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NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

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LIVING PSA DEVELOPMENT AND APPLICATION IN MEMBER COUNTRIES

Summary of TÜV Workshops held from 1988 to 1994

28780

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Or. Eng.

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 coordinate 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 cooperation 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 its programme of work. It also reviews the state of knowledge on selected topics of 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 coordination of work in different Member Countries including the establishment of cooperative research projects and results to participating organisations. Full use is also made of traditional methods of cooperation, such as information exchanges, establishment of working groups, and organisation of conferences and specialist meetings.

The greater part of the CSNI's current programme of work is concerned with safety 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 cooperative mechanisms with NEA's Committee of Nuclear Regulatory Activities (CNRA), responsible for the activities of the Agency concerning the regulation, licensing and inspection of nuclear installations with regards to safety. It also cooperates with NEA's Committee on Radiation Protection and Public Health and NEA's Radioactive Waste Management Committee on matters of common interest.

FOREWORD

At the OECD/NEA Symposium on Reducing Reactor Scram Frequency (Tokyo, April 1986), it was recommended that the collection of statistical data on reactor scrams be continued and updated regularly; this recommendation was subsequently endorsed by the NEA Committee on the Safety of Nuclear Installations (CSNI). As a follow-up to this initiative, the NEA Secretariat compiled a second issue of the statistical data on reactor scrams for 1987; that compilation was published as CSNI Report No. 157 in May, 1989. Based on the CSNI's recommendations, the NEA Secretariat subsequently produced annual reports entitled "Statistical Data on Reactor Scrams", the most recent one being that for the 1993 scram data, issued in August 1994.

The current report consists of graphs of the average scrams per unit, as well as the average scrams per 1000 hours critical with the turbine on-line, for the data collected during 1993, as well as graphs showing trends from 1989 to 1993. Part 1 gives one graph per country showing the trend for 1993 as well as graphs of percentage of main signals by plant designs; Part 2 is a compilation of tables and reports provided by Member countries.

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ABSTRACT

This report was prepared by Jürgen Rumpf, TÜV Nord e.V., Hamburg, Germany for OECD/CSNI-Principal Working Group 5, within a consultant contract of the OECD/NEA. It summarises the results of four workshops on Living PSA application held 1988, 1990, 1992 1994 in Hamburg, Germany. The workshops were organised by TÜV Nord e.V. to support the OECD/CSNI-Principal Working Group 5 (Risk Assessment) Task Group 95-2 and the co-operating IAEA with respect to the exchange of experiences on living PSA application and the state-of-the-art of this method.

The report points out characteristic features of LPSA application and development rather than being a systematic and comprehensive analysis of the state-of-the-art. It includes characterisations of current applications of LPSA as well as modelling and regulatory aspects. Open issues are listed.

It was concluded that the workshops turned out very useful on the way to a more sophisticated use of LPSA methods for plant specific applications. To further facilitate LPSA application and development discussions on selected areas are considered to be useful. Such discussions could cover a specification of conditions for plant specific use of LPSA as well as quality assurance and control measures.

1. INTRODUCTION

Four workshops on LPSA application were held at TÜV Nord e.V. in Hamburg since 1988. The workshops were organised to support the OECD/CSNI Principal Working Group 5 on Risk Assessment. 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 LPSA as well as a progressing trend towards practical plant specific applications of LPSA in 18 countries.
LPSA is well established in different uses at several utilities of NPP.

The TÜV workshops are aimed at encourage utilities and authorities to go the way towards plant specific application of LPSA by an appropriate exchange of experience, even though the conditions for application need further clarification. 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 LPSA approach is under way. Thus this report could initiate discussion on future ways how to support the process of LPSA development and application.

This report summarises the experiences that were reported at the four workshops. It mainly concentrates on the 4th workshop the contributions of which are assumed to represent important aspects of the state-of-the-art of application and development of LPSA. Statements from the previous workshops were taken into account to supplement the presentations of the 4th workshop as well as to delineate the development process in both LPSA development and application.

Chapter 2 gives a short overview on the four workshops. Chapter 3 summarises the presentations of the workshop with respect to main subjects of LPSA application.

A proposal on how to further support LPSA development and application is given in the concluding remarks of chapter 4.

2. OVERVIEW ON WORKSHOP CONTRIBUTIONS

Within the four workshops, held in 1988, 1990, 1992, 1994 (/1/, /2/, /3/, /4/), papers were presented by authors from 18 countries, the IAEA and CEC. Table 2.1 lists the countries represented by papers at the workshops. 22% of the total amount of 97 papers came from utilities, 10% from vendors, 8% expressed the views of licensing organisations and 60% were prepared by other institutions such as engineering companies, research institutes and review organisations. The number of papers presented by the different organisations at each workshop can be seen in table 2.2.

At all workshops most contributions were presented by engineering and research institutes. This situation reflects probably from the amount of development and research work needed for LPSA routine application by utilities and authorities. In addition plant specific use of LPSA was considered as to need PSA expects to a considerable extent.

No significant tendency appeared with respect to the need for the different types of contributing organisations over the time period which was considered. However a general tendency towards more specified application of LPSA in real plant use, which was accompanied by specific development of models and tools as well as management conditions, could be found.

The following general subjects were chosen for this report from the contributions of the workshops to represent the main aspects of LPSA:

- definition of LPSA
- objectives and scope of application
- regulatory aspects
- development programmes
- status of LPSA application
- modelling and management aspects
- computer codes
- open issues.

Table 2.1. Countries and international organisations represented by authors of workshop 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				
type of 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

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

3. LPSA SUBJECTS

3.1 Definition of living PSA

Formal definitions of the term "Living PSA" are given e.g. in the references /1/, /5/, /6/, /7/. In /1/ principles of LPSA are defined by focusing on the following questions:

- 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?

In /5/ LPSA is defined as being a "daily safety management system" which is "based on a plant-specific PSA and supporting information system". In this paper LPSA is assumed to express risk at a given time and plant configuration. Reference /6/ defines LPSA 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: "LPSA 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".

Despite these definitions are given in general terms they are, as definitions in other references, closely related to defined objectives/purposes as well as conditions of LPSA application. Thus a definition of LPSA needs reflection of what is stated with respect to these terms. Reference /5/ describes a "Nordic" approach for LPSA 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. The LPSA concept described in /5/ has led to a programme for implementing LPSA 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. This "Nordic LPSA application" comprises three main subjects of application:

- Long-term safety planning,
- Risk planning of operational activities and
- Risk analysis of operating experiences.

A characterisation of these three categories of LPSA application can be found in table 3.1 (from 5/).

Table 3.1. 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 reference /8/ 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 LPSA models should have the ability to maintain updated models and data. Based on these features LPSA should be able to give assistance to the plant staff on operational problems. In reference /8/ LPSA development is derived from specific level 1 PSA applications and aimed at operational tasks of the specific plant under consideration.

In reference /6/ LPSA 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 LPSA 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 LPSA.

In reference /9/ the objectives of LPSA are derived from PSA application to the plant under consideration. LPSA will assist on safety decisions which arouse from operation of the plant. From the point of view of the authors of reference /9/ LPSA is used for real time assessment, which, in a first step, is 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. LPSA is expected to give both safety and financial gains.

Reference /7/ points out a need for LPSA derived from:

- an unease with the current basis for some plant operations
- a belief that LPSA can provide the capability to scrutinise the plant in new ways and to optimise (in some sense) its operation where previous procedures have been lacking

In addition reference /7/ defines capabilities of LPSA including:

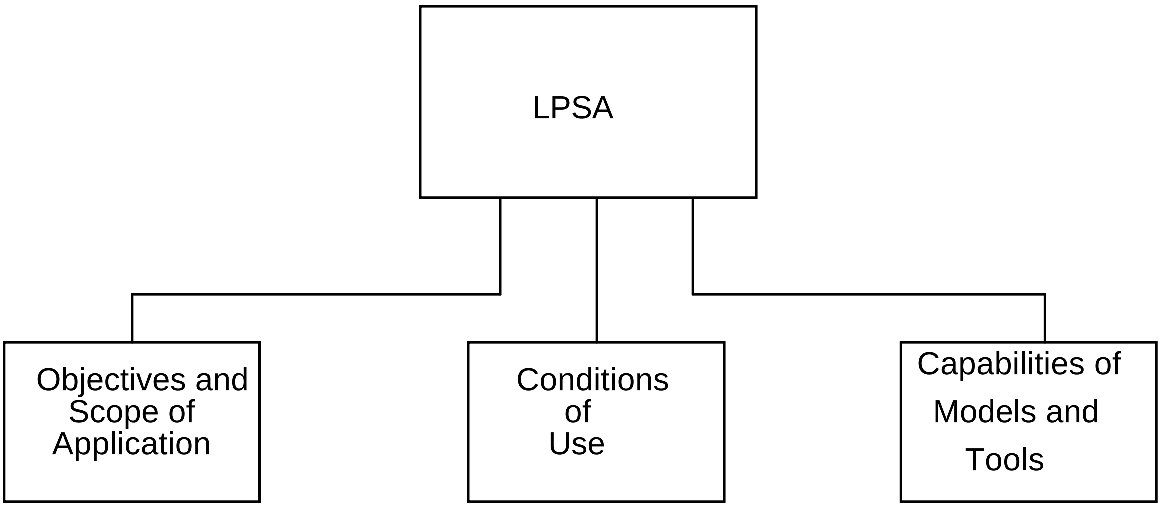
- to respond flexible to operational circumstances
- to effectively provide an environment within which risk profile can be quickly and accurately calculated
- to promptly and accurately measure risk (Risk Monitor).

A summary of differences between PSA and LPSA is also given in /7/. Despite the subject of LPSA was presented from different points of view with different aims some general conclusions will be given. It was concluded from the contributions that LPSA definition was not restricted to terms of modelling and computer tools only. Several aspects were stressed for describing the rational behind the term LPSA:

- Objectives and scope of application
- Conditions of use
- Capabilities of the models and tools.

Figure 3.1 summarises the different aspects which were used to define LPSA.

Figure 3.1. Aspects used for defining LPSA



Objectives:		
Long-term safety planning	plant operational experiences	Plant-specific information
(Risk assessment)	Level 1 PSA experiences	
		flexible and versatile methods
Risk planning of operational	concept for use of LPSA	and tools according to operational
activities	methods and tools	requirements
(Risk monitoring)	appropriate computer tools	Updating capability according
Risk analysis of operating		to operational requirements
experiences	programme for development	Off-line sufficient
(Risk follow-up)	of methods and tools	
Scope:		
Design and construction	Integrated approach on	On-going model development
	decision making including	user interface
Level 1 PSA	other aspects than LPSA	
(Level 2 PSA)	Utility and authority acceptance	Tools available on PC at plant site
(Severe accident management)	Direct involvement of plant staff	

3.2 Objectives, scope and conditions of use

Objectives and scope of application

The general objective of LPSA is to give assistance on safety (and availability) decisions to the plant staff. Such assistance is given in 3 different areas(from /5/):

- Long-term safety planning (risk assessment)
- risk planning of operational activities (risk monitoring)
- risk analysis of operating experiences (risk follow-up).

LPSA application range from a comprehensive approach comprising all these tasks (/5/) to single tasks that can be classified according to one of the above areas (e.g. /10/). At present LPSA activities are focused on level 1 PSA. However some activities were reported on research activities on level 2 PSA and severe accident management /13/, /10/, /11/, /12/.

The objectives of LPSA are explicitly discussed in references /5/, /8/, /6/ and /9/. A common objective of LPSA 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.

Important features were reported to be:

- time dependent risk monitoring
- on-line or almost on-line safety monitoring
- more realistic modelling
- flexibility and versatility.

Table 3.3 shows some statements with respect to objectives of LPSA.

Conditions of use

In this context the following aspects were emphasised:

- Despite LPSA 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/).

- LPSA implementation requires a specially defined system of application including a concept on how to use LPSA methods and tools, appropriate computer tools and a concept how to develop methods and tools (/5/).

- As LPSA 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 LPSA and operational indicators in reference /5/.

- The application of LPSA requires acceptance from both utilities/plant staff and regulatory/licensing authorities (e.g. /5/).

- Plant personnel must be directly involved in LPSA (e.g. /5/, /6/).

3.3 Regulatory aspects and related research projects

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

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

Regulatory needs

The following needs were pointed out:

- establishment of decision making criteria (/5/)
- promotion of PSA by research programmes (/23/)
- further development of guidelines on LPSA performance and PSA review (/23/).

Pre-requisites and problems

Pre-requisites and problems of LPSA application as they are seen from individuals of the UK regulatory body are mentioned in /7/. However these statements do not represent official views on the considered subjects. For details see table 3.4.

Decision making

Frequency and probability criteria are to be used within decision making. However probabilistic estimates, deterministic analyses and engineering judgement have to be combined within the decision making process (/5/).

Table 3.3. Statements on objectives of Living PSA (from the 4th workshop on Living PSA Application)

Reference	Statement
/13/	"the fundamental objectives of a Living PSA and Risk Monitor are: 1. time-dependent risk monitoring and prediction of plant safety operation, 2. evaluation of risk impacts of design and operational changes of the plant, 3. supporting operation, maintenance and repair strategies, 4. identifying long term ageing effects caused by the increase of component failure frequency as a consequence of degradation effects (reliability assurance of component performance), 5. supporting the development of accident management procedures by identification of additional plant safety features, 6. ranking the risk impact of regulatory issues, 7. improving the risk models to become more realistic by gathering plant operation experience and involving plant staff knowledge. "
/22/	"A Priori Living PSA ... is aimed at resolutions of early design process, recognising design vulnerabilities, balancing safety features and evaluation of new (advanced) designs." "There are an extensive spectrum of uses (of A Posteriori Living PSA) [2] during operation such as - long term safety issues assessment - short term safety issue assessment - on-line or almost on-line safety monitoring - precursor studies. " "Living level 2 PSA constitutes a severe accident management (SAM) strategy while recognising critical phenomena and associated uncertainties and evaluating the significance of the critical phenomena and the necessary mitigation measures."
/5/	"...the plant state should be monitored and evaluated, and undesired events or accidents will be prevented more effectively by a combined application of - Living probabilistic safety assessment (PSA) and - Operational safety indicators." "The essential objective with the development of Living PSA concept is to bring the use of the plant specific PSA model out to daily safety work to allow experience feedback of the operational risk and to increase the risk awareness of the intended users."

2 added by the author of this report

Table 3.3.: continued

Reference	Statement
/8/	"The main objective of a "living" PSA system is to provide flexible and versatile means to include the risk perspective as an essential factor in all important decisions concerning a nuclear power plant. In addition to maintaining updated models and data such a PSA should be able to assist in decision making concerning, for example, - plant modifications and temporary configurations, - allowed outage times and exemption applications, - relaxation and optimisation of testing and preventive maintenance - balancing preventive and corrective maintenance, and - evaluation of ageing and trends in risk contributors."
/6/	"... development of a Living Probabilistic Safety Assessment (LPSA) tool ... to aid in both safety assessment and configuration management." "The overall objective being to enhance safety by greater understanding, whilst at the same time maximising return of financial investment involved in production of a large PSA study." "... a dynamic PSA tool to assess real plant configuration and this tool we term "Living PSA." "The use of the Living PSA as an on-line monitor, or dynamic form of the technical Specification, must form the ultimate goal of LPSA tool."
/9/	"The need to continually demonstrate that the risk of radioactive releases into the environment were within certain predetermined limits forced Eskom to develop a comprehensive plant specific "living" PSA. "

Licensing

In /39/ LPSA was discussed as "a communication tool between regulator and utilities". Thus Finnish utilities are required to perform PSA studies up to level 2. A LPSA 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.

Plant personnel is expected by the regulatory body to do the majority of work due to meet these objectives.

According to /9/ 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 (/24/, /23/). The periodic safety assessment covers level 1 PSA and the assessment of active containment functions. The time schedule of the periodic safety assessment is planned to cover a range of about 10 years.

Guidelines on performing and reviewing PSA

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. Updating is required for performing PSA every 10 years for German NPP. Further developments of this guideline are under way. They are focused on the following subjects:

- updating in compliance with the international state-of-the-art
- methodic supplements
- treatment and interpretation of uncertainties in PSA
- evaluation of PSA results
- determination of quality criteria of PSA.

A project on developing and establishing guidelines on PSA reviews is sponsored by German authorities (/25/). This activity is aimed at the review process which is required for evaluating the results of the periodic safety assessment to be performed for each German nuclear power plant.

Research projects

Research projects, which are sponsored by licensing/regulatory organisations, were reported to be aimed at:

- development of models, data bases and computer codes (/5/, /8/, /23/, 15.4/), e.g.

  - methodical and data base development for the analysis of human factors, uncertainties, and common cause failures
  - investigation of non-full power states

- development of procedures for including external events into level 1+ PSA
- containment performance analysis
- PSA for new reactor concepts
-

- conditions for application of LPSA (/5/, /23/)

- safety criteria based on qualitative and quantitative results of PSA (/23/).

Statements on regulatory aspects from references /5/, /9/, /24/, /7/, and /25/ are summarised in Table 3.4.

3.4 Development programmes

Programmes for further development are addressed in references /5/, /8/, /6/, /14/, /25/, /15/. Each contribution of the workshops is understood to be part of a development programme. However only explicitly specified programmes for development of LPSA are described here. Moreover no mere lists of tasks to be solved are listed in this subsection. The projects mentioned in /25/ are described in subsection 3.3. Modelling aspects and computer tools are addressed in subsections 3.5 and 3.6 respectively.

Two general approaches for the development of LPSA were reported. In /5/, /15/ a general comprehensive development project on usage and application of LPSA is characterised. Similarly the process described in /14/ is based on general ideas. Whereas /8/, /6/ describe an ongoing improvement of level 1 PSA by operational use of LPSA.

The development programmes are performed by consortia of utilities/designers, research and engineering companies respectively as well as in some cases regulatory/licensing bodies.

Table 3.5 summarises main objectives and the status of the programmes. In addition short characterisations of the programmes are given as well as the main participants as far as they were mentioned in the papers.

Table 3.4. Statements on regulatory aspects from the 4th workshop

Reference	Subjects	Statements
/5/	decision making probabilistic criteria	"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."
/9/	licensing probabilistic criteria	"Since our licensing authority has always regarded PSA as fundamental to the licensing process ... it required a plant specific PSA to form part of our Final Safety Analysis Report." "...our Licensing Authority insisted that Eskom demonstrate that certain probabilistic criteria were met. This then formed part of the license." "Since commissioning this emphasis by the Licensing Authority on using reliability techniques to demonstrate an acceptable level of safety has continued."
/24/	licensing periodic updates of safety assessment	"Since in 1988 the German Federal Commission on Reactor Safety made the recommendation to carry out probabilistic safety analyses for every German nuclear power plant, and recommended a periodic update of these analyses, the issue of conducting large Living PSA projects has considerably gained importance:"
/7/	pre-requisites and problems	"A pre-requisite for LPSA is the availability of a suitable quality PSA." "There are some rather more fundamental doubts about data in general and its use within LPSA." "..., if LPSA is to be an operational tool that remains valid and usable for all plant states and conditions, it is believed that some question marks remain on the approach to modelling of transitional states." "Whilst NII are not inflexible over the question of 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 LPSA 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 LPSA and TS are both available, their advice must be harmonised, to avoid a situation which could be unhealthy from a safety standpoint."
/23/	guidelines research projects review	Growing relative importance of PSA for nuclear safety analysis ... "is promoted consequently in a regulatory nuclear research programme ... ." "Progress has been made to achieve guidance on PSA review. " "... these regulatory activities facilitate and support the use of PSA as living PSA by the NPP operators."

Table 3.5. Objectives, concepts, status and participants of development programmes reported at the 4th workshop

Ref.	Objectives	Concept of the programme	status	participants
/5/, /15/	- combined application of LPSA and operational safety indicators - to establish routines and procedures of how to utilise PSA - to enhance model completeness and reduce conservatism in assumptions - to develop user friendly and fast computer codes	based on PSA level 1 experience: - definition of a LPSA programme - demonstration studies - model development	based on plant experience: - case studies	utilities authorities research institutes consultants
/8/	- to maintain updated models and data - to assist in decision making concerning, 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	improvement of - PSA models - PSA tools - data handling	- plant use - based on plant use and independent review ongoing development	- utility and related company - review by licensing organisation
/6/	- "to enable all parties concerned operators, maintenance staff, safety analysts, management staff and regulators to gain sufficient confidence in LPSA tool" - off-line generation of lowest risk maintenance and test profiles as first real application for establishment of operational confidence to the LPSA tool - optimisation of technical specifications - on-line risk monitor (ultimate goal of LPSA tool)	based on the results of PSA level 1 - model development, e.g. - construction and incorporation of a shutdown model (all aspects of shutdown, including refuelling and low vessel water levels - establishment of sufficiently detailed data collection for component failure data - implementation of operational requirements (useful info. in a desired time scale by appropriate software and appropriate interfaces) - practical usage	- plant specific use - based on plant specific use plans for further development	engineering organisation and utility
/14/	- use of hard- and software for operational tasks by plant personnel - training of operational personnel - improvement of operational procedures	- installation of hardware and adaptation of a software tools	case studies	utility design company engineering organisations

3.5 Status of LPSA application

The status of LPSA application is characterised by the following general terms:

- plant specific use
- case studies
- concept
- plan.

Plant use means that the LPSA directly effects design and construction, operational procedures or operation of the plant under consideration. The term *case studies* was used for operational test phases based on real plant configurations. The term *concept* means that conditions for real plant application of LPSA were defined. The term *Plan* describes plans for implementation of LPSA at a specific plant.
The defined phases of application were related to the following five different fields:

- Design and construction
- Level 1 PSA
- External events
- Level 2 PSA
- Severe accident management.

These subjects are related to the scope of PSA approach used rather than presenting different methodical development stages, as e.g. different computer tools, plant models, data handling.
In addition to this assessment the reported LPSA were sorted into the three different classes of application as they were defined in /5/:

- Risk assessment
- Risk monitoring
- Risk follow-up.

These classes as they were used in this section are different methodical bases rather than different methodical development stages. So, a sophisticated approach to LPSA application includes all of those disciplines.

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 LPSA in operational decision making. Extensive plant specific applications were reported e.g. in /26/, /27/, /28/, /29/, /30/, /31/. These applications demonstrate ongoing qualification as well as are assumed well established and precisely defined at a routine level

They very well demonstrate the development process of applying LPSA for plant specific use. As an example the following main steps towards real plant specific use of LPSA can be taken from /27/:

- 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)

Comparing the presentations of the four workshops no significant increase of the numbers of contributions dealing with real plant specific use was found. (This simply reflects representation by the workshop contributions and does not necessarily indicate a missing development process towards increased LPSA application which is assumed to be evident in general.) However a development towards a more clearly defined and flexible use of PSA was evident. A characterisation of the status of application in terms of results and their implementation in plant specific use is given in table 3.6.

Sophisticated plant specific use was found to be concentrated at a few utilities with small changes within the course of the four workshops whereas other PSA teams are assumed to still seek for acceptance to a real operational plant use at both utilities and authorities.

Despite LPSA 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 LPSA depend on the methodical approach. For some tasks no consensus is available, e.g. for determining time dependent results and their interpretation.

Tables 3.7 and 3.8 list numbers of LPSA applications that were reported at the workshops.

Table 3.6. Results of Living PSA and Implementations

Reference	Result	Reported implementation
/8/	- dominant risk contributors - risk contribution by inter system loss-of-coolant accidents - evaluation of plant modifications - evaluation of modifications caused by identification of new phenomena - evaluation of emergency and maintenance procedures - propose plant modifications and backfitting measures by fire, flood and weather analyses	- safety assessment - modifications of design and procedures
/6/	standard PSA results: - averaged core melt frequencies, - dominant sequence identification - component importance	- overall safety assessment
/10/	evaluation of hardware and procedural changes evaluation of urgency of configurational change evaluation of potential accident management measures	- overall safety assessment - safety assessment of configurational and procedural changes
/9/	assistance to maintenance optimisation (examples): - reducing the number of license bound maintenance actions - reducing the maintenance action frequency on specific components assistance to operation (examples): - evaluation of impact of valve actuator defects on safety - assessment of the impact of specific steam generator leaks on the reliability of the auxiliary feedwater pump system, the overall impact on the auxiliary feedwater system and the core damage frequency - assessment of the impact on safety of defined options of degraded system configurations in response to injection pump electrical defects during plant operation - assessment of impact on safety of emergency supply gas turbines and diesel generators	- overall safety assessment - safety assessment of configurational and procedural changes - design and procedurational modifications
/32/	seismic analysis: - significant seismically induced failures - core damage frequencies by seismically induced failures	- safety assessment of seismic influence
/33/	- significant core accident frequencies - plant damage states - release states - radionuclide source terms - development of deep plant understanding of the key plant features and operational characteristics - derivation of risk management insights (proposals on modifications of design and procedures)	- overall safety assessment - engineering insights

Table 3.7. Numbers of LPSA plant usage and related classes of application

Objective	No. of studies															
	plant specific use				case studies				concept				plan			
	88	90	92	94	88	90	92	94	88	90	92	94	88	90	92	94
Risk assessment	3	5	4	4	-	6	3	3	-	4	2	2	-	2	-	-
Risk monitoring	2	2	1	2	-	-	3	2	-	3	2	1	-	2	-	1
Risk follow-up	-	-	1	-	-	-	2	2	-	1	2	-	-	-	-	-
∑	5	7	6	6	-	6	8	7	-	8	6	3	-	4	-	1

Table 3.8. Numbers of LPSA plant usage and related scope

Scope	No. of studies															
	plant specific use				case studies				concept				plan			
	88	90	92	94	88	90	92	94	88	90	92	94	88	90	92	94
Design and construction	-	-	1	-	-	-	-	1	-	-	-	-	-	-	-	-
Level 1 PSA	3	6	3	4	-	1	3	3	-	3	2	2	-	2	-	1
External events	-	-	-	2	-	-	-	-	--	-	-	-	-	-	-	-
Level 2 PSA	-	-	-	2	-	-	-	-	-	-	-	1	-	-	-	-
Severe accident management	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
∑	3	6	4	9	-	1	3	4	-	3	2	3	-	2	-	1

3.6 Data, modelling and interpretation of results

Modelling means aspects that are related to input of LPSA, models for handling input information, output information and interpretation of results. Modelling aspects of computer tools are discussed in sub-section 3.7.

According to the character of LPSA as pointed out in 3.1 interpretation of LPSA results needs discussion and is related to the methods used. Thus each contribution discusses modelling aspects. The following issues were found specifically characterising LPSA modelling aspects. They were discussed in more or less detail in the papers:

- general requirements to and characteristics of models and methods
- problems in applying models
- limitations in models and methods
- uncertainties, trend analyses and decision making
- data and information handling
- analysis of Common-Cause Failures (/36/, /35/)
- human reliability analysis (/36/, /37/, /38/)
- fault tree modelling and calculation
- assessment of test and maintenance
- level 2 analyses

- analysis of seismic events

Discussions of these modelling aspects comprise both general PSA related views and specific problems of LPSA application. In the following emphasis is put on the specific LPSA issues. In some contributions a need for more realistic PSA approach was pointed out in order to fulfil the conditions required for LPSA application. In case of the contributions on Common-Cause Failures and Human Reliability Analysis, which are cited above, this need was considered applicable to PSA in general. Thus no detailed discussion of these contribution has been performed in this report.

General requirements to and characteristics of models and methods (/9/, /7/, /15/)

To meet the objectives of LPSA application specific requirements as to models and tools should be fulfilled:

- LPSA has to be based on plant-specific information (e.g. /8/, /9/).
- Models and tools of a LPSA system must be sufficiently flexible and versatile according to the specific operational requirements (e.g. /8/,./7/).
- LPSA must be capable of updating according to the operational requirements. An off-line application is considered sufficient (e.g. /5.4, /7/). However some activities on on-line linkage to plant data system was reported (/7/).
- LPSA is characterised by a continuing model development (e.g. /14/, /15/ - /16/, /17/, /18/, /19/, /20/, /21/).
- An operational interface allowing the user to carry out the LPSA is required (e.g. /14/).
- LPSA tools should be available at the plant site e.g. on a PC base (e.g. /14/).

A set of general modelling requirements were pointed out. They are aimed at features of information processing in the models, the output available to the user, the possibilities to handle the models and quality assurance.

Information processing in LPSA needs the following conditions:

- sufficiently complex and versatile models;
- fast response time according to the operational needs;
- time dependent modelling instead of averaging;
- capable of being re-run in an acceptable time limit;
- consistent approach to the different areas in the models such as success criteria, phenomenological modelling, data.

The output of LPSA should include:

- current risk output and not only average values;
- component importance rankings according to both "level 1" and "level 2" criteria;
- measures of interpretation, explanation and advice giving to the operators.

The following aspects with respect to the user interface were pointed out:

- users who are not risk specialists must be able to appropriately interpret the LPSA results;
- an updating must be possible in a smooth and consistent manner.

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 LPSA is due to the possibility of 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.

Problems in applying models (/22/, /7/)

A general aspect of developing and applying LPSA with respect to different approaches to LPSA is stressed in /22/. Accordingly LPSA should be more comprehensive than just applying dynamic Tech Specs analyses by on-line risk (safety) monitoring. Otherwise emphasis could be focused on the risk noise, which is mostly displayed by risk monitoring during plant operation, whereas other risk contributors such as serious, infrequent transients could be underestimated. On the other hand risk monitoring is an important part of LPSA capable to enable plant staff to control plant operating activities and keeping the staff aware of the plant status during operation.

Problems involved in LPSA model application are expressed in /7/ reflecting attitudes of a regulatory body's staff:

- ensuring an appropriate quality of the PSA application would be based on,
- interpretation of uncertainties involved in data,
- modelling of transition states,
- deriving and interpreting the particular risk criteria.

Limitations in models and methods (/5/)

In /5/ 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;
- in sufficient 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.

Uncertainties, trend analyses and decision making (/15/)

Uncertainties, trends and decision making are discussed in a context. An analytical approach is proposed for modelling parametric uncertainties including so called state-of-knowledge dependence. A Bayesian trend analysis which takes into account both increasing and decreasing trends was discussed.

Based on the experience that there is a need for a more systematic treatment a decision analysis and decision making approach was discussed. In a special study courses of short-term as well as long-term decision alternatives were investigated from both the authorities and utility point of view .

Data and information handling (/9/, /24/, /16/, /34/, /35/)

Data and information handling are treated in several contributions of the 4th workshop. They were focused on

- characteristics of data bases
- systems for documenting, handling and displaying information
- modelling aspects of a combination of different stochastic information.

In general these contributions deal with accuracy of data, as well as handling, structuring and displaying of huge sets of data and processing and interpretation of data of different nature and quality.

Fault tree modelling and calculation (/34/, /19/)

Fault tree analysis was put into relation to system and data analysis using a sophisticated software tool and taking into account operational conditions of NPP in /36/. The main aspects stressed were structuring and displaying of information, whereas a PSA approach and a special structuring of plant information are combined.

Assessment of test and maintenance (/18/, /20/)

Several aspects of surveillance test optimisation were discussed in /20/ including influence on unavailability of the time between the test intervals and the test strategy as well as risk related test effectiveness. The use of a safety monitor and a reliability centred maintenance programme for increasing reliability and availability of NPP is discussed in /18/.

Level 2 analyses (/11/)

In /11/ a procedure was shown how to process information on containment performance, severe accident phenomena and operator actions using a PC based software tool in order to extent LPSA to level 2.

Analysis of seismic events (/32/)

The use of LPSA for assessing seismically induced failures is outlined in /32/.

3.7 Computer codes

In this sub-section computer codes are addressed as far as specific LPSA features and applications were pointed out. This approach was used merely to give some information on what computer codes were reported to be under development or in application. Since the contributions characterise computer codes from different points of view this sub-section does not give a systematic and comprehensive characterisation of the codes as one would get from special presentations of computer software. Thus the list of computer codes and the fields of application in table 3.9 does not necessarily give a complete overview on the currently used computer codes for LPSA application.

Table 3.9 contains computer codes as well as their main fields of application and features as they were reported in the contributions.

The following specific LPSA related aspects were found to require handling by computer tools:

- the huge amount of information to be put into as well as processed within LPSA,
- 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 3.9. Computer codes and fields of application addressed at the workshops

Name	Field of application	Ref.
ESSM	database management and risk analysis	/44/
FAULT_TREE	fault tree and event tree analyses	/19/
IRRAS	Integrated reliability and risk analysis, models and results data base	/40/
LESSEPS 1300	integrated PSA tool	/42/
LIPSAS	integrated PSA tool	/43/
NUCAP	PSA level 2	/12/
NUPRA	PSA level 1	/12/
PSA-PACK	PSA level 1	/41/
QUEST	simplified FT/ET analysis	/45/
RISA+	Fault and event tree construction and analysis	/46/
RISKMAN	Modelling, quantification, monitoring	/22/
Risk Spectrum	database management and risk analysis	/47/
SAIS (incl. RISA+)	PSA level 1+ - information collection and processing	/14/, /34/
SPSA	PSA level 1 and 2 - common tool for safety management	/22/, /8/, /11/
STARS	PSA level 1+ - information collection and processing	/17/
Super-Net	Reliability and life cycle cost analysis	/48/
UPREPA	data handling, reliability parameters, automatic tests for trends, basic events probabilities	/8/
KOMPAS	collection and assessment of data	/24/

3.8 Issues for development

Conditions for application

- improving the use of LPSA in decision making processes. This includes e.g.:
  - combination of LPSA and other operational safety indicators;
  - combination of qualitative and quantitative results and criteria;
  - routines and procedures on how to utilise LPSA;
  - decision making criteria including uncertainty measures

- procedures on how to use LPSA in licensing.

- establishing regulations on the use of LPSA from the point of view of the authorities, including PSA review;

- establishing appropriate procedures for quality assurance and control modelling/tools subjects;

- improving models with respect to:

  - time dependent risk monitoring;
  - decreased response time;
  - updating of models and data;
  - completeness and realism;
  - data and modelling uncertainties;
  - display of results for operators;
  - test and maintenance;
  - common-cause failures and human factors;
  - level 2 aspects.

- improving data bases and data handling with respect to:

  - Common-Cause Failure analysis;
  - Human Reliability Analysis;
  - collection and processing of operational data, including automatic data transfer between different parts of LPSA.

- improving computer tools with respect to:

  - consistent and rapid processing of large sets of data;
  - rapid or on-line response time;
  - easy use by operators;
  - rapid updating of models.

4. CONCLUDING REMARKS

Four workshops on LPSA application were held from 1988 to 1994. They were aimed at exchanging international experience in living PSA application. The workshops displayed a development process of application of PSA models and tools from a more conventional usage towards a spectre of tasks in real plant operation. This process led to a more complex understanding of what the term LPSA is and will be used for. In addition the workshops show a development of LPSA models and tools towards more clarified operational needs.

In some countries LPSA was found to be well established in practical plant use at several utilities whereas other countries are assumed to need further clarification of the approach how to use LPSA. This statement especially addresses views of utilities and authorities as well as experience from application rather than the status of development of models and tools.

As pointed out in chapter 3 LPSA is generally discussed as diverse concepts. One concept defines LPSA as a new tool which need to be clearly separated from the traditional type of PSA. Whereas within another concept LPSA is seen as a more sophisticated, further developed PSA with extended applications and updates.

From the workshops contributions some general findings can be summarised:

- Successful LPSA development is closely related to practical plant specific use by the utility.
- Beneficial real plant specific use is possible at different levels of LPSA 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 LPSA methods some operational fields of application need additional practical experience.
- A common understanding on the LPSA approach among utilities authorities and external PSA organisations is helpful in development of practical use of LPSA.
- An appropriate LPSA usage at the current state-of-the-art needs accompanying model and tool development.

The workshop meetings on LPSA application, which comprised a broad spectrum of LPSA subjects approved very useful on the way to the current level of application. A list of open issues was well defined at the 4th workshop including conditions for application and modelling and tool development. It is felt that in future special discussions on single issues would be helpful for facilitating LPSA application rather than to treat the whole spectrum on general issues meetings. Conditions for application of LPSA 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 LPSA.

In addition quality assurance and control within the LPSA process needs further discussion to increase confidence in the results.

This report summarised the views and results which were presented at four TÜV workshops on Living PSA. Thus it is not a systematic and comprehensive analysis of the state-of-the-art of LPSA. In addition the different views presented in this report to some extent include interpretation of its author and so they do not necessarily represent the views of the authors of the workshops' contributions. Nevertheless the report points out important aspects of the process of LPSA application and development. Based on the insights gained when preparing this report a further discussion on development of specific issues of LPSA application within the framework of OECD/NEA PWG 5 or a related workshop is recommended.

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