety Assessment Principles (SAPs). The most accident sequences are in Dose Band 5 which groups the accident sequences that would give rise to an off-site dose of > 1 Sv. Although the analysis calculates the frequencies of the accident sequences in DB5, the work has not been carried out to define the source terms accurately.	NII has been carrying out research to consider how the Level 2 PSA information could be used in a systematic way for emergency planning purposes.

Country	Definition of emergency planning zones (EPZ)	Requirement to provide information for the public living in the EPZ in the event of radiological emergency	Basis for the emergency planning	Status of Level 2 PSA for the NPPs	Future activities for implementation of Level 2 PSA results into emergency planning
USA	To facilitate a preplanned strategy for protective actions during an emergency, there are two emergency planning zones (EPZs) around each nuclear power plant: 1) The plume exposure pathway EPZ has a radius of about 10 miles from the reactor. Predetermined protection actions include: sheltering, evacuation, and the use of potassium iodide where appropriate. 2) Ingestion Exposure Pathway EPZ. It has a radius of about 50 miles from the reactor. Predetermined protection actions include a ban of contaminated food and water.	State and local government officials have the overall responsibility of deciding and implementing the appropriate protective actions for the public during a nuclear power plant radiological emergency. They are responsible for notifying the public to take protective actions, such as evacuation, sheltering or taking of potassium iodide pills. State and local officials base their decisions on the protective action recommendations by the nuclear power plant operator and their own radiological or health organization. The NRC provides oversight and guidance of the protective action decision by the State and local government officials. Neither the nuclear power plant operator nor the NRC can order the public to take protective actions.	The approach to emergency planning is deterministic. The evacuation modelling is based on a site specific evacuation study. In this study is assumed that 95% of the population within EPZ would start moving 45 min after declaration of a general emergency. Evacuation notification is assumed to take place at the times specified for declaring a general emergency.	Level 3 PSA studies are prepared for the most NPPs operated in the USA.	Based on the limited feedback it can be concluded that this issue is not exactly clarified yet.

APPENDIX B

The USA Approach to Emergency Planning

The USA Approach to Emergency Planning

Since the early 1970s, there have been increasing efforts to determine severe accident risks more precisely and on a plant-specific basis in the USA. The first comprehensive plant-specific examination of risk was the Reactor Safety Study (RSS), WASH-1400 [42]. Later the RSS was updated and more complex and more intensive plant-specific risk studies were developed, both by NRC and the industry.

The most recent NRC studies of severe accident consequences are found in the NUREG-1150 analyses [41]. To date, about 40% of the 118 operating plants and plants under construction have had some level of plant-specific risk analysis reviewed by NRC. This body of knowledge was used in the prediction of environmental impacts of severe accidents for all plants. Both the frequency and magnitude of the source terms for such assessments were usually taken from the updated RSS. These source terms were then used with site-specific meteorological and demographic data to calculate off-site risk using the methodology of Level 3 PSA.

A separate set of source terms was provided for each of the two types of reactor designs, BWRs and PWRs. These same sets of data, without change, were used to evaluate off-site risks. As such, they do not represent plant-specific analyses but are sufficient to illustrate the developed general magnitude and types of risks that may occur from reactor accidents. Once the source term data were established, all plants used the Calculation of Reactor Accident Consequences (CRAC) code to determine environmental consequences. Site-specific information regarding meteorology, population, and evacuation was used. Assumptions regarding exposure pathway, exposure limits, and plume behaviour remained largely unchanged for all analyses.

The NUREG-1150 study [41] is an NRC sponsored risk examination of five U.S. nuclear power plants. These analyses used state-of-the-art technology in evaluation of source-term release frequency, source-term characteristics, and consequence evaluation. Efforts were made to explore uncertainties in accident frequency, containment behaviour, and radioactive material release and transport so that from this distribution of results, mean values of risk could be determined. Source terms and frequencies specific to the plant were determined. Advanced computer codes were used. For example, the MELCOR Accident Consequence Code System (MACCS) computer code for consequence evaluation was used instead of CRAC.

The industry-sponsored risk assessments (e.g., Oconee 3, Seabrook, Millstone 3, etc.) are similar in that effort. They are made to reduce the degree of conservatism and to use the best information available. For these studies, source-term levels and frequencies specific to the plant are calculated [35].

Finally, studies exist that provide a detailed assessment of the risk due to specific types of accidents. For example, two such studies are NUREG-0440 [43], which is a generic study of the radiological risks that could result from a severe accident that releases significant contamination into the groundwater, and NUREG-0769 [44], which estimates the risks from direct contamination of the Great Lakes due to fallout from a severe accident at the Enrico Fermi 2 power plant. These two as well as other specific risk studies are used provide information about the risk.

The Main Results of the Level 3 PSAs for the US Plants

The risk from individual nuclear power plants is small. It represents only a small fraction of the risk to which the public is exposed from other sources. Even if the predicted early and latent fatalities from all 118 plants were considered (that is, the risk to the population of the United States from all 118 nuclear power plants), this would only result in a predicted risk of approximately one additional early fatality per year and approximately 30 additional latent fatalities per year, which is still a small fraction of the approximately 100,000 early and 500,000 latent cancer fatalities per year from other sources. Table B.1 presents the predicted early and latent fatalities and dose estimates per reactor-year (ry) for all sites in the USA (to be conservative, the upper-bounds, not the mean values are presented) [35].

Also the off-site severe accident costs for the area contaminated by the accident were calculated. The off-site costs that were considered relate to avoidance of adverse health effects and are categorized as follows:

- Evacuation costs;
- Value of crops contaminated and condemned
- Value of milk contaminated and condemned;
- Costs of decontamination of property where practical;
- Indirect costs resulting from the loss of use of property and incomes; derived there from (including interdiction to prevent human injury).

The severe accident analysis for the plants uses these five cost category models to estimate an average (annual) expected cost due to a severe accident. These costs are a sum of the costs for a range of accidents multiplied by the probability that each of the accidents will occur. For the plants that have severe accident analyses, estimated off-site accident costs could reach as high as $6 billion to $8 billion, but the probability of an accident with such high consequences would only be once in one million operating years. Higher costs are estimated for accidents with much lower probabilities. Projected costs of adverse health effects from deaths and illnesses would average about 10-20% of off-site mitigation costs. These costs are not considered in the economic cost calculations.

Plant	Total early fatalities/ry	Total late fatalities/ry	Predicted total dose (person-rem/ry)^{x}
Arkansas	3.3×10^{-3}	1.7×10^{-2}	238
Beaver Valley	2.5×10^{-2}	1.3×10^{-1}	1 720
Bellefonte	4.0×10^{-3}	1.0×10^{-1}	1 335
Big Rock Point	2.7×10^{-3}	3.2×10^{-3}	48
Braidwood	3.6×10^{-3}	3.3×10^{-1}	4 418
Browns Ferry	4.3×10^{-3}	9.7×10^{-2}	1 446
Brunswick	3.5×10^{-3}	4.7×10^{-2}	704
Byron	2.3×10^{-3}	2.2×10^{-1}	2 867
Callaway	6.9×10^{-4}	3.6×10^{-2}	509
Calvert Cliffs	1.8×10^{-3}	2.3×10^{-1}	2 995
Catawba	1.7×10^{-2}	1.4×10^{-1}	1 880
Clinton	3.0×10^{-3}	1.8×10^{-1}	2 549
Comanche Peak	2.3×10^{-3}	3.3×10^{-2}	466
Cooper	2.6×10^{-3}	6.3×10^{-2}	955
Crystal River	1.5×10^{-3}	5.0×10^{-2}	700
D. C. Cook	8.4×10^{-3}	1.8×10^{-1}	2 311
Davis Besse	1.4×10^{-3}	1.5×10^{-1}	2 021
Diablo Canyon	1.5×10^{-3}	2.5×10^{-2}	346
Dresden	4.6×10^{-3}	1.4×10^{-1}	1 991
Duane Arnold	8.0×10^{-3}	3.7×10^{-2}	561
Farley	1.5×10^{-3}	2.4×10^{-2}	334
Fermi 2	6.8×10^{-3}	1.9×10^{-1}	2 722
FitzPatrick	3.8×10^{-3}	5.0×10^{-2}	728
Fort Calhoun	1.7×10^{-3}	8.0×10^{-3}	111
Ginna	3.9×10^{-3}	1.5×10^{-2}	203
Grand Gulf	2.8×10^{-3}	9.7×10^{-2}	1 441
Haddam Neck	1.2×10^{-2}	2.0×10^{-1}	2 618
Hatch	2.6×10^{-3}	5.7×10^{-2}	855
Hope Creek	4.1×10^{-3}	2.5×10^{-1}	3 604
Indian Point	6.5×10^{-2}	7.7×10^{-1}	9 727
Kewanee	8.9×10^{-4}	2.2×10^{-2}	303
La Salle	3.6×10^{-3}	2.0×10^{-1}	2 898
Limerick	1.1×10^{-2}	3.1×10^{-1}	4 461
Maine Yankee	1.8×10^{-3}	3.0×10^{-2}	414
McGuire	1.0×10^{-2}	1.4×10^{-1}	1 806
Millstone	2.5×10^{-2}	3.1×10^{-1}	3 988
Monticello	4.1×10^{-3}	5.0×10^{-2}	730

Table B.1 Predicted early and latent fatalities and dose estimates per reactor-year for all sites.

Plant	Total early fatalities/ry	Total late fatalities/ry	Predicted total dose (person-rem/ry)[x]
Nine Mile Point	3.8×10^{-3}	6.7×10^{-2}	996
North Anna	9.4×10^{-4}	1.1×10^{-1}	1 496
Oconee	1.1×10^{-2}	1.0×10^{-1}	1 311
Oyster Creek	7.4×10^{-3}	1.5×10^{-1}	2 125
Palisades	4.2×10^{-3}	1.3×10^{-1}	1 691
Palo Verde	1.1×10^{-4}	2.6×10^{-2}	369
Peach Bottom	4.2×10^{-5}	2.0×10^{-1}	2 950
Perry	6.9×10^{-3}	1.7×10^{-1}	2 544
Pilgrim	3.7×10^{-3}	6.0×10^{-2}	873
Point Beach	2.5×10^{-3}	2.3×10^{-2}	309
Prairie Island	3.7×10^{-3}	1.7×10^{-2}	237
Quad Cities	4.5×10^{-3}	1.1×10^{-1}	1 588
Rancho Seco	1.1×10^{-3}	1.3×10^{-1}	1 723
River Bend	4.1×10^{-3}	8.0×10^{-2}	1 168
Robinson	3.1×10^{-3}	7.0×10^{-2}	926
Salem	2.9×10^{-3}	5.0×10^{-1}	6 059
San Onofre	1.1×10^{-2}	2.4×10^{-1}	3 099
Seabrook	1.1×10^{-2}	6.0×10^{-2}	819
Sequoyah	6.6×10^{-3}	1.1×10^{-1}	1 474
Shearon Harris	2.8×10^{-3}	7.3×10^{-2}	1 001
South Texas	3.3×10^{-4}	8.0×10^{-2}	1 065
Saint Lucie	3.2×10^{-2}	8.0×10^{-2}	1 063
Shoreham	7.7×10^{-3}	6.3×10^{-2}	2 724
Summer	1.3×10^{-3}	1.0×10^{-1}	1 381
Surry	1.6×10^{-2}	9.0×10^{-2}	1 200
Susquehanna	6.0×10^{-3}	2.8×10^{-1}	4 010
Three Mile Island	2.8×10^{-2}	3.3×10^{-1}	4 381
Trojan	3.7×10^{-2}	1.5×10^{-1}	1 971
Turkey Point	6.0×10^{-2}	2.0×10^{-2}	278
Vermont Yankee	4.6×10^{-3}	9.0×10^{-2}	1 314
Vogtle	1.6×10^{-4}	7.3×10^{-2}	983
WNP-2[b]	2.3×10^{-3}	4.3×10^{-2}	649
Waterford	1.4×10^{-2}	3.3×10^{-2}	477
Watts Bar	1.8×10^{-3}	1.2×10^{-1}	1 540
Wolf Creek	4.7×10^{-4}	3.3×10^{-2}	466
Yankee Rowe	3.3×10^{-3}	6.7×10^{-2}	872
Zion	5.6×10^{-2}	1.8×10^{-1}	2 379

[x] ***Multiply person-rem by 0.01 to find person-sieverts***

Table B.1 Continuation.

The HNP Level 3 PSA Study

The main steps of the Level 3 PSA are illustrated on an example of the Edwin I. Hatch Nuclear Plant (HNP), Units 1 and 2 [36]. The study was prepared within the license renewal process of the plant.

The offsite risk at the HNP is calculated using the PSA, which has the following major elements:

1. the Level 1 and 2 risk models,
2. the Level 3 analyses performed to translate source terms and release frequencies from the Level 2 PSA model into offsite consequence measures.

The total CDF for internal events is 1.6E-5 per reactor year and the Large Early Release Frequency (LERF) is 2.7E-6/ry. The breakdown of CDF is provided in Table B.2. As shown in this table, the current analyses show that Loss of Feedwater events are a dominant contributor to CDF, followed by Loss of Station Battery A and Loss of Offsite Power.

The process used to extend the containment performance (Level 2) portion of the PSA to the offsite consequence assessment (Level 3). This included consideration of the source terms used to characterize fission product releases for each containment release mode and the major inputs and assumptions used in the offsite consequence analyses. The MAAP code was used to analyse postulated accidents and develop radiological source terms for each of the 15 bins into which the containment event tree end states had been grouped.

The point-estimate source term for dominant sequences was reviewed and found to either be in reasonable agreement with or higher than the NUREG-1150 Peach Bottom NPP estimates for the closest corresponding release scenarios. The Level 3 analysis uses the MELCOR code, Version 1.12, to determine the offsite risk impacts on the surrounding environment and public. Inputs for the Level 3 analysis include the HNP core radionuclide inventory, the Level 2 release fractions, site meteorological data, projected population distribution for the year 2030, emergency response evacuation modelling, and economic data.

The estimated dose to the population within 80 km (50 miles) of the HNP site to be 0.035 person-Sv/y. Table B.3 shows the distribution of containment performance contributions to the population dose. It indicates that early containment failure releases dominate. The early release category includes Sequence 2, a station blackout event; Sequence 4, a loss of containment heat removal/drywell failure event; and Sequence 11, an ATWS with drywell failure event. The risk is dominated by Sequence 2 because it is estimated to result in a higher dose (0.019 person-Sv) and because it has a relatively high estimate for its probability of occurrence (1.79 x 10^{-6}/y). The total early fatalities are 2.6 x 10^{-3}/y and the total late fatalities 5.7 x 10^{-2}/y.

Initiating event	Contribution to Total CDF [%]
Loss of Offsite Power	16.7
Loss of 600V AC Bus C	8.4
Loss of Feedwater	20.2
Loss of Station Battery A	18.0
Main Steam Isolation Valve Closure	7.3
Anticipated Transient Without Scram (ATWS)	4.3

Table B.2 The HNP core damage frequency profile.

Contributor	Contribution to Population Dose [%]
Bypass	5.4
Early	91.2
Late	3.3
Intact (venting)	<0.1

Table B.3 The containment failure profile.

Site-specific meteorological data was used processed from measurements taken hourly in 1997. These data were collected at the site meteorological tower. Hence, the meteorological data are applicable to the site.

The population distribution used as input to the analyses is based on the 1990 sector population data for HNP. Transient populations were not considered because of the rural setting of HNP and the small assumed transient population within 80 km (50 miles) of the site. The site-specific growth rates for the period between 1990 and 2000, which were obtained from census information, were used to estimate a constant growth rate applicable out to 2040 (population is expected to rise).

The evacuation modelling is based on a site specific evacuation study. In this study is assumed that 95% of the population within EPZ would start moving 45 min after declaration of a General Emergency. The study also assumed that 5% of the population will not evacuate. This assumption is conservative relative to the NUREG-1150, which assumes evacuation of 99.5% of the population within the EPZ.

Evacuation notification is assumed to take place at the times specified for declaring a general emergency. For Level 2 PSA sequence 4 this time is simultaneous to the predicted time for the core to be uncovered. For sequence 2 a general emergency is declared as the operators realize that they have a station blackout with no possibility of obtaining offsite or onsite power to restore decay-heat-removal systems. In sequence 11, an ATWS has occurred, the main steam isolation valve has closed and the standby safety system has failed to inject borated water into the reactor coolant system (RCS). A general emergency is declared based on a transient occurring with failure of a core shutdown system and containment failure is likely. In sequence 15, there are no water injection capabilities available. Core damage and vessel failure are unavoidable. A general emergency is declared when two of the three fission product boundaries (fuel cladding, reactor vessel and containment) have failed and the failure of the third boundary is likely.

Also the off-site severe accident costs for the area contaminated by the accident were calculated.

The methodology used to estimate the CDF and offsite consequences for HNP provides an acceptable basis for an assessment of risk reduction potential for candidate severe accident mitigating alternatives.

Uncertainties in the Risk Assessment

Although substantial improvements have been made in the PSA methodology since, large uncertainties in the results of these analyses remain, including uncertainties associated with the likelihood of the accident sequences and containment failure modes leading to the release categories, the source terms for the release categories, and the estimates of environmental consequences. A comprehensive discussion of the uncertainties associated with risk assessments is provided in NUREG-1150 [41]. The relatively more important contributors to uncertainties in the results presented above are described here.

Probability of Accident Occurrence

If the probability of a release category were to change by some percentage, the probabilities of various types of consequences from that release category would also change by the same percentage. Thus, an order of magnitude uncertainty in the probability of a release category would result in a corresponding order of magnitude uncertainty in the risks stemming from the release category. Uncertainties in the probabilities of the release categories are due to difficulties associated with the quantification of human error probabilities and to limitations in the database on failure rates of individual plant components and in the database on external events and their effects on plant systems, structures, and components that are used to calculate the probabilities. However, substantial programs to improve nuclear power plant safety have been implemented. These programs all served to reduce the average risk of the overall nuclear industry such that the use of RSS risk values and their associated frequencies of an accident (because they are embodied within the risk calculation) are reasonable upper estimates of risk for the industry. This is true for even those plants that have not had the benefit of a PSA analysis.

Quantity and Chemical Form of Radioactivity Released

There are also significant uncertainties associated with the timing, quantity, and chemical form of each radio nuclide species that would be released from a reactor unit during a particular accident sequence. Radioactive material originates in the fuel and would be released from any damaged fuel during an accident. Depending on the accident sequence, such factors as attenuation in the reactor vessel, the rest of the cooling system, the containment, and adjacent buildings would influence both the magnitude and chemical form of radioactive releases. Information available in NUREG-1150 [41], and from the latest research activities sponsored by NRC and the industry indicates that the uncertainty in radio nuclide source terms is large and represents a significant contribution to the uncertainty in the absolute value of risk. In comparison with the RSS source terms, source terms in recent studies were in some instances higher and in other instances lower. However, for the early containment failure sequences, which have the greatest impact on risk, the RSS source terms appear to be larger than the mean values estimated from the recent work and are typically at the upper bound of the uncertainty range of estimates for NUREG-1150 [41].

Atmospheric Dispersion Modelling for the Radioactive Plume Transport

Uncertainties are involved in modelling the atmospheric transport of radioactivity in gaseous and particulate states and the actual transport, diffusion, and deposition or fallout that would occur during an accident (including the effects of condensation and precipitation). The phenomenon of plume rise from heat associated with the atmospheric release, effects of precipitation on the plume, and fallout of particulate matter from the plume all have considerable impact on the magnitudes of early health consequences along with the distances from the reactors where these consequences would occur. These factors can result in overestimates or underestimates of both early and later effects (health and economic impacts).

Other areas that have effects on uncertainty are as follows:

- Duration, energy release, and in-plant radio nuclide decay time;
- Meteorological sampling scheme used;
- Emergency response effectiveness and warning time;
- Dose-conversion factors and dose-response relationships for early and latent health consequences;

- Economic data and modelling.

The NUREG-1150 study [41] found that for the five plants studied, the fatality magnitudes (early and latent) were driven primarily by the core-damage frequency, the source term releases, site meteorology, population distribution, and the effectiveness of emergency response measures.

APPENDIX C

Call for Papers: Seminar on Emergency & Risk Zoning around NPP, 26 – 27 April 2005, EC DG - JRC/IE Petten, The Netherlands

EUROPEAN COMMISSION
DIRECTORATE-GENERAL
Joint Research Centre

OECD

Seminar on

Emergency & Risk Zoning around Nuclear Power Plants

26-27 April 2005

Petten, The Netherlands

Institute for Energy

CALL FOR PAPERS

Co-organised by:

European Commission,
DG Joint Research Centre, Institute for Energy

Nuclear Energy Agency of the Organization for Economical Cooperation and Development (OECD-NEA)

SCOPE & OBJECTIVES OF SEMINAR

Plant-specific Probabilistic Safety / Risk Assessment (PSA / PRA) can provide together with other, more deterministic information sources relevant information for strategic planning purposes in the area of emergency zoning (risk zones) around a Nuclear Power Plant (NPP), as well as information to the public on the geographical component of plant risk.

Not least due to the close relation of this issue to security and civil protection, there is currently discussion within the nuclear safety community whether or not PSA technology in its current state (Levels 2 & 3) is mature enough to be used - as a complementary tool - to address the issues of levels of plant emergency classification, concept of risk and emergency zones, relevant risk acceptance criteria, information to the public in the event of a radiological emergency, and public evacuation and sheltering.

The **purpose of the seminar** is to provide a forum for presentation and discussion of status of emergency planning and risk assessment approaches, safety policies as well as current and possible future requirements for emergency and risk zoning, and consider needs for international harmonisation.

The aim is to help relevant stakeholders on both national and international levels to decide on the relevance of this issue and on related research and development needs. Relevant stakeholders would be representatives from regulatory authorities, utilities, emergency response organisations as well as PSA users and developers from all over the world.

The seminar will provide an opportunity for sharing of experiences in the field on both good practice and identification of problem areas, incl. comparison to other major-hazardous industries, such as the chemical process industries.

The following **objectives** are envisaged:

- To get an overall view of current probabilistic / deterministic information sources used to define risk and emergency zones around NPPs in various countries.
- To share experience in the current applications and interface between PSA for NPP operation and emergency planning (EP).
- To identify current regulations and practices for using outcomes of PSA Levels 2 & 3 for EP.
- To identify requirements for possible future use of PSA in EP.

SEMINAR THEMES

The seminar sessions will be organised along the following thematic lines:

- Approaches to NPP risk/emergency zoning.
- Corresponding regulatory requirements.
- Comparison to other industries (e.g. chemical).
- Current harmonisation efforts (PSA standards, acceptance criteria, risk zones, etc.).
- Examples of current research in the area.

SUGGESTED PAPER TOPICS

Seminar contributions are expected from all relevant stakeholders, i.e. regulators, emergency response organisations, utilities, PSA users and developers, R&D organizations, engineering contractors and consultants. Major topics are:

- *Current approaches to deal with definition of NPP risk and emergency zoning.*
- *National codes and regulations, including risk informed support to emergency planning.*

- *Maturity of current PSAs to support plant emergency classification and risk / emergency zones.*
- *Specific requirements for PSA Levels 2 & 3 to make plant-specific PSAs applicable in EP.*
- *Technical basis for the radii for the risk / emergency zones and evacuation time criteria for these zones.*
- *Concrete examples of risk informed support for defining risk zones and relevant information to the public, e.g. by using NPP operational experience and plant-specific PSA.*
- *Alternatives: more deterministic approaches, engineering judgment, medical judgment, etc.*
- *Towards international harmonisation of risk / emergency zoning.*
- *Towards international harmonisation of how to present the geographical component of plant risk to different stakeholders, incl. the general public.*
- *EP and risk zoning in the light of increased security concerns.*
- *Comparison to other major-hazardous industries.*

SUBMISSION OF CONTRIBUTION

Authors who wish to present a paper are requested to submit an Extended Abstract (2-3 pages) by e-mail to:

Christian Kirchsteiger
European Commission - DG JRC - IE
Postbus 2 - 1755 ZG Petten - The Netherlands
E-mail : christian.kirchsteiger@jrc.nl

or to one of the Programme Committee Members. The abstract should not include formulas or figures and has to indicate the reference thematic session, the title of paper and the Author(s) Name(s).

The abstracts will be evaluated by the members of the Programme Committee; the judgement will be forwarded to the authors by e-mail.

On the basis of the accepted abstract, the author is expected to develop his/her presentation in full detail.

FULL PAPER SUBMISSION

Full presentations and papers should be sent in electronic form directly to the Secretariat e-mail address by the designated deadline. The length of contributions should fit within a 30 min presentation & discussion time and papers should not exceed a maximum length of 15 A4 pages. The papers will be accepted after the reviewing process performed by the members of the Programme Committee. Accepted papers will be published in the Seminar Proceedings.

PROCEEDINGS

Proceedings of the seminar will be published (CD) and distributed to all participants after the seminar. Additionally, the Programme Committee intends to send a selection of the most relevant papers to a specialised international peer reviewed journal for publication as a special issue.

SEMINAR DEADLINES

- Submission of Abstracts **21 February**, 2005
- Acceptance of Extended Abstracts **7 March**, 2005
- Full Papers/Presentations Submission **4 April**, 2005
- *Submission of Paper in camera-ready final version by 6 June 2005 (guidelines will follow)*
- Seminar **26-27 April** 2005

SEMINAR CHAIRMAN

DG TREN - H4 Radiation Protection Unit

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SEMINAR LANGUAGE

The Seminar language is English. No translation will be provided.

SEMINAR LOCATION

JRC - Institute for Energy, Petten, The Netherlands.

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SEMINAR FEE

There is no seminar fee. Lunches during the workshop will be free of charge for the registered participants. A dinner is provisionally scheduled on April 26, 2005 (more information will follow later on).

NPP Emergency & Risk Zoning
Petten, The Netherlands, 26-27 April 2005

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Emergency & Risk Zoning around
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26-27 April 2005

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☐ An Extended Abstract for the seminar is attached.

☐ I am not submitting an abstract, but I am interested in attending the seminar. Please, send me an official JRC meeting registration form.

European Commission

EUR 21580 EN – Risk-informed Support of Nuclear Power Plant Emergency Zoning

Jozef Kubanyi
Christian Kirchsteiger

Luxembourg: Office for official Publications of the European Communities

2005 – 71 pp. – 21 x 29.7 cm

Scientific and Technical Research series

P 2005/049

EUROPEAN COMMISSION
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