PLATFORM FOR IMPROVED INTERACTION BETWEEN FIRE SAFETY ANALYSES AND SYSTEMATIC FIRE PREVENTION WORK AT NUCLEAR FACILITIES

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Fire protection maintains safety and reduces hazards associated with fires. Each licensee of a nuclear facility must maintain a robust fire protection program and ensure the ability to shut down the facility safely in the event of a fire. This paper presents a platform for improved interaction between different fire safety analyses (deterministic and probabilistic) and daily fire prevention work. The platform describes how the input from the different fire-related activities work can be used to obtain a common view of risk associated with fire. The focus of this paper is towards Swedish facilities and legislation but the framework can be applied internationally and for other hazards than fire.

Based on a state-of-practice analysis and a literature study a platform which describes how the different fire-related activities can interact in order to fulfil the main fire protection objectives has been developed. The platform describes what is included in the different analyses, requirements on the analyses, guidelines to be used and connection between the analyses. A description of the connection between the analyses and the daily fire prevention work can also be found in the platform. The outlined platform is generic and it must be always adapted to plant-specific practices and safety management policies.

I. INTRODUCTION

Fire protection maintains safety and reduces hazards associated with fires. Each licensee of a nuclear facility must implement a robust fire protection program and ensure the ability to shut down the facility safely in the event of a fire. 'Fire protection programme' is an integrated effort involving equipment, procedures and personnel necessary to conduct all fire protection activities. It includes system and facility design and analysis; fire prevention, detection, annunciation, confinement and extinguishing; administrative controls; fire brigade organisation; training; inspection, maintenance and testing; and quality assurance, IAEA NS-G-1.7 (Ref. 1). The content of the fire protection programme is dependent on the national legislation. In Sweden, the fire protection programme is related to daily fire prevention work (called also systematic fire prevention work in Sweden, SBA). In the continuation of this paper the daily fire prevention work is denoted SBA.

Different fire related safety analyses needs to be performed in order to verify the facilities ability to cope with a fire. The following analyses can be performed: fire-related Deterministic Safety Analysis/Safe Shutdown Analyses (Fire-DSA/SSA) in order to verify safe-shutdown capability, fire-related Probabilistic Safety Analysis (Fire-PSA) showing the risk picture of facility and in connection with these analyses Fire Hazard Analyses (FHA) can also be performed in order to support Fire DSA/PSA or as stand-alone analyses. In the context of this paper, Fire-DSA and Fire-PSA is not considered to be a part of FHA.

In this paper a platform for interaction between different fire-related analyses and the daily fire prevention work is presented, more details about the development of the platform can be found in Ref. 2. The outlined platform is generic, but based on Swedish conditions regarding state-of-practice and legislation, and it must be always adapted to plant-specific practices and safety management policies.

The outline of this paper is as follows; in section II the Swedish state-of-practice is summarised; in section III the limited international literature study is described; the platform is developed and described in section IV and in section V the conclusions of this paper are found.

II. SWEDISH STATE-OF-PRACTICE

The first step in developing a platform for improved interaction between different fire safety analyses (deterministic and probabilistic) and daily fire prevention work was to perform a state-of-practice analysis. The state-of-practice analysis is performed by questionnaire and follow-up interviews with Swedish nuclear facilities including the facility for interim storage for spent nuclear fuel. The questionnaire was divided into two parts, one part with questions related to fire-safety analysis (Fire-DSA, Fire-PSA and FHA) and one part with questions related to the daily fire prevention work.

In Sweden there are three site consisting of a total of 10 reactors. There is also an interim storage for spent nuclear fuel is located in the vicinity of one of the sites (Oskarshamn) and the planned spent fuel repository is to be built close to one site (Forsmark).

II.A. Swedish requirements for fire safety analyses at nuclear facilities

Swedish Radiation Safety Authority (SSM) has requirements regarding analysis and prevention of fire in the nuclear safety perspective. According to Swedish Radiation Safety Authority's regulations SSMFS 2008:1 Chap. 4 §1 and the connected general advice a probabilistic safety analysis shall be performed at all nuclear facilities in Sweden. The level of detail of the PSA is determined by the type of facility and the complexity and risk picture of an operation. Generally, hazards such as fire are to be included in the PSA.

According to SSMFS 2008:17 §14 and the connected general advice, all Nuclear Power Plants in Sweden shall be designed to withstand natural phenomena and other events that arise outside or inside the facility and which can lead to a radiological accident. A fire that causes all equipment in a fire compartment to fail should be assumed to occur. Fire is an example of an event inside the plant and one possible way of demonstrating that the plant is designed for an internal fire is to perform a Fire-DSA.

According to the general advice connected to SSMFS 2008:17 §14 FHA can be used to show (distance between components, fire protective measurements, etc.) that the probability of failure of an entire fire compartment is low then the burn-out of the entire cell need not be assumed.

II.B. Results from state-of-practice analysis

The results from the state-of-practice analysis is summarised in table I.

TABLE I. Summary of state-of-practice analysis

Task	Facility			
	Ringhals NPP	**Forsmark NPP**	**Oskarshamn NPP**	**Interim storage for spent nuclear fuel**
Fire-PSA	BWR: Fire-PSA assuming burn-out of closed room. Fire spreading and fire-fighting included in analysis. PWR: Fire-PSA assuming complete burn-out of analytical fire cells. Fire spreading and fire-fighting included in analysis.	Fire-PSA assuming burn-out of closed room, partly based on NUREG/CR-6850 (Ref. 3). Fire spreading included in analysis.	Fire-PSA performed as barrier analysis. Fire frequency not included in total CDF. A frequency assessment is also made in conjunction with the barrier analysis.	Fire-PSA under development.
Fire-DSA	BWR: General approach showing sufficient separation for fire, lightning and earthquake. PWR: Full scope conservative Fire-SSA using PSA-model based on NUREG Guideline 1778 (Ref. 4).	Fire-SSA based on PSA-model. Limited to fires with a frequency of less than 10^{-6}/year.	No specific Fire-DSA/SSA. General plant design used to verify safe-shutdown capability after initiating events.	Fire-DSA used to verify separation of facility with respect to fire. IAEA Safety Guide NS-G-1.7 (Ref. 1) is used as a guideline in the analysis
FHA	Used as stand-alone analysis, e.g. load/transient analyses. Used in an iterative process with Fire PSA/SSA.	Used in an iterative process with Fire PSA/SSA.	Input to PSA/DSA or to verify assumptions made in PSA/DSA.	Input to PSA/DSA or to verify assumptions made in PSA/DSA.
SBA - Daily fire prevention work	Fire protection program: •Fire prevention •Fire detection and suppression •Mitigate consequences of fire	The aim of SBA is to prevent fire from starting and reduce consequences. The main focus related to protection of staff.	• Prevent fire occurrence • Enable safe evacuation • Reduce the risk of fire spreading • Maintain the structural properties of buildings in case of fire • Facilitate fire fighting • Secure safe handling of flammable material and gas tubes.	• Organization • Test and maintenance • Indicators • Fire drills • Educations • Following up of deficiencies in fire protection Experience feedback.
Collaboration Analyses-SBA	In general no collaboration between SBA and analyses. PSA is used to classify doors with respect to fire. During development of Fire-SSA some cooperation where established.	During the development of Fire-SSA resulted in major co-operation between analysts and SBA-experts	No organised connection between analyses and SBA.	Top management exchange of information.

BWR: Boiling Water Reactor (ASEA-ATOM design), PWR: Pressurised Water Reactor (Westinghouse design)

III. LITERATURE STUDY OF INTERNATIONAL GUIDELINES AND REGULATIONS

A limited literature study on international guidelines and regulations has been performed in order to place the Swedish state-of-practice in an international context. The literature study is not a complete study of all available international guidelines and regulations. The focus on the study is based on the survey made in report by Nationella Brandsäkerhetsgruppen (NBSG) (Ref. 5) and on US and Finnish guidelines and regulations. The aim of the literature study is to search for complementary references for the platform.

The following international guidelines and regulations related to fire hazards are some examples that are used as input for the development of the platform:

- IAEA NS-G-1.7 (Ref. 1)
- IAEA NS-G-2.1 (Ref. 6)
- U.S. NRC, Reg.Guide 1.189 (Ref. 7)
- U.S. NRC, Appendix A to 10 CFR Part 50 (Ref. 8)
- U.S. NRC, NUREG-1778 (Ref. 4)
- NEI 00-01 (Ref. 9)
- STUK, YVL B.8 (Ref. 10)

IV. DESCRIPTION OF PLATFORM

This section outlines a generic platform for the interaction between different fire safety analyses and between the analyses and SBA, more details about the platform can be found in Ref. 2. The purpose of the platform is to explicitly define relationships between these elements of the fire protection programme.

IV.A. Outline of the platform

The overall target of the platform is to ensure fulfilment of the main fire protection objectives[1]:

1. To prevent fires from starting;
2. To detect and extinguish quickly those fires that do start, thus limiting the damage done;
3. To prevent the spread of those fires which have not been extinguished, thus minimising their effects on systems performing essential safety functions.

The platform is structured in table II and III and some of the elements defined in the two tables are also described more in detail in the following subsections.

The generic platform outlined in the tables must always be adapted to plant-specific practices and safety management policies. Each plant should be able to associate the items of the platform with its own policies, programs and activities.

In table II the main elements of each fire safety analysis activity (FHA, Fire SSA, Fire PSA) is defined. This comprises of the following elements:

- Purpose of the fire safety analysis activity: what are the objectives, what can be analysed by each approach
- Guidelines: Methodological references which can be followed
- Input to analyses: which input is needed
- Analysis parts: which different analysis parts are included in each analysis
- Results
- Output to SBA

In table III, the daily fire prevention work, SBA, is defined to consist of the following elements:

- Organisation, responsibilities: personnel and their tasks/roles
- Instructions and procedures: all written documents followed in SBA
- Control and quality assurance: activities related to quality assurance (i.e. instruction) control of materials
- Inspection, maintenance and testing: activities related to keeping fire protection systems reliable
- Training and drills: competence building
- Technical fire protective measures: activities related to technical fire protective equipment
- Reporting: follow-up of SBA for experience feedback
- Guidelines: guidelines that can be used for SBA

In table IV, each SBA elements is defined in the following manner:

- what is the meaning and content of the element
- what is the interaction with fire safety analyses.

TABLE II. Platform, analysis part.

Objective	FHA	Fire SSA	Fire PSA
Purpose	• Verify assumptions made in SSA and PSA and other safety related analyses. • Aid SBA in order to fulfil the different levels in the fire-related defence-in-depth. • Verify structure, system and component fire resisting capability	Verify safe shut-down capability after fire events.	• Identify and quantify risks related to fire hazards. • Supplements deterministic fire analysis. • Supplements to the overall PSA so that PSA can be used for risk-informed applications
Guidelines	IAEA NS-G-1.7 (Ref. 1) Reg.Guide 1.189 (Ref. 7) BTP CMEB 9.5-1 NUREG-1805, NUREG-1824, NUREG-1934	IAEA NS-G-1.7 (Ref. 1) Reg.Guide 1.189 NUREG-1778 (Ref. 4) NEI 00-01 (Ref. 9) BTP CMEB 9.5-1 NUREG/CR-7150	NUREG/CR-6850 (Ref. 3) and its supplements EPRI 101673 (Ref. 11) and EPRI 1019259 (Ref. 12) NUREG-2169 (update of fire ignition frequencies) SKI 97:25 “Yttre händelser” projekt
Input from daily fire prevention work (SBA)	• Maintaining plant status according to analysis assumptions. • Configuration of rooms regarding fire related issues • Presence of combustible material	• Maintaining plant status according to analysis assumptions.	• Maintaining plant status according to analysis assumptions • Data from inspection/testing to be used when determining failure data • Time for fire brigade to extinguish fires. Used as data for HRA-analysis/estimation of probability for fire suppression.
Input from other fire safety analyses	• From SSA/PSA: Rooms/fire cells/fire compartments of interest to analyse with FHA.	• FHA: Verification of fire cells/fire compartments, calculations of fire spread in fire cells/fire compartments, FHA walk-downs • PSA logic model in terms	FHA: • Verification of fire cells/fire compartments • Calculations of fire spread in fire cells/fire compartments

Objective	FHA	Fire SSA	Fire PSA
Analysis parts	• Fire compartment/cell inventory and combustibles inventory • Definition of safety relevant systems/components (fire related) and its room oriented location • Identification of relevant data like physical properties of combustibles. Constructions that absorb energy from fire • Fire simulation analyses to evaluate fire development and the ambient effects of fire, temperature increase in particular • Secondary effects caused by fires and/or actions of protection systems	Based on NUREG 1773 (Ref. 7): • Defining SSD (Safe Shut Down) functions and requirements • Defining SSD system performing SSD functions (availability according to Tech. Spec.) • Fire scenario selection (defining fire cells based on FHA) • Circuit analysis (analysing circuit failure modes) • Locating cables and circuits of concern to safe-shutdown. • SSD function performance (demonstrates safe-shutdown capability)	NUREG/CR-6850 (Ref. 9): • Plant Boundary Definition and Partitioning Analysis • Fire Equipment Selection Analysis • Fire Cable Selection and Detailed Circuit Analysis • Qualitative Screening Analysis • Fire Plant Response Model • Fire Ignition Frequency Calculation • Quantification Screening Analysis • Fire Scenario Selection and Analysis • Fire Plant Response Model Analysis • Fire Human Reliability Analysis • Seismic/Fire Interaction Analysis • Fire Risk Quantification Analysis • Uncertainty and Sensitivity Analysis
Results	• Impact of fire per fire scenario • Identified weakness in design • Fire compartment/cell verification • Structural verification of buildings regrading fire load	• Assessment of achievement of safe shutdown conditions per analysis case	• Fire CDF and LRF • Minimal cut sets • Room (fire area) specific risk importance

Output to daily fire prevention work (SBA)	• Realistic calculations of fire spread in a fire cells/fire compartments.
	• Information about fire sensitive fire cells/fire compartments.
	• Information about doors between fire compartments/cells, can be used to highlight doors
		• Identification/classification of fire sensitive rooms/fire cells/fire compartments /doors
		  ○ Test interval
		  ○ Information during training
		  ○ Used to highlight when in case of job performance
		• Support when analysing LERs
			• Identification of fire sensitive rooms/fire cells/fire compartments /doors based on CDF
			  ○ Test interval
			  ○ Information during training
			  ○ Used to highlight when in case of job performance
			• Support when analysing LERs

TABLE III. Platform, daily fire prevention part.

SBA activities	Tasks, purposes, content	Link to fire safety analyses
Organisation, responsibilities	• Key element to perform SBA • Structured into an organisation, defined responsibilities (related to other SBA activities) and well-documented	• Key persons to provide information for the analyses as well to receive information from the analyses.
Instructions and procedures	• To ensure that the personnel perform their tasks as intended: o prevent from forgetting tasks o minimise variability in performances o reduces mental load • Policy documents: Principles to guide decisions • Handbook: Reference work, collection of instructions • Procedures: step-by-step instructions (e.g. testing and maintenance)	• References for safety analyses
Control and quality assurance	• To ensure that mistakes are not made (administrative barrier) • Control of combustible materials and ignition sources • Control of explosive materials • Housekeeping • Pre-job briefing	• Boundary conditions for the analyses (i.e. maintaining plant status according to analysis assumptions)
Inspection, maintenance and testing	• Perform testing according to SBA requirements o Escape routes o Fire doors o Fire compartments • Perform testing according to Tech. Spec o Fire detection and suppression systems • Preventive maintenance	• Testing data can be used to estimate different probabilities in Fire-PSA (e.g. fire spreading probabilities can be estimated from test data on fire doors) • System operability verifications, which system can be assumed to be in operation in the analysis. • Boundary conditions for the analyses (i.e. maintaining plant status according to analysis assumptions)
Training and drills	• Training and education in order to maintain the quality of the SBA. • Fire drills for the rescue service and fire brigades	During training of SBA staff the connection to fire-related safety analysis should be highlighted: • Importance of performing SBA in order to maintain plant conditions according to assumptions in safety analysis. • Fire sensitive areas • Quick fire suppression reduces the CDF significantly.
Technical fire protective measures	• Examples of technical fire protective measures that needs to be maintained through SBA: o Escape routes o Fire cell o Fire alarm o Fire doors o etc.	• Boundary conditions for the analyses (i.e. maintaining plant status according to analysis assumptions)
Reporting	• Evaluation of licensee event reports • Yearly report on SBA activates	• References for safety analyses • Data for PSA
Guidelines	• IAEA NS-G-2.1 (Ref. 4) • SRVFS 2004:3	-

IV.B. Interaction between analyses and daily fire prevention work (SBA)

In the following section an overview of the interaction between analyses and SBA is described using fire protection design as a starting point. The fire protection design aims at minimizing fire-related risks. Both the risk related to radioactive release to the environment and the risk the plant staffs is exposed to should be minimized. This is utilized by a balanced fire-related defence-in-depth design. This is in accordance with the main fire protection objectives as stated in IAEA NS-G-1.7 (Ref. 1).

The fire-related defence-in-depth consists of the following three levels:

- Level 1: Fire prevention
  - Fire load minimisation
  - Fire ignition sources minimisation
  - Explosion prevention
- Level 2: Fire detection and suppression
  - Detection system
  - Automatic suppression system
  - Manual fire-fighting (plant staff, plant fire brigade, external fire brigade)
- Level 3: Mitigation of consequences of fire
  - Building/room configuration
  - System configuration (redundancy/separation)
  - Fire compartment/fire cell (fire barrier components and functions)
  - Ventilation system
  - Protection of staff (escape routes)

The main purpose of SBA is to maintain the different levels of defence-in-depth. This is realised with the different SBA activities presented in Table III.

SSA/PSA can be used to verify that fire-related nuclear specific requirements are meet at the facilities. PSA can be used to show that the overall risk related to fire is on an acceptable level meaning that the plant is designed with a well-functioning defence-in-depth. PSA can also be used to identify dependences between the different levels of defence-in-depth. SSA shows that the deterministic requirements are met, which also indicate a well-functioning level 3 of the defence-in-depth.

FHA is the connection between plant design and the analyses (SSA/PSA) and between the plant design and the SBA and also between SBA and PSA/SSA. FHA can also be a stand-alone analysis, e.g. verify structure, system and component fire resisting capability. Figure 1 illustrates the relations between the SBA/FHA/SSA/PSA in connection to the fire protection design.

In the analytical aspect SBA is of importance in order to maintain plant status which is the boundary conditions for the analysis (i.e. maintaining plant status according to analysis assumptions). The assumptions in the analyses are connected to plant status (e.g. integrity of fire compartments/cells), system availability (e.g. availability of fire suppression system) and manual actions (e.g. time for manual firefighting). SBA ensures that these assumptions are valid through activities (inspections, maintenance and testing) related to the maintaining of fire safety.

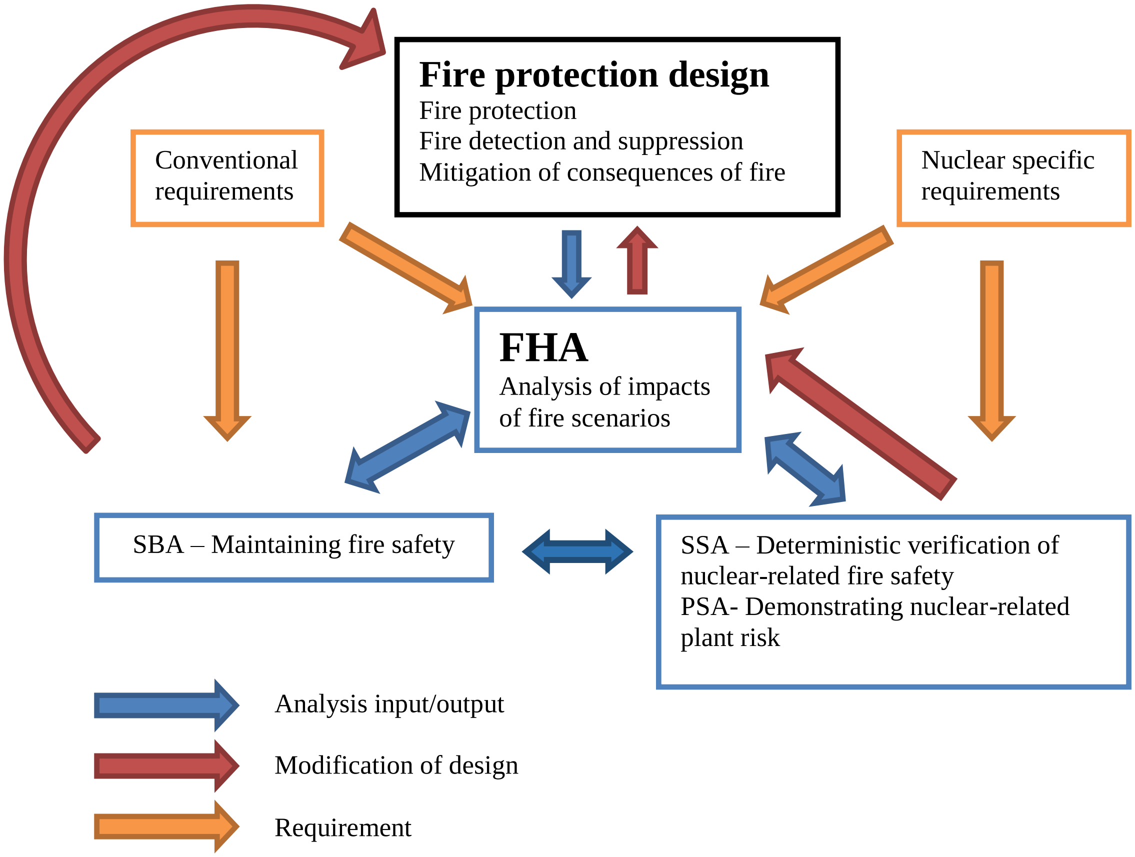

Fig. 1. Illustration of relation between SBA/FHA/SSA/PSA based on fire protection design.

IV.C. Experience feedback/Knowledge transfer

It is of paramount importance to transfer information between the experts involved in fire-related activities. Knowledge can be transferred between the different analyses and also between the analyses and SBA. Proper routines and documentation will make the knowledge transfer quality assured.

One way to improve the knowledge transfer can be to create a forum for discussion. A forum can be a reoccurring series of meetings between PSA/SSA/FHA-experts and SBA expert. Such a forum can facilitate that relevant information between the different experts are transferred.

Example of issues that can be discussed in a fire-related forum:

- Do the sensitive/important fire compartments/cells according to PSA/SSA correlate with the expectations of FHA- and SBA-experts?
- Interpretation of results.
- How can data from test/inspection of fire related equipment in SBA be used in the analysis?

Information about fire safety analyses also needs to be transferred to the staff performing SBA activities. This can be included in the education of SBA staff. In order to improve the understanding of the importance of the SBA activates, it is important to highlight:

- how fire safety analyses are performed
- which assumptions are used in the analyses
- what is the result from the analyses.

The main goal of experience feedback and knowledge transfer is to establish a common view of fire-related plant risks/hazards between the different groups of fire experts/analysts, see Figure 2.

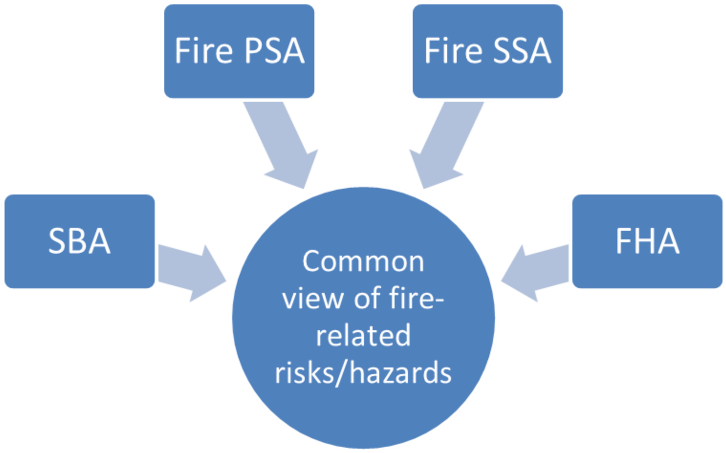

Fig. 2. Common view of fire-related risks/hazards.

V. CONCLUSIONS

Fire protection maintains safety and reduces hazards associated with fires. Each licensee of a nuclear facility must maintain a robust fire protection program and ensure the ability to shut down the facility safely in the event of a fire.

Content of the fire protection programme is dependent on the national legislation. In Sweden the fire protection programme is related to daily fire prevention work (systematiskt brandskyddsarbete, SBA).

Different fire related safety analyses need to be performed in order to verify the facilities ability to cope with a fire. The following analyses can be performed: fire-related Deterministic Safety Analysis (Fire-SSA) in order to verify safe-shutdown capability, fire-related Probabilistic Safety Analysis (Fire-PSA) showing the risk picture of facility and in connection with these analyses Fire Hazard Analyses (FHA) can also be performed in order to support Fire SSA/PSA or as stand-alone analyses. The SBA is of importance in order to maintain plant status according to analysis assumptions.

In this paper a platform for an improved integration between fire safety analyses (FHA/SSA/PSA) and daily fire prevention work (SBA) at the plants is presented. One purpose with the platform is to enable the possibility to establish a common view of fire-related plant risks/hazards based on the different analyses and SBA.

The platform describes what is included in the different analyses, requirements on the analyses, guidelines to be used and connection between the analyses. The platform also describes the concept of SBA. A description of the connection between the analyses and the SBA can also be found in the platform.

One conclusion from the state-of-practice study is that the different facilities in Sweden have different approaches on how to handle fire safety analysis and SBA but the requirements and goal of the work is the same. Hence, the outlined platform is generic and it must always be adapted to plant-specific practices and safety management policies. Each plant should be able to associate the items of the platform with its own policies, programs and activities.

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ABBREVIATIONS

Acronym	Description
CDF	Core damage frequency
DSA	Deterministic safety analysis
FHA	Fire hazards analysis
HRA	Human Reliability Analysis
IAEA	International Atomic Energy Agency
LER	Licensee event report
NBSG	Nationella brandsäkerhetsgruppen
NUREG	NRC technical report designation
NPP	Nuclear Power Plant
PSA	Probabilistic safety assessment
PRA	Probabilistic risk analysis
PWR	Pressurised water reactor
SBA	Systematiskt brandskyddsarbete (Systematic fire prevention)
SSM	Swedish Radiation Safety Authority (Strålsäkerhetsmyndigheten)
SSMFS	Swedish Radiation Safety Authority's regulations (Strålsäkerhetsmyndighetens föreskrifter)
SSA	Safe shutdown analysis
STUK	Radiation and Nuclear Safety Authority of Finland
US NRC	US Nuclear Regulatory Commission
YVL	Ydinvoimalaitos (nuclear power plant), STUK regulatory guide designation

NOMENCLATURE

Term	Definition
Fire hazards analysis (FHA)	A safety analysis to show that a plant meets the fire related safety objectives. Usually assumed to be the deterministic part of fire safety analyses, but sometimes fire PSA may be included in fire hazards analyses.
Fire risk analysis, Fire PSA	Probabilistic analysis to identify and quantify risk related to fire events at nuclear power plants. Applies the same risk metrics as other parts of PSA for nuclear power plants, i.e., core damage risk at level 1 PSA, and large release risk at level 2 PSA.
Fire SSA	Safe shut down analysis for the internal event Fire.
Safe shutdown analysis (SSA)	Safe shut down analysis is a deterministic analysis which shows (verifies) that a plant can reach and maintain a safe state after an internal initiating event (e.g. fire or pipe break).
Systematic fire prevention (SBA, systematiskt brandskyddsarbete in Swedish)	Systematic fire prevention (work) is an organised way to plan, document and control the fire protection of an organisation, following the Swedish legislation for fire protection of buildings and facilities.

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