Unclassified **NEA/CSNI/R(99)15**

Organisation de Coopération et de Développement Economiques
Organisation for Economic Co-operation and Development

OLIS : 05-Aug-1999
Dist. : 09-Aug-1999

English text only

NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

STATE OF LIVING PSA AND FURTHER DEVELOPMENT

July 1999

NEA/CSNI/R(99)15
Unclassified

English text only

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ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Pursuant to Article I of the Convention signed in Paris on 14th December 1960, and which came into force on 30th September 1961, the Organisation for Economic Co-operation and Development (OECD) shall promote policies designed:

– to achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;
– to contribute to sound economic expansion in Member as well as non-member countries in the process of economic development; and
– to contribute to the expansion of world trade on a multilateral. non-discriminatory basis in accordance with international obligations.

The original Member countries of the OECD are Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The following countries became Members subsequently through accession at the dates indicated hereafter: Japan (28th April 1964), Finland (28th January 1969), Australia (7th June 1971), New Zealand (29th May 1973), Mexico (18th May 1994), the Czech Republic (21st December 1995), Hungary (7th May 1996), Poland (22nd November 1996) and the Republic of Korea (12th December 1996). The Commission of the European Communities takes part in the work of the OECD (Article 13 of the OECD Convention).

NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1st February 1958 under the name of the OEEC European Nuclear Energy Agency. It received its present designation on 20th April 1972, when Japan became its first non-European full Member. NEA membership today consists of all OECD Member countries except New Zealand and Poland. The Commission of the European Communities takes part in the work of the Agency.

The primary objective of the NEA is to promote co-operation among the governments of its participating countries in furthering the development of nuclear power as a safe, environmentally acceptable and economic energy source.

This is achieved by:

– *encouraging harmonization of national regulatory policies and practices, with particular reference to the safety of nuclear installations, protection of man against ionising radiation and preservation of the environment, radioactive waste management, and nuclear third party liability and insurance;*
– *assessing the contribution of nuclear power to the overall energy supply by keeping under review the technical and economic aspects of nuclear power growth and forecasting demand and supply for the different phases of the nuclear fuel cycle;*
– *developing exchanges of scientific and technical information particularly through participation in common services;*
– *setting up international research and development programmes and joint undertakings.*

In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has concluded a Co-operation Agreement, as well as with other international organisations in the nuclear field.

COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

The Committee on the Safety of Nuclear Installations (CSNI) of the OECD Nuclear Energy Agency (NEA) is an international committee made up of senior scientists and engineers. It was set up in 1973 to develop, and co-ordinate the activities of the Nuclear Energy Agency concerning the technical aspects of the design, construction and operation of nuclear installations insofar as they affect the safety of such installations. The Committee's purpose is to foster international co-operation in nuclear safety among the OECD Member countries.

The CSNI constitutes a forum for the exchange of technical information and for collaboration between organisations, which can contribute, from their respective backgrounds in research, development, engineering or regulation, to these activities and to the definition of the programme of work. It also reviews the state of knowledge on selected topics on nuclear safety technology and safety assessment, including operating experience. It initiates and conducts programmes identified by these reviews and assessments in order to overcome discrepancies, develop improvements and reach international consensus on technical issues of common interest. It promotes the co-ordination of work in different Member countries including the establishment of co-operative research projects and assists in the feedback of the results to participating organisations. Full use is also made of traditional methods of co-operation, such as information exchanges, establishment of working groups, and organisation of conferences and specialist meetings.

The greater part of the CSNI's current programme is concerned with the technology of water reactors. The principal areas covered are operating experience and the human factor, reactor coolant system behaviour, various aspects of reactor component integrity, the phenomenology of radioactive releases in reactor accidents and their confinement, containment performance, risk assessment, and severe accidents. The Committee also studies the safety of the nuclear fuel cycle, conducts periodic surveys of the reactor safety research programmes and operates an international mechanism for exchanging reports on safety related nuclear power plant accidents.

In implementing its programme, the CSNI establishes co-operative mechanisms with NEA's Committee on Nuclear Regulatory Activities (CNRA), responsible for the activities of the Agency concerning the regulation, licensing and inspection of nuclear installations with regard to safety. It also co-operates with NEA's Committee on Radiation Protection and Public Health and NEA's Radioactive Waste Management Committee on matters of common interest.

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ABSTRACT

This report summarises the state of Living PSA in the international field. The information is based on four (4) Living PSA Workshops from 1988 to 1994 and the state of Reliability Data Collection based on the results of the PWG5 Task Group report on Reliability Data Collection and Analysis to Support PSA and the two Data-Workshops from 1995 and 1998.

FOREWORD

In October 1985 OECD-Principal Working Group (PWG 5) - Risk Assessment has initiated the Task Force 7 “Use of PSA in Nuclear Power Plant Management” to explore and report on the principles, characteristics, requirements and status of PSA oriented safety management.

This overall process is known as Living PSA.

Since 1986 OECD-PWG 5 has arranged a series of international workshops on Living PSA application to support this development, to facilitate exchange of international experience and to summarise the state-of-the-art of Living PSA methodology. These activities were accompanied by following Task Groups of OECD-PWG 5 and the work results were published in state-of-the-art reports:

- Task 4 : The Role of Quantitative PSA Results in NPP Safety Decision Making, 1992 /37/
- Task 7 : Probabilistic Safety Assessment in NPP Management, 1989 /46/
- Task 10: Living Probabilistic Safety Assessment for NPP Management, 1991 /44/
- Task 11: PSA Application to Technical Specifications, 1992 /47/
- Task 12: Reliability Data Collection and Analysis to Support PSA, 1994 /38/
- Task 14: Risk Based Management of Safety Systems Availability - Risk-Based Configuration Control, 1994 /49/

According to the increasing development of Living PSA in the international field and its capacity to support plant safety management in a broad sense, OECD PWG 5 has continued its work in setting up the Task Group 96-1 “State of Living PSA and Further Development“ to clarify specific aspects of Living PSA”.

PWG5 and the Task Group offers their thanks and appreciation to Mr. Hans-Peter Balfanz, who provided valuable time and considerable knowledge towards the production of this report and to PWG5 for many years on this topic. The Task Group Members contributing to the report are:

Hans-Peter Balfanz - Germany, Task Group Leader and Editor

Mr. Reino K. Virolainen	Finland	Mr. Magiel F. Versteeg	Netherlands
Dr. Jeanne-Marie Lanore	France	Dr. Charles H Shepherd	United Kingdom
Mr. Elüd Holló	Hungary	Mr. Joseph A. Murphy	United States
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1. INTRODUCTION

In October 1985 OECD-Principal Working Group (PWG 5) - Risk Assessment has initiated the Task Force 7 “Use of PSA in Nuclear Power Plant Management” to explore and report on the principles, characteristics, requirements and status of PSA oriented safety management.

During this study, it became apparent that the utilisation of PSA techniques in nuclear plant safety management requires the development of supporting programmes to ensure that PSA models are being updated to reflect plant changes, and to direct their use towards the evaluation and determination of plant changes. These requirements also influence the software and hardware characteristics necessary to support the programme. This overall process is known as Living PSA.

In this context OECD-PWG 5 has arranged international workshops on Living PSA application to support this development, to facilitate exchange of international experience and to summarise the state-of-the-art of L-PSA methodology.

The series of OECD-Workshops characterises this development:

1986	Workshop on Probabilistic Safety Assessment as an Aid to Nuclear Power Plant Management, Brighton, Hosted by the UKAEA /42/
1987	Specialist Meeting on Improving Technical Specifications for NPPs, Madrid , Hosted by the Consejo de Seguridad Nuclear Spain /48/
1988	Workshop on Program-Systems and Computer-Codes for Living-PSA-Application, Hamburg, hosted by TÜV Norddeutschland /1/
1990	2nd TÜV Workshop on Living PSA Application, Hamburg, hosted by TÜV Norddeutschland /2/
1990	Workshop on Applications and Limitations of PSA, Santa Fe /40/
1992	3rd TÜV Workshop on Living PSA Application, Hamburg, hosted by TÜV Norddeutschland /3/
1994	4th TÜV Workshop on Living PSA Application, Hamburg, hosted by TÜV-Nord /4/
1995	International Workshop on Reliability Data Collection in Support of PSA, Maintenance and Life Assurance Programmes, Toronto, Hosted by Ontario Hydro /43/
1998	International Workshop on Reliability Data Collection for Living PSA, Budapest, Hosted by VEIKI /62/

These activities were accompanied by following Task Groups of OECD-PWG 5 and the work results were published in state-of-the-art reports:

- Task 4 : The Role of Quantitative PSA Results in NPP Safety Decision Making, 1992 /37/
- Task 7 : Probabilistic Safety Assessment in NPP Management, 1989 /46/
- Task 10: Living Probabilistic Safety Assessment for NPP Management, 1991 /44/
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- Task 14: Risk Based Management of Safety Systems Availability - Risk-Based Configuration Control, 1994 /49/

According to the increasing development of Living PSA in the international field and its capacity to support plant safety management in a broad sense, OECD PWG 5 continues its work in setting up the Task Group 96-1 State of Living PSA and Further Development“ to clarify specific aspects of Living PSA:

- How to integrate L-PSA into the decision making process, including dialogue between regulatory body and plant safety management and how to adapt the requirement in a risk-based approach, risk-based regulation.
- Quality assurance of L-PSA and data collection to control this process.
- Safety issues and requirements of risk-monitoring systems as part of operator tool in the control room.
- Computer based management systems available at plant to be used in support of L-PSA (database, event reports).
- Use of plant specific reliability data collection for L-PSA and how to fit into the management process (quantitative indicators for intervention).
- Reflections of human reliability data by plant experiences (how to receive relevant information on HF and how to assess these data).
- Organisational and management factors having impact on plant safety (how to measure and what is the role of L-PSA in this context).

This report summarises the state of Living PSA in the international field based on the above mentioned four Living PSA Workshops from 1988 to 1994 /52/ (Chapter 2) and the state of Reliability Data Collection based on the results of Task Group 12 "Reliability Data Collection and Analysis to Support PSA" and the two Data-Workshops from 1995 and 1998 (Chapter 3). The specific items of further development of Living PSA application as mentioned above are treated in Chapter 4. Chapter 5 gives a summary of the current state of Living PSA as well as outlook and recommendations of further development.

2. STATE OF L-PSA APPLICATIONS PRESENTED AT 4 WORKSHOPS FROM 1988 - 1994

2.1 Overview on Workshop Contributions

Four workshops on L-PSA application were held at TÜV Nord in Hamburg since 1988. The workshops were organised to support the OECD/CSNI Principal Working Group 5 on Risk Assessment. All work of TÜV Nord was sponsored by the Federal Minister for Environment, Nature Conservation and Reactor Safety of Germany (BMU).

The workshops were aimed at encouraging utilities and authorities to go the way towards plant specific application of L-PSA by an appropriate exchange of experience, even though the conditions for application need further clarification. The almost 100 papers published in four summary reports (/1/, /2/, /3/, /4/), a series of computer presentations and a lot of discussions at the workshops reflect the state-of-the-art of L-PSA as well as a progressing trend towards practical plant specific applications of L-PSA in 18 countries. The countries and the different organisations represented by papers at the workshops can be seen in the following tables.

Table 2.1: Countries and international organisations represented by authors of work shop contributions

1988	1990	1992	1994
Canada Denmark Finland Germany Italy Japan Sweden Switzerland USA IAEA	Canada Finland France Germany Japan Mexico Sweden SU (Russia) UK USA IAEA	Finland Germany Italy Japan Mexico Slovenia Spain Sweden UK USA	Finland Germany Romania Slovenia South Africa Sweden Switzerland Taiwan R.O.C UK USA CEC
10	11	10	11

Table 2.2: Numbers of workshop papers presented by different types of organisations

	No. of contributions				
Organisation [1]	1988	1990	1992	1994	sum
Utility (plant staff, headquarters or comparable department)	5	7	4	5	21
Licensing organisation/regulatory body	3	2	1	2	8
Vendor	2	3	3	2	10
Other institution	11	12	17	18	58
sum	21	24	25	27	97

Most contributions were presented by engineering and research institutes. This situation probably reflects the amount of development and research work needed for L-PSA routine application by utilities and authorities. In addition plant specific use of L-PSA was considered as to need PSA experts to a considerable extent.

A general tendency towards more specified application of L-PSA in real plant use, which was accompanied by specific development of models and tools as well as management conditions, could be found. To this respect management aspects have to be taken into account in an improved way, quality assurance has to be improved as well as models and tools require ongoing development. In some countries a clarification process on L-PSA approach is under way. L-PSA is well established in different uses at several utilities of NPP.

2.2 Given Definitions of Living PSA

Definitions of the term Living PSA were discussed during the workshops, focusing on the following questions /1/:

- What is a L-PSA?
- What are the main practices of L-PSA?
- What are the safety relevant factors to be monitored by a L-PSA (Level 1)?
- What are the tools for L-PSA?
- Who should perform a L-PSA and how?

1. If different organisations contributed to a paper, the organisation of the author which was considered most closely to the content was counted. This might have resulted in slightly subjective portions of the different organisations.

In /5/ L-PSA is defined as being a "*daily safety management system*" which is "*based on a plant-specific PSA and supporting information system*". In this paper L-PSA is assumed to express risk at a given time and plant configuration. Reference /6/ defines L-PSA as a dynamic PSA tool for assessing real plant configuration and which is capable of producing results in useful time scales. In /7/ a definition is given as:

– "L-PSA is that technology which allows the performance of PSA within an appropriately small time period and which is updated sufficiently regularly to remain valid at all times".

Reference /5/ describes a "Nordic" approach for L-PSA application which is a combined application of:

– Living Probabilistic Safety Assessment (PSA) and

– Operational safety indicators".

It is aimed at decision making on safety issues. This L-PSA concept has led to a programme for implementing L-PSA and is based on level 1 PSA application and a common conviction on the usefulness of PSA among the persons that are involved in PSA activities at the utilities as well as the regulatory bodies.

2.3 Objectives, Scope and Conditions of Use

The general objective of L-PSA is to give assistance on safety (and availability) decisions to the plant staff.

The "Nordic L-PSA application" /5/ comprises three main subjects of application (reference table 2.3):

– Long-term safety planning,

– Risk planning of operational activities and

– Risk analysis of operating experiences.

Table 2.3: Application of living PSA (from /5/)

Application	Long term safety planning	Risk planning of operational activities	Risk analysis of operating experience
Approach	Risk assessment	Risk monitoring	Risk follow-up
Result	Identification of risk contributors. Comparison of alternative design and procedures	Test planning. Maintenance planning. Operational decision making	Analysis of operating experience. Operational risk experience feedback. Verification of PSA models.
Risk measure	Nominal risk Inherent risk	Instantaneous risk frequency	Retrospective risk Probabilistic indicators

In /8/ (NPP Loviisa) the main objective of a living PSA system is characterised as “to provide flexible and versatile means to include risk perspective as an essential factor in all important decisions concerning a nuclear power plant”. Accordingly L-PSA models should have the ability to maintain updated models and data. Based on these features L-PSA should be able to give assistance to the plant staff on operational problems.

In /6/ (Electrowatt/NPP Leibstadt) L-PSA requirements are also derived from operational needs of a specific NPP and based on experiences gained from a specific level 1 PSA. As an overall objective an enhancement of safety “*by greater understanding* “ and “*maximum return of financial investment in the production of a large PSA”* was defined in /6/. In addition it is stated that a L-PSA tool “*must be able to provide information to station’s operational staff in a format most useful to them and in the time scale they require”*. The use as “*on-line risk monitor, or dynamic form of the Technical Specifications” was defined as the “ultimate goal”* of L-PSA.

In reference /9/ (Eskom) the objectives of L-PSA are derived from PSA application to the plant under consideration. L-PSA is expected to assist on safety decisions, which arouse from operation of the plant. L-PSA carried out on an off-line base. However development of an on-line tool, which is linked to the plant data system, is under work. L-PSA is expected to give both safety and financial gains.

A common objective of L-PSA can be derived from all contributions as being a risk assessing means which is applied within decision making processes of a NPP. Under this general aim several aspects of the decision making processes and features of models and tools were reported. Such areas of decision making include e.g.:

- plant modifications and temporary configurations,
- allowed outage times and exemption applications,
- relaxation and optimisation of testing and preventive maintenance
- balancing preventive and corrective maintenance,
- evaluation of ageing and trends in risk contributors,
- importance of risk awareness/risk impact,
- operator training,
- safety culture.

2.4 Regulatory Aspects and Related Research Projects

Workshop contributions, which deal with regulatory aspects, mention the following subjects:

- regulatory needs
- decision making
- pre-requisites and problems
- licensing
- guidelines on performing and review PSA
- research projects.

The following regulatory needs were pointed out (/5/):

“A proper use of the applications requires that decision making criteria are established. Probability and frequency criteria are not sufficient in complex decision making situations. They might however give guidance or first indication about the acceptability of the decision alternative. The decision making procedure shall include and allow a combined use of probabilistic estimates, deterministic analyses and engineering judgement. The recommendation to prepare decision criteria is in the first place directed towards the regulatory side, but must be prepared and implemented in agreement with the industry. Regulatory and inspection activities relate to all applications of PSA.“

Pre-requisites and problems of L-PSA application are mentioned in /7/ (UK regulatory body):

“A pre-requisite for L-PSA is the availability of a suitable quality PSA. ...There are some rather more fundamental doubts about data in general and its use within L-PSA. ... if L-PSA is to be an operational tool that remains valid and useable for all plant states and conditions, it is believed that some question marks remain on the approach to modelling of transitional states. ...

Risk based decision making, the particular risk criteria which are to be applied ... are likely to be difficult to derive. ...Should a set of risk criteria and limits be derived that were seen to be acceptable, one consequent concern is the danger that these limits might be seen as legitimate ‘targets’; boundaries to which the plant may be driven in an effort to extract maximum output and unavailability. ... Should the concept of L-PSA be accepted and approved, it will be probably necessary for it to operate throughout a trial period. It is unlikely that paper based Technical Specifications could ever be replaced entirely , but if L-PSA and TS are both available, their advice must be harmonised, to avoid a situation which could be unhealthy from a safety standpoint.”

In /27/ L-PSA was discussed as “a communication tool between regulator an utilities”. To meet these objectives plant personnel is expected by the regulatory body to do the majority of work . Thus Finnish utilities are required to perform PSA studies up to level 2. A L-PSA programme was set up to achieve the following objectives, which were defined by the Finnish regulatory body:

- to identify the most outstanding accident sequences, i.e. to work out risk topography of the plant

- to reveal the weak points in design, procedures and equipments and needs for backfitting
- to make the plant staff to understand the plant as a whole, to understand the physical and temporal progress of accidents and
- to make the personnel to understand the sensible and timely measures to prevent and mitigate the consequences of accidents.

In /19/ the licensing authority requires demonstration of compliance with probabilistic criteria for the safety of NPP. A periodic safety assessment including PSA is required for all German NPP every 10 years.

A guideline on how to perform PSA was issued in Germany in 1990. It is aimed at level 1+ PSA and requires the usage of plant-specific data to receive plant specific results and to be used in a L-PSA approach. Updating is required for performing PSA every 10 years.

2.5 Development Programmes

Most contributions of the workshops are understood to be part of a L-PSA development programme.
In this context the following conditions of use were emphasised:

- Despite L-PSA development needs much theoretical research on models and computer codes it should be strictly related to application, that means derived from plant operational and level 1 PSA experiences (e.g. /8/).
- L-PSA implementation requires a specially defined system of application including a concept on how to use L-PSA methods and tools, appropriate computer tools and a concept how to develop methods and tools (/5/).
- As L-PSA is used to assist in decision making. Other contributions of the decision making process should be integrated in an appropriate approach. This is e.g. demonstrated by the combined application of L-PSA and operational indicators in reference /5/.
- The application of L-PSA requires acceptance from both utilities/plant staff and regulatory/licensing authorities (e.g. /5/).
- Plant personnel must be directly involved in L-PSA (e.g. /5/, /6/).
- SAIS - computer system integrates L-PSA tool as well as items of safety system attributes and data, to support the use of L-PSA in the decision making process /13,26/.

2.6 Status of L-PSA Application

Looking at the four workshops under consideration, it was found that plant specific use has developed towards an application of improved models, tools and data handling systems, which is characterised by a more specific use of L-PSA in operational decision making. Extensive plant specific applications were reported e.g. in /20/, /21/, /22/, /23/, /24/, /25/. These applications demonstrate ongoing qualification of PSA as well as are assumed well established and precisely defined at a routine level.

Main steps towards real plant specific use of L-PSA can be taken from /21/ (Northeast Utilities, US):

- The use of PSA methods was initiated after plant safety features were questioned following abnormal plant-specific safety related events.

- From limited PSA weaknesses in systems were found that were believed acceptable because they met licensing requirements.

- At the beginning a few engineers did PSA work in addition to other safety related duties.

- A large amount of backfitting measures derived from the accident in Three Mile Island led to a growing sentiment that there had to be a better way to understand, prioritise, and manage safety issues and to assure that utility originated safety projects would be given equal consideration.

- PSA capability was improved and activities increased in response to PSA initiatives of the regulatory body. This includes management aspects such as subjects defined at the beginning of work:

- Rather than contracting out PSA work to outside consulting firms, a Probabilistic Risk Assessment (PRA) Section would be formed in the Safety Analysis Branch.

- The PRA Section would be responsible for providing PSA related support to the design and licensing groups.

- The PRA section was to develop and maintain living PSA models for all NU operated nuclear power plants.

- A general five year plan was developed to staff up and initiate PSA models for each of the operating nuclear units, with priority based on the age of the plants.

- These activities were aimed at developing full plant models.

- Safety goals identifying public risk and core melt frequency levels were defined.

- Plans were established for using the living PSA models in all plant support activities (Design Changes, Technical Specifications Changes, Procedural Changes, training).

Despite L-PSA plant use is well established at some utilities the methodology is still partly questioned in many presentations of the fourth workshop. In fact each contribution more or less points out modelling aspects. This situation reflects that “living” PSA at the current status is a concept that can be successfully used in plant operation but needs ongoing development. In addition the results and insights of L-PSA depend on the methodical approach. For some tasks no consensus is available, e.g. for determining time dependent results and their interpretation.

2.7 Methods, Limitations and Interpretation of Results

L-PSA modelling means aspects that are related to input data of models for handling input information, output information and interpretation of results. Modelling aspects of computer tools are delineated in sub-section 2.8.

The following issues were found specifically characterising L-PSA modelling aspects:

- L-PSA has to be based on plant-specific information
- L-PSA must be capable of updating according to the operational requirements. An off-line application is considered sufficient. However some activities on on-line linkage to plant data system was reported /32,9/.
- L-PSA tools should be available at the plant site e.g. on a PC base
- Fast response time according to the operational needs capable of being re-run in an acceptable time limit.

The output of L-PSA should include:

- Time dependent values of current risk output and not only average values are needed.
- Component importance rankings according to both “level 1” and “level 2” criteria.
- Measures of interpretation, explanation and advice giving to the operators, in a way that users who are not risk specialists must be able to appropriately interpret the L-PSA results.

To ensure accuracy of the results specific quality assurance requirements have to be fulfilled. Control structures have to be established to ensure the effectiveness of the quality assurance programmes. The specific quality assurance for L-PSA is due to the intended changes in methods in computer codes, plant models and data base. In /9/ principle features of a quality assurance programme are pointed out as
a statement of the policy and objectives for, and commitment to quality:

- the responsibility, authority and the interrelation of the personnel involved in the PSA
- a clear programme of audits of all aspects of the PSA
- a systematic and orderly documentation system ensuring quality records
- software security of codes and databases.

In /5/ similar to other contributions the following general limitations are discussed:

- incompleteness and conservatism of the models which could lead to wrong non-conservative decisions
- a need to qualitatively evaluate quantitative results because of the above mentioned incompleteness and conservatism

- insufficient modelling of the influence of Common-Cause Failures on time dependent system unavailabilities
- simplified assumptions on test effectiveness when generating failure data of standby components
- practical time constraints
- simplified approach to time-dependent evaluations
- insufficient integration of uncertainty analyses.

2.8 Computer Codes

The computer codes, which were presented and described in the 4 Workshops, addressed specific L-PSA features applications (Tab. 2.4). Thus the list of computer codes and the fields of application does not necessarily give a complete overview on the currently used computer codes for L-PSA application.

The following specific L-PSA related aspects were found to require handling by computer tools:

- the huge amount of information to be put into and processed within L-PSA
- rapid or on-line response time
- capability of rapid updating
- appropriate and rapid display of output information
- quality assurance and control
- easy use by operators
- combination of different tasks in a consistent way, such as plant data collection, plant information structuring and documentation, information processing.

Table 2.4: Computer codes and fields of application addressed at the workshops

Name	**Field of application**	**Ref.**
ESSM	Database management and risk analysis	/32/
FAULT_TREE	Fault tree and event tree analyses	/15/
IRRAS	Integrated reliability and risk analysis, models and results data base	/28/
LIPSAS	Integrated PSA tool	/31/
NUCAP	PSA level 2	/11/
NUPRA	PSA level 1	/11/
PSA-PACK	PSA level 1	/29/
QUEST	Simplified FT/ET analysis	/33/
RISA+	Fault and event tree construction and analysis	/34/
RISKMAN	Modelling, quantification, monitoring	/45/
Risk Spectrum	Living PSA, database management and risk analysis	/35/
SAIS (incl. RISA+)	PSA level 1+; information collection and processing	/12/, /26/
SPSA	PSA level 1 and 2; common tool for safety management	/16/, /8/, /10/
STARS	PSA level 1+; information collection and processing	/14/
Super-Net	Reliability and life cycle cost analysis	/36/
UPREPA	Data handling; reliability parameters; automatic tests for trends; basic events probabilities	/8/
KOMPAS	Collection and assessment of data	/18/
KIRAP	Fault Tree Construction and Analysis	/57/
CONPAS	Event Tree Construction and Analysis	/58/
RAM-Pro	Reliability Data Collection and Analysis	/59/
NTRDP	Treatment of Generic Component Reliability Data Considering Dependency among Data Sources by Three Stages Bayesian Update Technique	/60/
Risk Monster	Risk Monitor Program	/61/
COCOA	Common Cause Failure Database and Analysis of Impact Vectors	
KACAP	Level 3 PSA Code	

2.9 General Findings and Issues of Development

The four workshop meetings on L-PSA application from 1988-1994, which comprised a broad spectrum of L-PSA subjects approved very useful on the way to the current level of application. A brief presentation of L-PSA objectives, conditions of use and capabilities of models and tools is given in Figure 2-1.

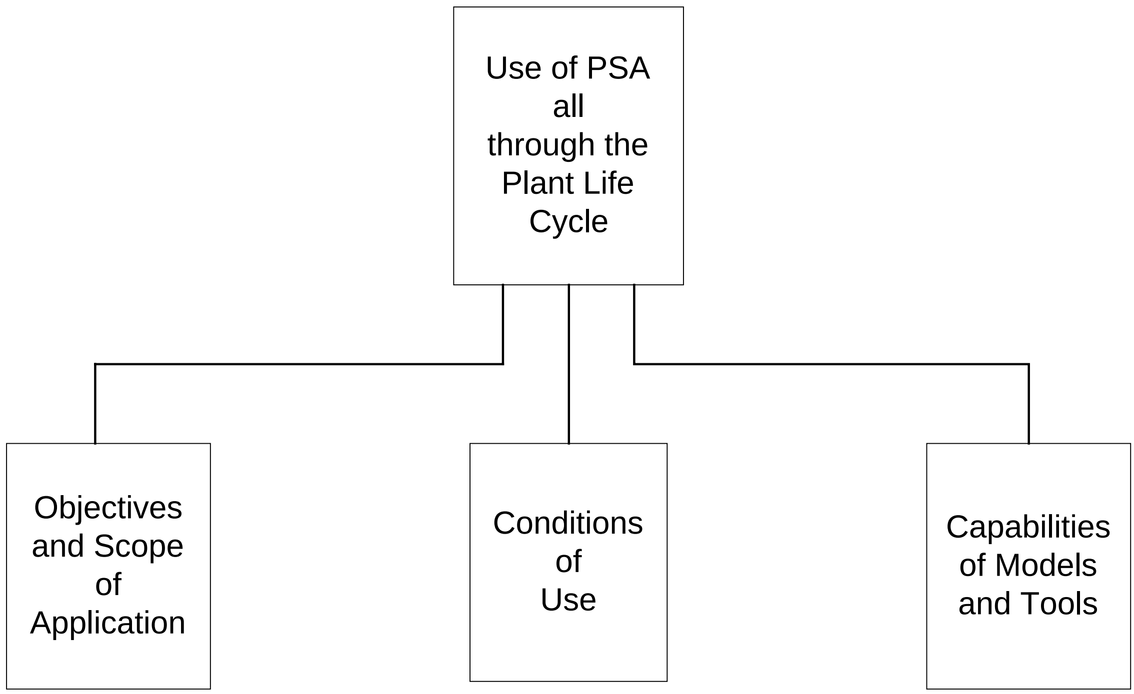
From the workshops contributions some general findings can be summarised:

- Successful L-PSA development is closely related to practical plant specific use by the utility.
- Beneficial real plant specific use is possible at different levels of L-PSA such as long-term safety planning, off-line risk planning of operational activities, on-line and off-line risk analysis of plant performance. However for increasing confidence in L-PSA methods some operational fields of application need additional practical experience.
- A common understanding on the L-PSA approach among utilities, authorities and external PSA organisations is helpful in development of practical use of L-PSA.
- An appropriate L-PSA usage at the current state-of-the-art needs accompanying model and tool development.

It is felt that in future special discussions on single issues would be helpful for facilitating L-PSA application rather than to treat the whole spectrum on general issues meetings. Conditions for application of L-PSA could be an important subject for exchange of experience among utilities and authorities. This especially includes the organisation of the decision making process covering:

- a combination of different aspects of the safety and availability decision making process
- a combination of quantitative and qualitative results to be used within decision making processes
- interpretation of uncertainties
- routines and procedures on how to utilise L-PSA.

In addition quality assurance and control within the L-PSA process needs further discussion to increase confidence in the results. These issues are discussed further in chapter 4.



- Long-term safety planning / risk assessment, Level 1 PSA

- Risk planning of operational activities / risk monitoring, Level 1 PSA

- Risk Analysis of operating experiences / risk follow-up, Level 1 PSA

- Design and construction of NPP (generic data) Level 1 PSA

- Severe Accident management / Level 2 PSA

- System for collecting plant specific operational experiences

- Concept for use of L-PSA methods and tools

- Appropriate computer tools

- Programme for development of methods and tools

- Integrated approach on decision making including aspects other than L-PSA

- Utility and regulatory authority acceptance

- Direct involvement of plant staff

-Processing of plant-specific information

- Flexible and versatile methods and tools according to operational requirements

- Updating capability according to operational requirements

- Off-line use is sufficient

- On-going model development

- User interface

- Tools available on PC or workstation at plant site

Figure 2-1: L-PSA Objectives, Conditions and Capabilities

3. STATE OF RELIABILITY DATA COLLECTION

3.1 OECD-Related Work on Data Collection

Reliability data collection from plant operating experiences forms a main part of PSA, especial of L-PSA in receiving adequate probabilistic values.

In 1990, OECD PWG5 has established the Task Group 12, to focus on the subject of reliability data collection and analysis to support PSA.

A questionnaire was set up to get answers about the main principles of data collection and analysis:

- Organisations involved in PSA and plant-specific data collection
- Objectives of reliability data collection
- Types of events to be collected for data evaluation (component failure events, initiating events, human interaction)
- Scope of data evaluation (safety and non-safety components)
- Elements of data collection (data sources of incident events, plant engineering data, operational data, component boundaries and populations)
- Tools and computer systems for data collection and assessment
- Evaluation of reliability data from the operational feed back (trend analysis, reference values, safety indicators, precursor events, verification of analysis models and assumptions)
- Management aspects of data collection and analysis (data treatment and quality assurance, frequency of data evaluation, man power requirements).

The results of the responses of 44 organisations of 26 countries were evaluated and summarised in the OECD-report /38/. In 1996 a follow-up questionnaire was initiated and responded by 10 OECD member states.

The discussion about the state of reliability data collection was at two international OECD workshops on “Reliability Data Collection in Support of PSA, Maintenance and Life Assurance Programmes”, in Toronto, 1995 and on “Reliability Data Collection for Living PSA”, in Budapest, 1998. The workshop results are documented in /43/ and /62/.

The results from these activities are summarised in the following chapters (details of the results, see the references given above).

3.2 Organisations Involved in Plant-Specific Data Collection

The majority of responding organisations are the utilities running NPP. They have either already implemented or plan to implement a reliability data system to support PSA. More than half of them plan to maintain a L-PSA, which is usually to be updated of 1 up to 5 years.

Other organisations such as national institutes are also in charge of data collection, e.g. for facilitating national data banks, for storing data from the national NPP‘s.

Experiences from following National databases were reported (see the following chapters and /62/):

- Spanish database DACNE covering all Spanish NPP, based on the requirement of Spanish Regulatory Body
- France databases, SAPHIR
- German databases ZADB is a centralised databases operated by the utilities of NPPs
- Swedish and Finnish NPP perform a common databases, known by the reports named
- T - Book - Component data
- I - Book - Initiating Events
- X - Book - External events (fire frequencies).

3.3 Objectives of Reliability Data Collection

As a general result from the contributions of the questionnaire and workshops, a wide agreement of the objectives of data collection can be stated:

- Obtaining realistic PSA data as well as verification of PSA models (e.g. CCF models)
- Maintaining a plant specific PSA / L-PSA (for risk based regulation, as formulated by the US-NRC)
- Reliability centred maintenance (RCM), spare parts management, material procurement, trend and ageing analysis
- Regulator use of reliability data for scaling events.

From the national data bases the following objectives of reliability data collection were indicated:

- Spanish DATABASE DACNE
- Plant specific data to ensure realistic PSA results
- Performance based maintenance regulation

- Maintenance optimisation program
- Data trend analysis (ageing)
- Sharing information between different NPPs
- Reducing uncertainties
- Establish typical industrial parameters

France DATABASE

- reflect operating experiences
- equipment ageing
- changes of maintenance practices.

3.4 Types of Events Collected for Data Evaluation

Plant specific data collection on component level and of initiating events are well established.

As a result from the questionnaire, only few or no data assessments concern common cause failure data, human factor data, passive component-, electronic- and software - failure data. The following aspects are given:

- common cause failure data through root cause analysis,
- human factor data through incident analysis of plant trips and tests,
- passive components (e.g. heat exchangers, failure modes of external leakages, plugging),
- data of shut down state (initiating events only).

In Swedish and Finnish - NPP fire events from plant operation were estimated and encompasses about 210 reactor years, taken into account the different characters and size occurred (s. Data Workshop /62/).

3.5 Scope of Data Evaluation

The majority of data bases are focused on the scope of PSA-related data (up to 1000 components are treated).

Data collection of electronic devices (subcomponents) are not generally treated separately (as mentioned: cost effective and not sensitive to CDF).

Systems outside the scope of PSA are indicated, such as, fuel handling and transporting system, conventional safety valves and overpressure protection system.
Some indicate data treatment of all plant components (up to 35.000 components).

3.6 Elements of Data Collection

The original sources of failure events are contained in the divers operational plant documents, such as operation logs, order-to-operate forms, calibration sheets, maintenance reports, test records.

Attributes of failure events to be selected from the event reports are generally indicated:

- Failure event and component identification code
- Time of failure detection
- Time of component restoration and unavailability
- Consequence of failure, failure mode, failure cause (root cause, CCF-indicator).

Some contributions indicate data storage of specific component design data (up to 20 attributes), operational environment data, operational data (hours, number of starts and cycles) and costs of event restoration.

The need of "component boundary definition" are generally stated, for consistency of failure data in the data base and to be consistent with the component models of fault trees. Component boundaries are generally defined according to the component function level. Subcomponents and - in some cases - component parts are also treated in this context.

Component populations are generally compiled from similar components to increase the sample size of components, thus to obtain better statistics, e.g. of failure rates.

Some indications are given about the dependency of population, e.g. of the environmental impact. Neglecting this impact would result in an underestimation of failure rate. To this respect further investigation based on plant experiences is recommended.

3.7 Tools and Computer Systems for Data Collection and Assessment

For storing the large number of information most data bases are PC-based or part of the plant computer system. Thus the data base can be handled in a way where data are consistent and traceable for quality assurance. The reliability data analysis are generally performed on basic statistics or by Bayesian analysis for failure rate and frequency estimation.

3.8 Evaluation of Reliability Data from the Operational Feed Back

Reliability data based on plant operational experiences are commonly evaluated of:

- Component failure rates
- Unavailabilities of components and systems
- Frequencies of initiating events
- CCF-rates
- Uncertainty parameters.

The derived values from the operational feed back are evaluated according to trends, ageing and maintenance effects and against generic data. If the plant experience of a specific subject is small, e.g. the plant-specific component failure rate is greater than the upper bound (95%) of the generic failure rate, the plant-specific failure rate will be neglected.

At the Data Workshop /62/ questions on how to treat generic PSA data for plants which have no or small operational experiences were discussed in respect of the following items:

- How to reflect the different quality of generic data.
- Criteria of neglection of events which are estimated not to be applicable for the plant under consideration.
- In this context, what is the meaning of a conservative approach; it depends on the type of use of PSA
- It was concluded, engineering investigation and insight of the selection process of generic data are highly important.

Specific aspects for further investigations were indicated in this context, e.g. of :

- how to assess CCF event data,
- verification of failure models of stand-by and demand cases (e.g. identification of the main impact on failure mechanism),
- identification and evaluation of environmental impacts on failure mechanism from real incident demands, not verified in regular tests,
- how to apply reference values under the aspect of data uncertainties (safety indicator and precursor evaluation).

3.9 Management Aspects of Data Collection and Analysis

Plant specific data collection is an on-going work at plant site, such as selecting relevant failure events from the total event and maintenance reports as well as up-dating the failure events according to specific failure attributes. This initial process of data collection is an important step of data evaluation and requires adequate QA.

For data review and data screening plant personnel with engineering knowledge is required. In addition for getting qualified data from field-events maintenance people should be necessarily involved. For getting best information, they should see a benefit from this work. In this context it should be recognised, that maintenance people look for failure causes (how to restore a defect component) and PSA-people look for component failure modes/effects (how the system is effected).

The plant staff should see the rational of databases so as to increase the adoption of their knowledge.

“The more limited the knowledge of defect, the greater the uncertainty associated with the choice” (UK /62/). Hence, many contributors stress the importance of quality assurance of failure event investigation so as to receive consistent failure data, taken into account some hundreds of event reports each year.

Experiences are mentioned that data evaluation of historical plant data, which were not initially up-dated due to the reliability aspects, were highly time consuming or rejected. For example, 2 man-years for updating of 10 years-plant experiences were necessary. Thus well-developed procedures and guidelines for data analysis, QA and transparency (tracebility) of data assessment are important. To this respect, standard procedures of data treatment, e.g. event data forms, coded failure attributes and component boundaries definitions, are helpful and supports quality checks as well. Manpower of the current data evaluation process is mentioned about 1 - 2 engineers per plant-unit and year.

3.10 General Findings and Issues of Development

The contributions from the questionnaires and the workshop on data collection in the international field indicate a high engagement in the process of collecting plant-specific data for PSA and maintenance aspects (RCM). It brings plant staff and PSA-people more together so that plant safety will regularly be reviewed by measuring the actual plant experience against PSA results, input data, models and assumptions.

Due to the high number of information and data to be treated in the collection process, procedures and standards for data collection, computer tools and adequate quality assurance are necessary for receiving consistent data. In this context the given examples indicate a well developed state of data collection concerning component failure data and initiating events.

Long term trends to be observed from data evaluation /62/:

- decrease of IE frequencies (France, Germany)
- increase of component failure rates due to ageing.

Concerning other types of reliability data the questionnaire results and the Data Workshops show, only few or no data assessment concerns of common cause failure data, human factor data, failure data of passive components, electronic devices and software. To this context the following aspects are stated:

- Common cause failure data are identified through root cause analysis, but formal procedures of evaluation are missing.
- Human factor data assessment through incident analysis of plant trips and tests are indicated.
- Failure data assessment of passive components are mentioned only for heat exchangers (failure modes of external leakages and plugging).
- Failure data of shut down state are restricted to initiating events only.

Concerning data assessment, additional aspects for further development were indicated:

- Component populations are generally compiled from similar components to increase the sample size of components, thus to obtain better statistics, e.g. of failure rates. Some indications are given about the dependency of population, e.g. of the environmental impact. Neglecting of this impact would result in an underestimation of failure rate.

- Identification and evaluation of environmental impacts on failure mechanism from real incident demands, not verified in regular tests.

- Indications are given about the dependency of initiating event and a mitigation system due to a common cause failure; such dependencies were observed from plant experience but generally not modelled in a PSA.

- Indications are given about the dependency of maintenance and human errors, which can cause component failures, by human errors in maintenance passing several barriers of surveillance; such failure events were observed from plant experience but generally not modelled in a PSA.

- Verification of failure models of stand-by components with the aim to find time dependency or demand frequency respectively (identification of the main impact on failure mechanism). This is an important aspect due to the assessment of surveillance test intervals.

- The meaning of data uncertainties with respect to application of reference values, safety indicators and precursor evaluation.

- Management and organisational factors (M/O):

- M/O-factors have strong impact on events but are hidden

- not modelled in the PSA and no models are available

- Reliability data depend on persons who are in charge of the equipment. Frequent changes of personnel has a negative impact of the component reliability, new personnel need, e.g. 2 years to understand specific component mechanisms (Example from Korea /62/).

To these aspects further investigations based on operational plant experiences is recommended.

4. ISSUES OF DEVELOPMENT IN SUPPORTING LIVING PSA APPLICATION

4.1 General Aspects

The preceding chapters 2 and 3 refer to general experiences of Living-PSA and reliability data collection as well as issues of further development which result from a series of workshops and questionnaires. In this context it was recommended that in future special discussions on single issues would be helpful for facilitating L-PSA application rather than to treat the whole spectrum on general issues meetings. Conditions for application of L-PSA could be an important subject for exchange of experience among utilities and authorities. This especially includes the organisation of the decision making process and quality assurance of L-PSA.

Based on these results and the increasing development of Living PSA in the international field and its capacity to support plant safety management in a broad sense, OECD PWG 5 continues its work by clarifying specific aspects of Living PSA. These aspects are treated in this chapter:

1. How to integrate L-PSA into the decision making process, including dialogue between regulatory body and plant safety management and how to adapt the requirement in a risk-based approach, risk-based regulation.

2. Quality assurance of L-PSA and data collection to control this process.

3. Safety issues and requirements of risk-monitoring systems as part of operator tool in the control room.

4. Computer based management systems available at plant to be used in support of L-PSA (data base, event reports).

5. Use of plant specific reliability data collection for L-PSA and how to fit into the management process (quantitative indicators for intervention).

6. Reflections of human reliability data by plant experiences (how to receive relevant information on HF and how to assess these data).

7. Organisational and management factors having impact on plant safety (how to measure and what is the role of L-PSA in this context).

Before treating the specific issues of L-PSA an interpretation of the definition of L-PSA will be given.

4.2 General Definition of L-PSA

For utilisation of a L-PSA in the safety management process its principles, characteristics and requirements must be clarified. As a result from the four Living PSA workshops, reported in chapter 2.2, different definitions of L-PSA were found:

- L-PSA is a daily safety management system which is based on a plant-specific PSA and supporting plant information system:
- L-PSA expresses plant risk at a given time and plant configuration.
- L-PSA and operational safety indicator evaluation is a combined application.
- L-PSA concept has led to a programme for implementing L-PSA and is based on level 1 PSA application and a common conviction on the usefulness of PSA among the persons that are involved in PSA activities at the utilities as well as the regulatory bodies /5/.
- L-PSA is a dynamic PSA tool for assessing real plant configuration and which is capable of producing results in useful time scales /6/.
- L-PSA is that technology which allows the performance of PSA within an appropriately small time period and which is updated sufficiently regularly to remain valid at all times /7/.
- "Living" means that the PSA is frequently updated, e.g., per modification, plant changes, etc. (a statement from the PWG5 discussion 1996).

From the international literature we can find the following definitions of PSA and L-PSA.

The US-PRA Procedure Guide, NUREG/CR-2300 /51/ defines a PRA as follows:

- "The probabilistic risk assessment is an analytical technique for integrating diverse aspects of design and operation in order to assess the risk of a particular NPP and to develop an information base for analysing plant-specific and generic issues. In achieving these objectives, PRA serves many purposes.

  An assessment of the plant-specific risk provides both a measure of potential accident risk to the public and insights into the adequacy of plant design and operation."

The IAEA-Procedure Guide "Procedures for Conducting Probabilistic Safety Assessments Nuclear Power Plants (Level 1)" /50/ gives the following definitions on the objectives of PSA and L-PSA:

- "PSA is one of the most efficient and effective tools to assist decision making for safety and risk management in NPPs. As such, it can have one or more of the following three major objectives:
- to assess the level of safety of the plant and to identify the most effective areas for improvement;
- to assess the level of safety and compare it with explicit or implicit standards;
- to assess the level of safety to assist plant operation."

"Operating experience can be assessed in a systematic way using the PSA results. Implications of trends and near misses can be determined. By following a Living PSA programme, the significance in failure data and operational procedures can be evaluated."

The IAEA "Reliability Assurance Programme Guidelines for ALWR" /54/ gives the following definition of "Living" PRA Plant Model:

– "A completed PRA is a "snapshot" in time of a plants characteristics. Maintaining a living PRA requires that all changes be evaluated and, when applicable, incorporated into the PRA, since any change in the plant procedures and/or hardware has the potential to change the plant characteristics and the PRA results. The living PRA provides a current model which can be used to quickly evaluate the merit of potential changes or alternative operational".

The IAEA Expert Group /53/ gives the following statement on PSA, Living PSA and Risk Monitor:

– Nuclear facilities, because of their complex nature, are subject to change with time. These changes can be physical (resulting from plant modifications, etc.), operational (resulting from enhanced procedures, etc.) and organisational. In addition, there are also changes in our understanding of the plant, due to the analysis of operational experience, implementation of data collection systems, development of improved models, etc. Therefore, if the PSA, which is a risk model of the plant, is to be more than a statement of the plant risk at the time of its development, but is also to be of continuing use in the enhancement and understanding of plant safety, the PSA must be updated or modified when necessary to reflect the above changes. This has led to the concept of a LIVING PSA.

The IAEA Expert Group recommends a clear distinction of what is meant by PSA, Living PSA and Risk Monitor and gives the following definitions:

– A **Living PSA** (L-PSA) can be defined as a PSA of the plant, which is updated as necessary to reflect the current design and operational features, and is documented in such a way that each aspect of the model can be directly related to existing plant information, plant documentation or the analysts' assumptions in the absence of such information. The LPSA would be used by designers, utility and regulatory personnel for a variety of purposes according to their needs, such as design verification, assessment of potential changes to the plant design or operation, design of training programs and assessment of changes to the plant licensing basis.

– A **risk monitor** is a plant specific real-time analysis tool used to determine the instantaneous risk based on the actual status of the systems and components. At any given time, the risk monitor reflects the current plant configuration in terms of the known status of the various systems and/or components, e.g., whether there are any components out of service for maintenance or tests. The risk monitor model is based on, and is consistent with, the LPSA. It is updated(2) on the same frequency as the LPSA. The plant staff in support of operational decisions uses the risk monitor.

2. To update the risk monitor means, in this context, to revise the models and database as changes are made to plant design and operational features, as the level of understanding of the thermal-hydraulic performance or accident progression increases, or as improvements are made in modelling techniques. This update needs to be done with the same frequency and in a manner consistent with the update of the LPSA.

4.3 Integration of L-PSA into the Plant Safety Decision Making Process

Task Group 96-1 defines specific issues of Living PSA for further clarification:

- How to integrate L-PSA into the plant safety decision making process, including dialogue between regulatory body and plant management and how to adapt the requirement in a risk-based approach, risk-based regulation,

- Quality assurance of L-PSA and data collection to control this process.

General observations of Living PSA applications:

As indicated by the IAEA Expert Group /53/ (s. chapter. 4.2):

- "Nuclear facilities, because of their complex nature, are subject to change with time. These changes can be physical (resulting from plant modifications, etc.), operational (resulting from enhanced procedures, etc.) and organisational...."

For adequate plant safety management control, all NPP are equipped with a large amount of documents, such as, safety reports, technical specifications, system and component descriptions and surveillance test procedures, which describe NPP safety as specified. This information represents the important deterministic data base for Living PSA as well.

The principles of a safety management process is illustrated in Fig. 4.3-1. On the left side the plant software is indicated - as safety is specified - and on the right (opposite) side - the real world - of man-machine system of NPP is shown.

PSA / L-PSA can support this process by:

- describing the elements of the hierarchical structure of plant safety features, from high level plant safety features down to system and component levels as well as plant parameters, which are in principle modelled and displayed in the PSA,

- identifying dependencies, such as, structural dependencies of common support functions, common environment, common component design features or maintenance,

- indicating (measuring) the risk impact of an event,

- ranking alternative solutions of desired plant modifications.

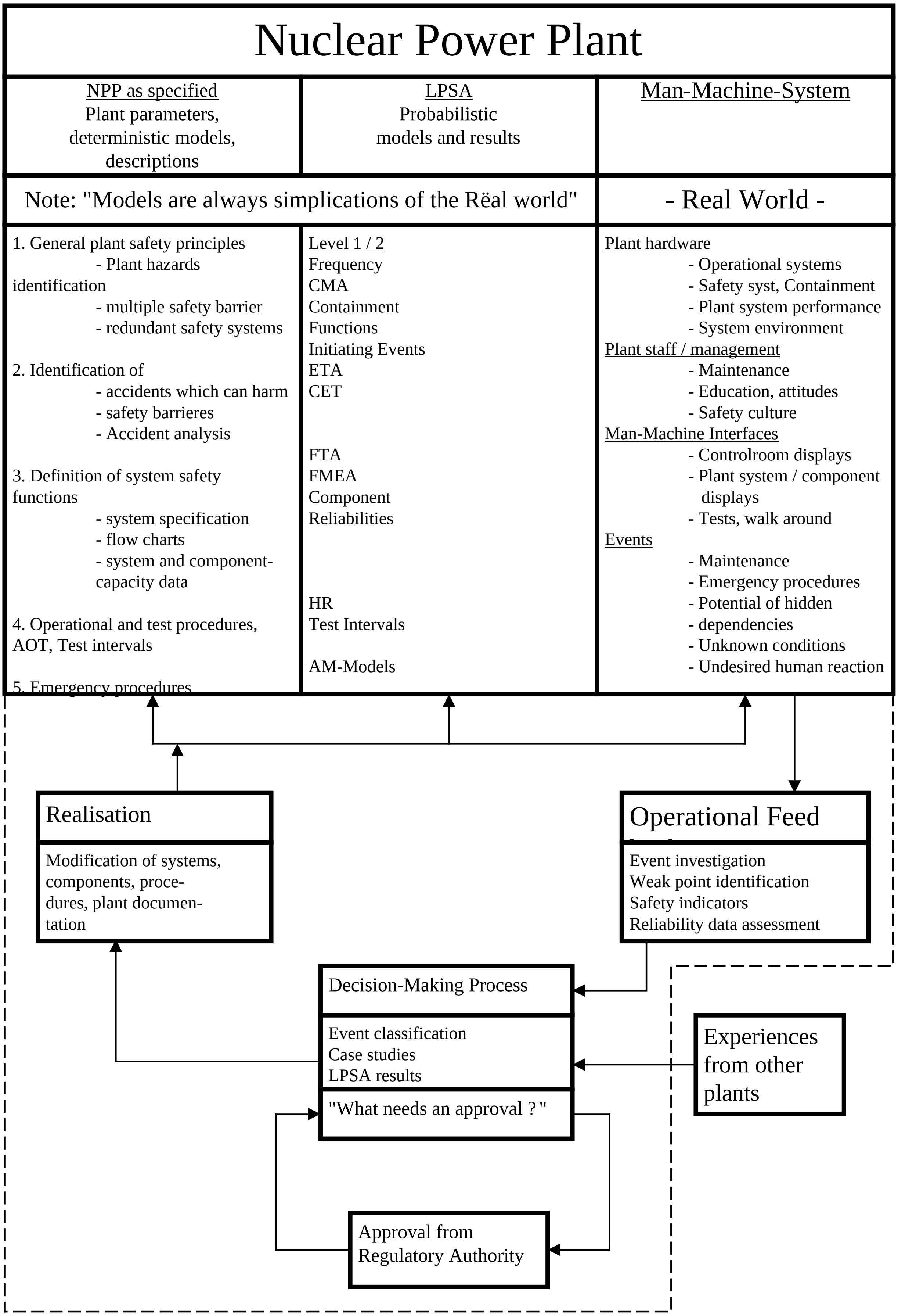
However PSA is generally done by experts, often in an isolated form so that plant engineers have the difficulty to get familiar with models, assumptions and limitations. An often raised question is:

- "What is and what is not modelled in the PSA?"

Updating does not include reconfiguration of the risk monitor , which may be performed on a daily basis or as often as necessary to monitor the operational risk of the plant.

Thus in the past a major problem was often stated that PSA was not prepared and documented in such a way that it could easily be updated. In this context it should be considered, that the main attribute of PSA is the reduction of the high number of plant components which are safety relevant and modelled in the fault trees with respect to the TOP-event. However the models do not show the influence of the neglected components.

Figure 4.3-1 Principles of Decision-Making Process in NPP Operation (see next page)


Nuclear Power Plant
NPP as specified
Plant parameters, deterministic models, descriptions
LPSA
Probabilistic models and results
Man-Machine-System
Note: "Models are always simplications of the Rëal world"
- Real World -
1. General plant safety principles
- Plant hazards identification
- multiple safety barrier
- redundant safety systems
2. Identification of
- accidents which can harm
- safety barrieres
- Accident analysis
3. Definition of system safety functions
- system specification
- flow charts
- system and component-capacity data
4. Operational and test procedures, AOT, Test intervals
5. Emergency procedures
Level 1 / 2
Frequency
CMA
Containment
Functions
Initiating Events
ETA
CET
FTA
FMEA
Component
Reliabilities
HR
Test Intervals
AM-Models
Plant hardware
- Operational systems
- Safety syst, Containment
- Plant system performance
- System environment
Plant staff / management
- Maintenance
- Education, attitudes
- Safety culture
Man-Machine Interfaces
- Controlroom displays
- Plant system / component displays
- Tests, walk around
Events
- Maintenance
- Emergency procedures
- Potential of hidden
- dependencies
- Unknown conditions
- Undesired human reaction
Realisation
Modification of systems, components, procedures, plant documentation
Operational Feed
Event investigation
Weak point identification
Safety indicators
Reliability data assessment
Decision-Making Process
Event classification
Case studies
LPSA results
"What needs an approval ?"
Experiences from other plants
Approval from Regulatory Authority

1. For adequate use of L-PSA in the plant safety management process, PSA models, data and results must be highly transparent and traceable. In addition the linkages between PSA models and data on the one hand and the plant and system safety features on the other hand must be clearly visible to the L-PSA user. A selection of examples are given to illustrate specific aspects, problems and observations of Living PSA application and its integration into the plant safety management process:

Northeast Utilities (USA) indicates main steps towards real plant specific use of L-PSA /21/

PSA capability was improved and activities increased in response to PSA initiatives of the regulatory body. This includes management aspects such as subjects defined at the beginning of work:

- Rather than contracting out PSA work to outside consulting firms, a Probabilistic Risk Assessment (PRA) Section was formed in the Safety Analysis Branch.
- The PRA Section would be responsible for providing PSA related support to the design and licensing groups.
- The PRA section was to develop and maintain living PSA models for all NU operated nuclear power plants.

The "Nordic L-PSA application" (Finland, Sweden) /5/ comprises

L-PSA implementation requires a specially defined system of application including a concept on how to use L-PSA methods and tools, appropriate computer tools and a concept how to develop methods and tools. L-PSA application is "a combined application of Living Probabilistic Safety Assessment (PSA) and operational safety indicators". It is aimed at decision making on safety issues. This L-PSA concept has led to a programme for implementing L-PSA and is based on level 1 PSA application and a common conviction on the usefulness of PSA among the persons that are involved in PSA activities at the utilities as well as the regulatory bodies.

A proper use of PSA applications requires established decision making criteria. Probability and frequency criteria are not sufficient in complex decision making situations. They might however give guidance or first indication about the acceptability of the decision alternative. The decision making procedure shall include and allow a combined use of probabilistic estimates, deterministic analyses and engineering judgement. The recommendation to prepare decision criteria is in the first place directed towards the regulatory side, but must be prepared and implemented in agreement with the industry. Regulatory and inspection activities relate to all applications of PSA /5/.

In Risk-based regulation and safety management in Finland:

Formal licensing process of NPPs has been based on deterministic rules and criteria. During last ten years the use of PSA has increased quickly level 1 (Internal and external initiators) and level 2 PSAs of Loviisa and OL plants have been completed.

STUK and utilities (IVO and TVO) have made an agreement on how to introduce the Living PSA and to implement the regulatory and plant safety management applications under common procedure . The guidelines for applying the Living PSA are set forth in the Regulatory Guide YVL 2.8. In compliance with those guidelines the Living PSA is formally integrated in the licensing procedure already in the early design and it is to run through the construction and operation phases all through the plant service time. Many specific applications of the Living PSA are already introduced but many are still waiting for further development such as ISI, IST and Risk Based Tech Specs (including configuration control).

The established Living PSA programme is shown in Fig 4.3-2.

The expansion of the Living PSA up to level 2 is underway. Accordingly Level 2 PSA methodology and PSA code development has been completed by STUK. Pilot studies for a BWR and a PWR plants have already been completed using new methodology and related computer code. The level 2 PSA methodology and code and related BWR and PWR applications are aimed to be used for reviewing the level 2 PSAs by utilities. In compliance with the requirements posed in the Regulatory Guide YVL 2.8 (published 1996) the licensee has to use the results of PSA in support of decisions on operational safety issues as follows:

- plant changes and backfits
- directing and weighting the In- Service Inspections and Testing
- applications of Tech Specs
- case by case assessment of risks resulted from component failures
- training of plant personnel
- working out of emergency operation procedures
- risk follow-up of Licensee Events
- maintenance and surveillance programme planning

If any plant modification have an evident contribution to the risk of the plant, the licensee must submit to the STUK a report of the intended modification and of its impact on the risk. The report has to be submitted to the STUK independent of the safety class, which the modified systems belong to.

In context of the aforementioned activities by the utilities the STUK has to use both deterministic and probabilistic reviews in parallel while controlling and regulating the issues.

A new project dealing with PSA support to regulatory audits has been initiated at STUK in 1997. The aim of the project is to explore on how the plant specific PSAs can best be used effecting specific regulatory tasks such as ISI, IST, preventive and corrective maintenance activities. The pilot studies on ISI of piping both of PWR and BWR plants are in progress. The systems subject to the pilot study are the high pressure injection system and emergency feed water system at PWR and the shut down cooling system and the feed water system at BWR plant.

2. The STUK‘s risk-informed procedure combines both the plant specific PSA information and the deterministic insights in support of the system specific, detailed ISI program selection. Piping of all systems important to safety are exposed to the selection procedure irrespective of the ASME class (1,2,3 or even non-code piping). The selection procedure includes several steps such as selection of systems and identification of the evaluation boundaries and functions, consequence evaluation and qualitative degradation mechanism evaluation of piping and division of the segments into different inspection

categories. Division of pipe segments into various degradation categories is to be based mainly on qualitative identification of the mechanism which the pipe segment is exposed (such as erosion corrosion, vibration fatigue, water hammer, thermal fatigue, stress corrosion cracking and others). Division of pipe segments into various consequence categories is based on conditional core damage probability estimated by PSA applications. Finally the expert panel containing all affecting engineering disciplines combines the deterministic and probabilistic information. The pipe segments are divided into different inspection categories containing high, medium and low risk segments, respectively.

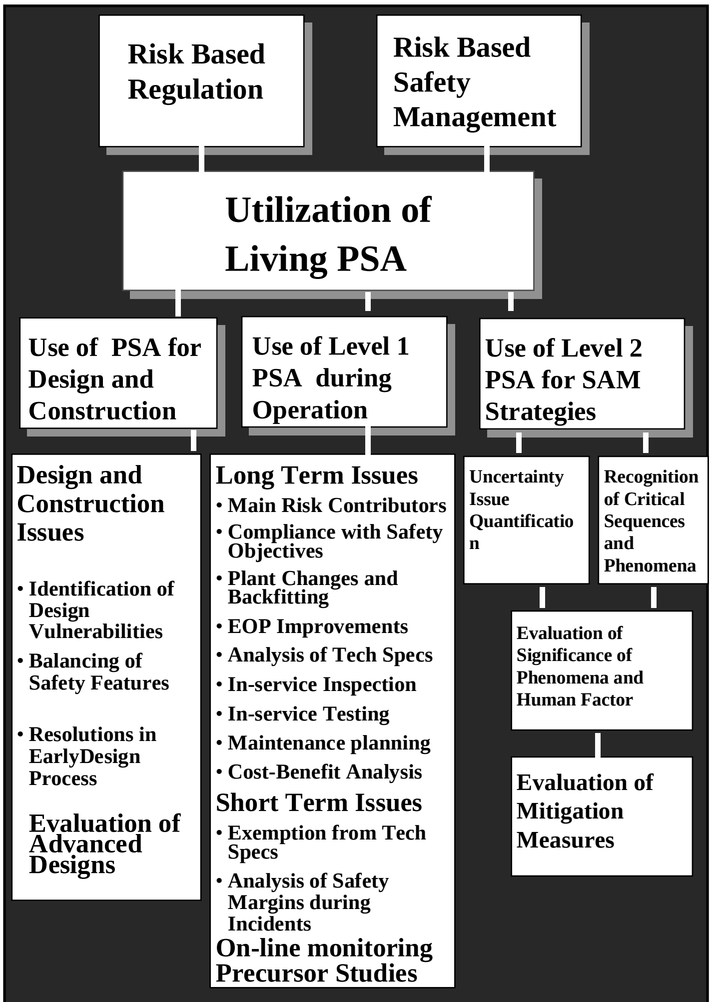


Figure 4.3-2 Finnish Living PSA Programme

ESCOM Utility (South Africa) indicates principle features of a quality assurance programme of L-PSA /9/

- a statement of the policy and objectives for, and commitment to quality
- responsibility, authority and interrelation of the personnel involved in the PSA
- a clear programme of audits of all aspects of the PSA
- a systematic and orderly documentation system ensuring quality records
- software security of codes and databases.

Germany

TÜV Nord (Germany) in support of the Regulatory Body applies a mixed deterministic and probabilistic safety criteria to evaluate proposed changes of surveillance test intervals of safety systems /56/. The concept is based on a formalised list of 16 specific criteria related to the features of tests, such as, requirements from safety standards, comparison with good practice of similar plants, value of component reliability from the feed-back of plant specific experience, level of importance of the probability of safety function with respect to the surveillance test to be under consideration. In each case in principle all criteria should be applied as a whole for evaluating the test in respect to the desired modification. This approach is supported by the Regulatory Body and being used by German utilities as well.

Hungary

VEIKI Institute for Electric Power Research (Hungary) is responsible for PSA updates. It is one of the main tasks of the Risk and Reliability Project within the Nuclear Engineering Division. The Project, i.e. the PSA team involves 6 experts, is located at VEIKI headquarters (Budapest) and is responsible for PSA update.
The updated PSA models are passed to the PSA team of the Paks NPP and installed at their Computers to be used for different application purposes (at plant site). PSA updates are done in close co-operation with the Paks NPP, where the PSA team within the Safety Analysis Department is the responsible organisation. The basic Level-1 PSAs are documented in details in written form following the IAEA PSA documentation guidelines. The models (event/fault trees), data and results are stored in the respective files of the Risk Spectrum PSA code package used for the analysis.

The stored basic models and data are used as initial information for the modification assessment, too. The PSA approach is integrated into the plant modification process during the engineering design period. I.e. the design activity (done by an independent qualified design company) is supported by both deterministic and probabilistic safety analysis. It is the design company who has the task to integrate the two types of safety analysis and produce a design documentation verified by safety evaluations.

The LPSA is defined as a daily safety management system and it is based on the plant-specific PSA and supporting information system. The main purpose to develop an LPSA provide a risk evaluation tool for analysing the safety effects of changes in physical, operational and organisational state of the plant and in the enhanced understanding knowledge of the plant from the safety point of view.

Data evaluation for safety indicators: preliminary processing - four times in a year, detailed evaluation - once a year. Data evaluation for operational safety assessment: occasionally. Reliability and safety data are used for safety assessment and preparing safety indicators. Modifications should be based on PSA analysis. Two reports have been presented to the plant management and to Operational Review Committee about the state of data collection and safety indicators. The guideline for data collection and evaluation for safety indicators is prepared and it is just under approval. In the Periodic Safety Review prescription of the regulatory body has been issued to prepare an activity plan for extension of safety indicators and reliability data base.

The regulatory body (Nuclear Safety Directorate) uses both deterministic and probabilistic principles during evaluation of plant modifications. Emphasis is laid upon the deterministic design principles (single failure criterion, defence against CCFS) and upon the results of thermohydraulic/reactor physics calculations. No authorised probabilistic criteria are used, the PSA result are evaluated on case by case basis.

International Organisations

IAEA Report /54/ give guideline on reliability assurance programme: The relationships between the plant Reliability Assurance (RA) and Quality Assurance (QA) programs are of particular interest. Both programs have similar objectives, assurance of plant safety and reliability, but achieve them through different mechanisms. However, because they are both focused on the same objective, the two programs complement and augment each other and broaden the individual impact and effectiveness of each other. The reliability assurance programme can typically be defined in terms of five major functional elements:

- Goal and performance criteria
- Management systems and RAP procedures
- Investigated methods
- Analytical tools
- Pant information and data base.

CNRA-Report /55/ and Special Issue Meeting on „Review Procedures and Criteria for Different Regulatory Applications of PSA“ provides general observation on PSA use:

- PSA experience and practices in most countries, are already sufficiently mature enough to allow PSA to contribute to the regulatory decision making process. Accordingly, many countries are progressing towards more extensive and systematic PSA use, or even integration of PSA, in the regulatory system.

- PSA applications at a general level, without careful analysis of assumptions and boundary conditions, may be misleading. In general, acceptance of PSA results and applications amongst decision makers seems to increase as detailed personal knowledge of PSA keeps increasing.

- Increasing the use of PSA in regulatory matters leads to the added need for the regulator to be equipped with the special skills and knowledge, by which assessment and review of PSA matters can take place.

- These acceptance criteria could be a relative measure, that is a criteria on the ratio of results between a base case PSA and a sensitivity study, or an absolute measure.

- Numerical criteria should be seen as targets, since uncertainty analyses which, are not currently in all PSA studies, need to be included in the future in order to establish a standard treatment for acceptability procedures to be developed.

- It seems evident that to some extent the integration of systematic PSA applications into regulatory systems is being achieved in several countries.

- Currently, these countries would be in transition from purely deterministic to a mixed deterministic and probabilistic regulatory system. The framework for a future system including an appropriate and fair balance between deterministic and probabilistic regulatory rules is worthy of further extensive discussion by national and intentional parties.

4.4 Risk-Monitoring and Computer-Based Management Systems

Specific issues of Living PSA for further clarification are defined by Task Group 96-1:

- Safety issues and requirements of risk-monitoring systems as part of operator tool in the control room.

- Computer based management systems available at plant to be used in support of L-PSA (data base, event reports).

- Use of plant specific reliability data collection for L-PSA and how to fit into the management process (quantitative indicators for intervention).

General aspects, problems and observations of Living PSA applications:

1. Safety management of NPP means to keep plant safety over plant life time at an acceptable safety level as specified and approved in the regulatory process.

2. Thus current evaluation of plant operation, incident event investigation (whether any correction is necessary and how to react) and safety assurance of current maintenance work are the main parts of this process.

3. In principle all plant parameters and other indicators (including organisational factors) should be part of current plant observation, e.g. of revealing any deficiency which can result in hazard plant conditions.

4. In this context management decisions are required on whether and how a modification of plant operation, hardware or software (procedure) is necessary, and whether the modification under consideration needs a permission from the regulatory body.

(OECD had initiated a broad discussion to this issue, named “In-Depth Discussion on Event Investigation”/41/.)

5. Plant incidents, such as component failures, system unavailabilities, transient events, operator failures, on the one hand are subjects of maintenance and recovery actions, on the other hand they are also indicators of the performance of plant operation and the efficiency of the management and maintenance process.

6. Incident investigation in principle has two parts under consideration:

   - Looking for the consequences of faulty components effecting safety functions and setting priorities of urgency of restoration.

   - Assessing the root cause of failure event, so as to identify each dependency in order to prevent failure recurrence and multiple failure.

7. PSA can support these management tasks with respect to both items, by assessing the risk impact of the event under consideration (e.g. the degree of precursor). The result will stimulate the risk awareness in dealing with the events.

8. The frequencies of events can be used as safety indicators and for reliability data evaluation. The numerical results will be measured against the reference data of PSA, so that maintenance planning has targets for improvements.

9. In this approach system and component reliability will be improved and PSA data are under current review and become more realistic.

10. The integration of a plant data base in the L-PSA system, describing the component design features, installation and maintenance data, qualifies this approach (s. chap. 3).

11. The experience shows that an adequate reliability data management stimulates the maintenance process in setting priorities, and in consequence an increase of system and component reliability will result.

From the workshop contributions (chapter. 2) we can find the following statements:

- A L-PSA tool “must be able to provide information to station’s operational staff in a format most useful to them and in the time scale they require”. The use as “on-line risk monitor, or dynamic form of the Technical Specifications” was defined as the “ultimate goal” of L-PSA /6/.

- In reference /9/ the objectives of L-PSA are derived from PSA application to the plant under consideration. L-PSA is expected to assist on safety decisions, which arouse from operation of the plant. L-PSA carried out on an off-line base. However development of an on-line tool, which is linked to the plant data system, is under work. L-PSA is expected to give both safety and financial gains.

4.5 Human, Organisational and Management Factors

Specific issues of Living PSA for further clarification are defined by Task Group 96-1:

- Reflections of human reliability data by plant experiences (how to receive relevant information on HF and how to assess these data).

- Organisational and management factors having impact on plant safety (how to measure and what is the role of L-PSA in this context).

General aspects, problems and observations of Living PSA applications:

1. In PSA human factors (HF) are generally modelled only in the context of specified operator actions, e.g. to activate a component as required. Unplanned operator actions are normally not modelled due to a lack of methods. The impact of organisational and management factors (O/MF) on plant risk are not modelled in a PSA either.

2. During normal plant operation these factors are generally not visible and can not be measured explicitly.

3. Evaluations of severe accidents of several industries have shown a strong impact of organisational factors on the events.

4. For getting more insight into the meaning of these risk relevant factors, comprehensive development work is under way. It is aimed at accident evaluation and related root cause analyses, e.g. uncovering hidden organisational and management factors.

5. Broad international discussion on this subject, e.g. IAEA / INSAG 4 report on „Safety Culture“ /39/, results in the following statement:

   - Organisational factors are based on organisations, management and staffs attitude in combination with the organisational policy of working conditions and safety-aims of organisation.

   - A clear statement of safety policy, of management and staff responsibilities as well as a transparent structure of the decision-making process and an open in-house discussion on these subjects will have a positive impact of plant safety in total.

6. Living PSA application as integral part of safety management processes can play an important role in this context. By integrating NPP staff in this analysis process, insights can be gained in respect to the following subjects:

   - Organisational factors and HF on incident events can be better identified.

   - Shaping factors of operator reliability can be identified.

7. Risk awareness of plant staff can be positively stimulated in an active L-PSA process.

8. According to this state of knowledge several organisations have adopted the results of discussion on how to improve „Safety Culture“ of the plant operational process. These experiences deliver valuable information on how to get into this complex subject. So far it is highly important to proceed in the exchange of this specific experience.

5. CONCLUSIONS

The state of Living PSA of NPP operation has been discussed in the international field since 1986 in a series of international workshops initiated by the OECD-Principal Working Group No. 5, Risk Assessment. The gained experiences indicate that the conditions for application of Living PSA are different from the traditional PSA, because they have to be plant-specific and usable for non-PSA-experts of plant staff. These conditions and especially the subject on how to integrate Living PSA into the organisation of the decision making process have been found important for the exchange of experience among utilities and authorities. The given examples of Living PSA application indicate of real plant specific use of PSA by supporting operational plant safety and safety management decision-making.

The Living PSA is used by designers, utility and regulatory personnel for a variety of purposes according to their needs, including design verification, assessment of potential changes to the plant design or operation, design of training programmes and assessment of changes to the plant licensing basis. Because of the complex nature of nuclear facilities, they are subject to changes with time. These changes can be physical (resulting from plant modifications, etc.), operational (resulting from enhanced procedures, etc.) and organisational. In addition, there are also changes of our understanding of the plant, due to the analysis of operational experience, implementation of data collection systems, development of improved models, etc. Therefore, if the PSA, which is a risk model of the plant, is to be more than a statement of the plant risk at the time of its development, but is also to be of continuing use in the enhancement and understanding of plant safety, the PSA must be updated or modified when necessary to reflect the above changes. This has led to the concept of a *LIVING PSA* /53/.

A *Living PSA* can be defined as a PSA of the plant, which is updated as necessary to reflect the current design and operational features, and is documented in such a way that each aspect of the model can be directly related to existing plant information, plant documentation or the analysts' assumptions in the absence of such information.

A *risk monitor* is a plant specific real-time analysis tool used to determine the instantaneous risk based on the actual status of the systems and components. At any given time, the risk monitor reflects the current plant configuration in terms of the known status of the various systems and/or components, e.g., whether there are any components out of service for maintenance or tests. The risk monitor model is based on, and is consistent with, the Living PSA.

For adequate use of Living PSA in the plant safety management process, PSA models, data and results must be highly transparent and traceable. In addition the linkages between PSA models and data on the one hand and the plant and system safety features on the other hand must be clearly visible to the Living PSA user.

General findings about Living PSA application:

- Successful Living PSA development is closely related to practical plant-specific use by the utility.

- A common understanding on the Living PSA approach among utilities, authorities and external PSA organisations is helpful in development of practical use of Living PSA.

- Beneficial real plant-specific use is possible at different levels of Living PSA:

- Long-term safety planning (Plant changes and backfitting, analysis of Tech. Specs, optimisation of testing and preventive maintenance, balancing preventive and corrective maintenance),

- Off-line risk planning of operational activities (Risk based system configuration control, exemption from Tech. Specs, safety related event and Precursor analyses)

- On-line and off-line risk analysis of plant performance (Risk monitoring).

Currently, integration of systematic PSA applications into regulatory systems is being achieved in several countries. These countries are in transition from a purely deterministic to a mixed deterministic and probabilistic regulatory system. The framework for a future system - including an appropriate and fair balance between deterministic and probabilistic regulatory rules - is worthy of further extensive discussion by national and intentional parties /55/.

Concerning this subject it is stated in /37/:

Probabilistic analyses constitute a necessary supplement to traditional deterministic studies. In addition to the quantitative perspective on plant safety, the PSAs provide in many cases a more balanced and realistic picture than the predominately conservative deterministic analyses. Both types of analysis are subject to numerical uncertainties, but the PSA approach can make them better visible.

The most important insights provided by a PSA are engineering ones, i.e., those related to the identification of potential plant vulnerabilities. In many cases, once such insights have been obtained the value of the predicted frequencies involved becomes less important. Such results of PSAs are usually not undermined by the numerical uncertainties involved. Confidence in the completeness and correctness of the PSA with respect to engineering insights is justified if the PSA has relevant scope, uses state-of-the-art approaches to modelling topics and has been subject to an adequate review process.

The international experiences indicate a high engagement in the process of collecting plant-specific probabilistic data for Living PSA and maintenance aspects (RCM). This process brings plant staff and PSA-people closer together so that plant safety will regularly be reviewed by measuring the actual plant experience against PSA results, input data, models and assumptions.

Due to the high amount of information and data to be treated in the collection process and for receiving consistent data, procedures and standards for data collection, computer tools and adequate quality assurance measures have been developed. The examples, which have been given, indicate a well developed state of data collection concerning component failure data and initiating events (in a developed state, fire initiating risk data).

The following items of data assessment for further development were indicated:

- Common cause failures are identified by root cause analyses, but formal procedures of data evaluation are missing.
- Human factor data are identified by incident analyses of plant trips and tests, but formal procedures of data evaluation are missing.
- Failure data assessment of passive components and failure data specific to shut down states (not only to be restricted to initiating events) should be integrated.

Further development of specific aspects is necessary for increasing confidence in Living PSA methods and appropriate Living PSA usage at the current state-of-the-art:

- Routines and procedures on how to utilise and integrate Living PSA into the plant safety decision making process (Risk informed regulation).
- Quality assurance and control within the Living PSA process to increase confidence in the results.
- Treatment of quantitative and qualitative results and interpretation of uncertainties and limitations of the Living PSA approach within the decision-making process.
- Integration of human, organisational and management factors having impact on plant safety.
- Treatment of balance between safety and availability within the decision-making process.
- Framework for an appropriate and fair balance between deterministic and probabilistic regulatory rules is worthy of further extensive discussion by national and intentional parties.

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