

Event Combinations of Fire and Other Events

The Fire Incidents Records
Exchange Project
Topical Report No. 3

Unclassified

NEA/CSNI/R(2016)7

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

27-Jul-2016

English - Or. English

**NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS**

Event Combinations of Fires and Other Events

Fire Incidents Records Exchange Project

Topical Report No. 3

JT03399536

Complete document available on OLIS in its original format

This document and any map included herein are without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.



NEA/CSNI/R(2016)7
Unclassified

English - Or. English

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

The OECD is a unique forum where the governments of 35 democracies work together to address the economic, social and environmental challenges of globalisation. The OECD is also at the forefront of efforts to understand and to help governments respond to new developments and concerns, such as corporate governance, the information economy and the challenges of an ageing population. The Organisation provides a setting where governments can compare policy experiences, seek answers to common problems, identify good practice and work to co-ordinate domestic and international policies.

The OECD member countries are: Australia, Austria, Belgium, Canada, Chile, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission takes part in the work of the OECD.

OECD Publishing disseminates widely the results of the Organisation's statistics gathering and research on economic, social and environmental issues, as well as the conventions, guidelines and standards agreed by its members.

NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1 February 1958. Current NEA membership consists of 31 countries: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, the Netherlands, Norway, Poland, Portugal, Russia, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission also takes part in the work of the Agency.

The mission of the NEA is:

- to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes;
- to provide authoritative assessments and to forge common understandings on key issues, as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

Specific areas of competence of the NEA include the safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information.

The NEA Data Bank provides nuclear data and computer program services for participating countries. In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

This document and any map included herein are without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

Corrigenda to OECD publications may be found online at: www.oecd.org/publishing/corrigenda.

© OECD 2016

You can copy, download or print OECD content for your own use, and you can include excerpts from OECD publications, databases and multimedia products in your own documents, presentations, blogs, websites and teaching materials, provided that suitable acknowledgement of the OECD as source and copyright owner is given. All requests for public or commercial use and translation rights should be submitted to rights@oecd.org. Requests for permission to photocopy portions of this material for public or commercial use shall be addressed directly to the Copyright Clearance Center (CCC) at info@copyright.com or the Centre français d'exploitation du droit de copie (CFC) contact@cfcopies.com.

THE COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

The NEA Committee on the Safety of Nuclear Installations (CSNI) is an international committee made up of senior scientists and engineers with broad responsibilities for safety technology and research programmes, as well as representatives from regulatory authorities. It was created in 1973 to develop and co-ordinate the activities of the NEA 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 NEA member countries. The main tasks of the CSNI are to exchange technical information and to promote collaboration between research, development, engineering and regulatory organisations; to review operating experience and the state of knowledge on selected topics of nuclear safety technology and safety assessment; to initiate and conduct programmes to overcome discrepancies, develop improvements and reach consensus on technical issues; and to promote the co-ordination of work that serves to maintain competence in nuclear safety matters, including the establishment of joint undertakings.

The priority of the committee is on the safety of nuclear installations and the design and construction of new reactors and installations. For advanced reactor designs, the committee provides a forum for improving safety-related knowledge and a vehicle for joint research.

In implementing its programme, the CSNI establishes co-operative mechanisms with the NEA's Committee on Nuclear Regulatory Activities (CNRA), which is responsible for the Agency's programme concerning the regulation, licensing and inspection of nuclear installations with regard to safety. It also co-operates with the other NEA Standing Technical Committees as well as with key international organisations such as the International Atomic Energy Agency (IAEA) on matters of common interest

FOREWORD

The Fire Incidents Records Exchange (FIRE) Project Database is one of the four nuclear power plants (NPPs) operational events databases currently operated under the umbrella of the NEA. The need for such a database emerged in the late 1990s when it became evident that the only international recording of fire events by the International Recording System (IRS) was not suitable for specific analysis and use in risk assessment. In this respect only dedicated databases allow for “topic focused” lessons learnt as well as for quantitative analysis.

The purpose of the FIRE Project is therefore to provide a platform for multiple countries to collaborate and exchange fire data and thereby to enhance the knowledge of fire phenomena and in turn improve the quality of risk assessments that require fire related data and knowledge. Applicable to commercial NPP only, the FIRE Project exchanges fire events data covering all plant operational modes including the construction and decommissioning phases.¹

Improving the safety of NPP by better accounting for feedback from operating experience and by providing common resources for analytical work in the frame of deterministic and probabilistic assessments is the main objective of the FIRE Project. To meet this objective, the project includes the establishment of a framework for a multi-national co-operation in fire data collection and analysis.

The objectives of the FIRE Project are:

- to collect fire event experience by international exchange in an appropriate format in a quality assured and consistent database (the “FIRE Database”);
- to collect and analyse fire events over the long term so as to better understand such events and their causes, and to encourage their prevention;
- to generate qualitative insights into the root causes of fire events in order to derive approaches or mechanisms for their prevention and to mitigate their consequences;
- to establish a mechanism for the efficient operational feedback on fire event experience including the development of policies of prevention, such as indicators for risk informed and performance-based inspections; and
- to record characteristics of fire events in order to facilitate fire risk analysis, including quantification of fire frequencies.

The Database is envisioned to be used to:

- support model development, validation;
- identify all types of events and scenarios for inclusion in probabilistic safety assessment (PSA) models ensuring that all mechanisms are accounted for;
 - support fire PSA by real data, in particular to evaluate fire occurrence frequencies, and
 - compare fire event data from member countries with the accumulated international data collected within the FIRE Database.

This work represents the collective effort of the task group members, all of whom provided valuable time and considerable knowledge towards its production. In offering its thanks to these experts, the NEA

1. The FIRE Database at present contains a limited number of construction phase fire events and up to now no decommissioning phase events. However, the database infrastructure is capable of handling the reporting of fire events during these phases.

wishes to express particular appreciation to Dr Heinz Peter Berg, who as task leader performed the overall co-ordination of the task together with Nicole Fritze, and to Dr Diego Escrig Forano, Eunate Armañanzas Albaizar and Dr Marina Röwekamp, who provided considerable assistance as members of the core team for this task. This task benefitted greatly from support, advice, and technical assistance provided by the national co-ordinators of the FIRE Database Projects. Of particular note is the support provided by Dr Wolfgang Werner and Andreas Werner as Operating Agent.

The Task Group members and staff contributing to this report were: Ivan Bolliger (Canada), Frantisek Stvan (Czech Republic), Matti Lehto (Finland), Pauline Basillais (France), Remy Bertrand (France), Jean-Pierre Cayla (France), Fabienne Nicoleau (France), Heinz Peter Berg (Germany), Nicole Fritze (Germany), Marina Röwekamp (Germany), Wolfgang Werner (Germany), Hajime Kabashima (Japan), Jong-Seuk Park (Korea), Laima Kuriene (Netherlands), Eunate Armañanzas Albaizar (Spain), Diego Escrig Forano (Spain), Christian Karlsson (Sweden), Ralph Nyman (Sweden), Dominik Herrmann (Switzerland), Nicholas Melly (USA), Neil Blundell (NEA).

TABLE OF CONTENTS

EXECUTIVE SUMMARY	11
1. INTRODUCTION	13
Previous topics	13
Topics under discussion	13
2. SCOPE AND OBJECTIVES	15
3. BACKGROUND	17
4. RESULTS FROM THE NEA FIRE INCIDENTS RECORDS EXCHANGE (FIRE) PROJECT DATABASE	19
4.1. Initial fire and consequential event	21
4.2. Initial event and consequential fire	25
4.3. Fire and independent event	32
5. IN-DEPTH ANALYSIS OF THE EVENT COMBINATIONS OBSERVED	37
5.1. Fire and consequential event	37
5.2. Event and consequential fire	44
5.3. Fire and independent event	60
6. CONCLUSIONS AND RECOMMENDATIONS	63
6.1. General conclusions	63
6.2. Recommendations	64
REFERENCES	65
APPENDIX A: NATIONAL REGULATIONS REGARDING EVENT COMBINATIONS OF FIRES AND OTHER EVENTS	69
A.1. Canada	69
A.2. Czech Republic	73
A.3. Finland	74
A.4. France	77
A.5. Germany	78
A.6. Japan	81
A.7. Korea	82
A.8. The Netherlands	83
A.9. Spain	86
A.10. Sweden	87
A.11. Switzerland	88
A.12. United States	88
LIST OF FIGURES	
Figure 1 Categories of combinations of fires and other events	19
Figure 2 Different types of combinations of fires with other events	21
Figure 3 Operational mode before the start of the event combination and after the event	33
Figure 4 Operational mode changes for the event combinations	34
Figure 5 Event combinations – component where the fire started	35

Figure 6	Damages due to the fire in one of the event combinations of fire and consequential fire.....	39
Figure 7	Component where the fire started in the event “fire and consequential HEAF”	42
Figure 8	Lower part of the 6 kV cubicles no. 2 and 3 damaged by fire and HEAF.....	43
Figure 9	Damage of a fire with consequential HEAF: hole in the wall separating the cubicles no. 1 and 2, the hole in the wall separating the cubicles no. 2 and 3.....	43
Figure 10	Switchgear room with damaged and undamaged switchgears	44
Figure 11	Event combinations involving HEAF and consequential fire – component μ where the fire started	46
Figure 12	Damage at bus 5 and 4.....	47
Figure 13	Damage of a transformer after HEAF and consequential fire	49
Figure 14	Damage due to fire	49
Figure 15	Screws of steel employed to hold the wooden support pad of low voltage bus bar system	50
Figure 16	Seismically and HEAF induced fire at a station transformer	56
Figure 17	Damaged transformer after the fire	57
Figure 18	Earthquake first causing a HEAF resulting in a consequential fire.....	58
Figure 19	Damage of the water pipes to hydrants	58
Figure 20	Electric cabinet with the sector on the left where the fire started.....	59
Figure 21	The ten connected cabinets with damage after the event	59
Figure 22	Damage after the event in the control duct.....	59
Figure 23	External flooding situation of the plant affected by simultaneous flooding and fire.....	61

LIST OF TABLES

Table 1	Fire and consequential fire	22
Table 2	Fire and consequential explosion	22
Table 3	Fire and consequential flooding	22
Table 4	Fire and consequential HEAF	24
Table 5	Fire with consequential HEAF and subsequent fire	24
Table 6	Explosion and consequential fire.....	25
Table 7	HEAF and consequential fire	26
Table 8	HEAF with consequential fire resulting and subsequent flooding	30
Table 9	Missiles with consequential fire and subsequent flooding	30
Table 10	Earthquake with consequential HEAF and subsequent fire	31
Table 11	Weather (rain) induced event with consequential HEAF and subsequent fire.....	31
Table 12	External flooding and independent fire	32
Table 13	Measures for severity of single events and event combinations.....	34

LIST OF ABBREVIATIONS AND ACRONYMS

AOPs	Abnormal operating procedure(s)
BDBA	Beyond design basis accidents
BWR	Boiling water reactor
CDF	Core damage frequency
CP	Construction phase
DBA	Design basis
DEC	Design extension conditions
CSNI	Committee on the Safety of Nuclear Installations
EDMGs	Extensive damage mitigation guidelines
EHC	Electro- <i>hydraulic controller</i>
EOPs	Emergency operating procedures
EPR	European pressurised reactor
ERDS	Emergency response data system
ETC	EPR technical code
FEMA	Federal Emergency Management Agency
FHA	Fire hazard analysis
FIRE	Fire Incidents Records Exchange (database project)
HEAF	High energy arcing fault
HS	Hot stand-by
HV	High voltage
IAEA	International Atomic Energy Agency
IE	Initiating event
ITC	Complementary technical instructions
LOCA	Loss of coolant accident
LP	Low power
LV	Low voltage
MCP	Main coolant pump
MCR	Main control room
MV	Medium voltage
NEA	Nuclear Energy Agency
NPP	Nuclear power plant
OECD	Organisation for Economic Co-operation and Development
PIE	Postulated initiating event
PO	Power operation
POS	Plant operational state
PRA	Probabilistic risk assessment
PSA	Probabilistic safety assessment
PWR	Pressurised water reactor
RCP	Reactor coolant pump
RCS	Reactor coolant system
RHWG	Reactor harmonisation working group

SAMG	Severe accident management guidance
SBO	Station black-out
SD	Shutdown mode
SU	Start-up mode
SSC	Structures, systems and components (or systems, structures and components)
SSM	Swedish Radiation Safety Authority
SSMFS	Swedish Radiation Safety Authority's regulations and general advice
UAT	Unit auxiliary transformer
WENRA	Western European Nuclear Regulators Association

EXECUTIVE SUMMARY

Operating experience from nuclear installations worldwide has shown that combinations of fires and other events, in particular external and internal hazards, occur throughout their entire lifetime.

The main objective of the current analysis is to examine event combinations contained within the NEA Fire Incidents Records Exchange (FIRE) Project Database [1] following the lessons learnt from the Fukushima Daiichi reactor accidents. The investigations have shown that some types of combinations have not yet been observed in the operating experience of the FIRE member countries or are rare, conversely for others a non-negligible number of event combinations have been reported to the Database.

In order to support the discussion on how to improve suitable preventive measures, information is provided on how such combinations are addressed in different countries and which national regulations exist that already require protection means, to minimise or prevent consequences of such combined events.

This report presents the results of analysing event combinations of fires and other events in the FIRE Database [1], which at present contains 448 fire events from nuclear power plants (NPP) in twelve member countries. The fact that there is approximately 10% of such event combinations in the Database, of which the majority are fire events without safety significance, is notable.

In total 47 event combinations have been identified, the vast majority of them representing combinations of high energy arcing faults (HEAF) and consequential fires. Moreover, seven fire events resulted in flooding as a consequential event. These event combinations and their potential consequences need further investigations which may result in plant modifications including improved procedures in the future.

The number of records of fire event combinations with more than one consequential event, of which at least one represents a fire is seven. This is 15% of all event combinations identified in the Database and not only non-negligible but also demonstrates the potential domino effects which may impair nuclear safety.

On the other hand, the low number of explosions with consequential fires indicates that such event combinations are considered in the plant design.

One general conclusion is that event combinations of internal or external hazards with fires should be more systematically analysed and addressed in the plant design. This underpins similar lessons learnt from post-Fukushima investigations. While combinations of a majority of internal and external hazards not exceeding the design basis have already been accounted for in the plant fire safety concepts and are also addressed in the regulations of several countries, some consequences of fires, in particular flooding from extinguishing activities need a more systematic consideration. Moreover, the consequences of event combinations involving HEAF and fire need further investigation which may result in plant modifications including improved procedures in the future.

Finally, the investigations carried out within the frame of this Topical Report have shown not only the usefulness of the existing FIRE Database but also the need to extend the Database and further enhance the coding.

1. INTRODUCTION

The purpose of the NEA Fire Incidents Records Exchange (FIRE) Project Database Project is to provide a platform for multiple countries to collaborate and exchange fire data and thereby to enhance the understanding of fire phenomena in nuclear power plants (NPP) and in turn to improve the quality of quantitative fire risk assessment requiring fire related data. In that context, the Project aims to:

- Collect and analyse fire events in order to prevent fires by better understanding their causes.
- Provide means to acquire better knowledge (both qualitative and quantitative) of fire phenomena.
- Record characteristics of fire events in order to facilitate fire risk analysis, including quantification of fire frequencies.
- Develop and establish mechanisms and/or tools to gain feedback from nuclear power plant experience on fire events in an efficient manner.

The Topical Reports are developed by members of the NEA participating in the FIRE Database Project. The selections of the topic and of the participant members who are going to undertake the task are agreed upon during the FIRE Database Project meetings.

The following is a list of proposed topics recognised as being meaningful to be analysed in the frame of the FIRE Database Project is given:

- Challenging fires in areas relevant to safety, such as switchgear fires, relay room fires, main control room (MCR) fires.
- Combinations of fires and other hazards, such as seismic, flooding, or explosions.
- Fire suppression analysis.
- Rare events.
- Various applications related to the use of the database, e.g., deterministic fire hazard analysis, Fire PSA.
- Database use for support of modernisation projects and changes in regulations.

This Topical Report presents the results of the analyses with respect to event combinations of fires with other events, in particular from hazards, provided in the FIRE Database [1]. It has been developed in line with the FIRE Database Project Quality Assurance (QA) Manual and terms that are agreed upon.

Previous topics

The first Topical Report issued in 2013 [2] has provided results of the analysis of fires resulting from high energy arcing faults (HEAF).

The second Topical Report, to be published, will provide a comparison of fire protection standards in member countries [3].

Topics under discussion

Further national activities concern pump fires and fire events gaining a lot of public attention such as transformer fires. Details are provided in [4]. Members of the FIRE Database Project are also interested in apparent as well as root causes of fire events.

2. SCOPE AND OBJECTIVES

The required function of structures, systems or components (SSC) relevant to nuclear safety may be impaired in case of the occurrence of event combinations of fires and events. This may result in degradation or loss of their intended functions. In principle, combinations of events such as earthquakes and consequential fires may significantly impair or even totally disable SSCs and are often not limited to one reactor unit at multi-unit sites.

Therefore, the objectives of this Topical Report are to:

- Identify scenarios in the NEA Fire Incidents Records Exchange (FIRE) Project Database, where fire events and other anticipated events or hazards occurred either independently from each other or as consequence of each other.
- Investigate these event combinations, looking also for domino effects (e.g. earthquake – high energy arcing fault – fire).
- Determine if the investigations provide a better understanding of the causes and the interdependencies to prevent such event combinations or limit their consequences to safety in the future.

The scope of this topical report is to identify:

- event combinations of fires and other events in the FIRE Database;
- equipment/components involved in these events;
- fire duration;
- fire extinguishing means applied and assessment of their efficiency;
- the plant operational state (POS), when the events occurred, and potential changes of the POS as a result of the events;
- good practices to efficiently prevent these events in the future;
- to present national regulations/recommendations addressing event combinations of fires and other events and how to manage them.

3. BACKGROUND

Operating experience from different types of industrial installations has shown that event combinations of fires and other events occur throughout their entire lifetime.

Typically site-specific occurring hazards cause or induce other hazards to occur. Natural hazards, in particular, rarely happen alone. Thus, it is very important to note that almost any event combination of hazards is possible, and that it is necessary to identify these interactions and find ways to mitigate the effects of hazard combinations.

Combinations of events have already been investigated in the process/chemical industry for many years because several major accidents occurred, often damaging equipment enclosures. Typically the so-called domino effect is investigated by different methods [5]. The significance of domino effects in chemical accidents is described in [6]. A domino effect can occur in various types of scenarios. However an essential aspect is whether it is confined to a single plant or area or progresses to others.

A recent study [7] has assessed the main features of domino effect accidents in process/storage plants and in the transportation of hazardous (flammable) materials through an analysis of 225 accidents. One of the goals of this study was to analyse the domino effect sequences applying probability event trees. The most frequent sequences were explosions inducing fires (27.6 %), fires inducing explosions (27.5 %) and fires inducing secondary fires (17.8 %) for these specific types of installations.

Similarly, nuclear operating experience from recent years underlines the necessity to take into account event combinations in the safety assessment of nuclear power plants (NPP).

The required function of SSCs relevant to nuclear safety may be impaired in case of the occurrence of event combinations of fires and events. This may result in degradation or loss of their intended functions. In principle, combinations of events such as earthquakes and consequential fires may significantly impair or even totally disable SSCs and are often not limited to one reactor unit at multi-unit sites.

In light of that background recent documents of the International Atomic Energy Agency (IAEA) address this topic. For the design of nuclear power plants [8] it is required:

“Where the results of engineering judgement, deterministic safety assessments and probabilistic safety assessments indicate that combinations of events could lead to anticipated operational occurrences or to accident conditions, such combinations of events shall be considered to be design-basis accidents or shall be included as part of design extension conditions, depending mainly on their likelihood of occurrence. Certain events might be consequences of other events, such as a flood following an earthquake. Such consequential effects shall be considered to be part of the original postulated initiating event.”

The IAEA Safety Guide on Level 1 PSA [9] states and recommends: “Initiating events occurring at the plant may be the result of the impact of a single hazard or a combination of two or more hazards. The possible combinations of hazards should be identified on the basis of the list of individual internal and external hazards. The entire list of potential hazards should be used for this purpose before any screening analysis is carried out. The general approach used for the identification of a realistic set of combinations of hazards should be based on a systematic check of the dependencies between all internal and external hazards.”

Accordingly, it is important to analyse combinations of events. This topical report aims to carry out such an analysis of event combinations of fires and other events.

4. RESULTS FROM THE NEA FIRE INCIDENTS RECORDS EXCHANGE (FIRE) PROJECT DATABASE

The analysis has shown that up to the end of 2014, 47 out of 448 fire events in the FIRE Database [1] have been identified as event combinations of fires and other events. This contribution of approximately 10.5 % is non-negligible. Seven of these combinations (approximately 15 % of all 47 event combinations) are combinations of multiple events (so-called event chains).

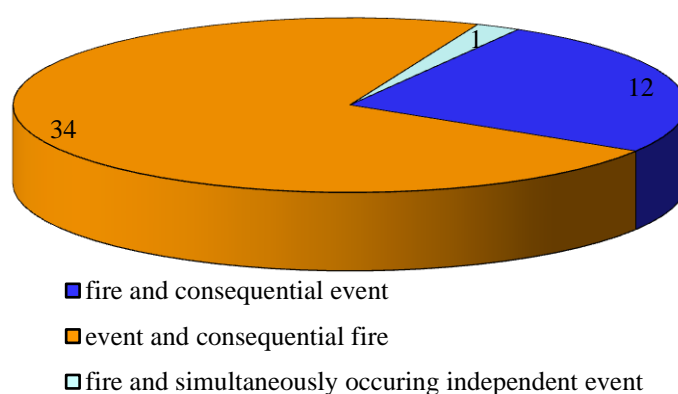


Figure 1. Categories of combinations of fires and other events

For each of these groups of event combinations, it has to be systematically identified, which types of events from internal or external hazards can be correlated to fire events.

It is generally seen that:

- only internal hazards have been observed to occur as consequence of a plant internal fire, while fires may be induced by several internal or external hazards.
- combinations of fires and independently occurring hazards are the rarest combinations.
- only very few external and internal hazards have to be considered to be significant.

This investigation revealed the following list of possible combinations, only some of which have been observed in the operating experience of nuclear power plants (NPP) in those member countries participating to the FIRE Database:

- Fire and consequential event:
 - fire and consequential fire;
 - fire and consequential explosion;
 - fire and consequential (internal) flooding;
 - fire and consequential high energy failure of electrical², mechanical or pressure confining components with the potential of impairing systems relevant to safety;
 - event chains with fires and more than one consequential events.
- Event and consequential fire:

2. These include high energy arcing faults (HEAF), which may result in explosion type consequences.

- internal hazard and consequential fire:
 - internal explosion and consequential fire;
 - high energy failure of electrical², mechanical or pressure confining components with the potential of impairing systems relevant to safety and consequential fire;
 - internal flooding and consequential fire.
- natural external hazard and consequential fire:
 - earthquake and consequential fire;
 - weather induced natural hazard and consequential fire;
 - other natural hazard and consequential fire.
- man-made external hazard and consequential fire:
 - external fire and consequential fire;
 - external explosion and consequential fire;
 - aircraft crash and consequential fire;
 - other man-made hazards and consequential fire;
- Event chains with fires as one of the consequential events;
- Fire and independent event:
 - internal hazard and independent fire:
 - fire and independent fire;
 - internal explosion and independent fire;
 - natural external hazard and independent fire:
 - earthquake and independent fire;
 - external flooding and independent fire.

Although the above combinations are considered possible or have been observed in other industry operating experience as well as from the Fukushima Daiichi reactor accidents, only a few of these potential event combinations have been reported to the FIRE Database. The corresponding distribution of event combinations is provided in Figure 2.

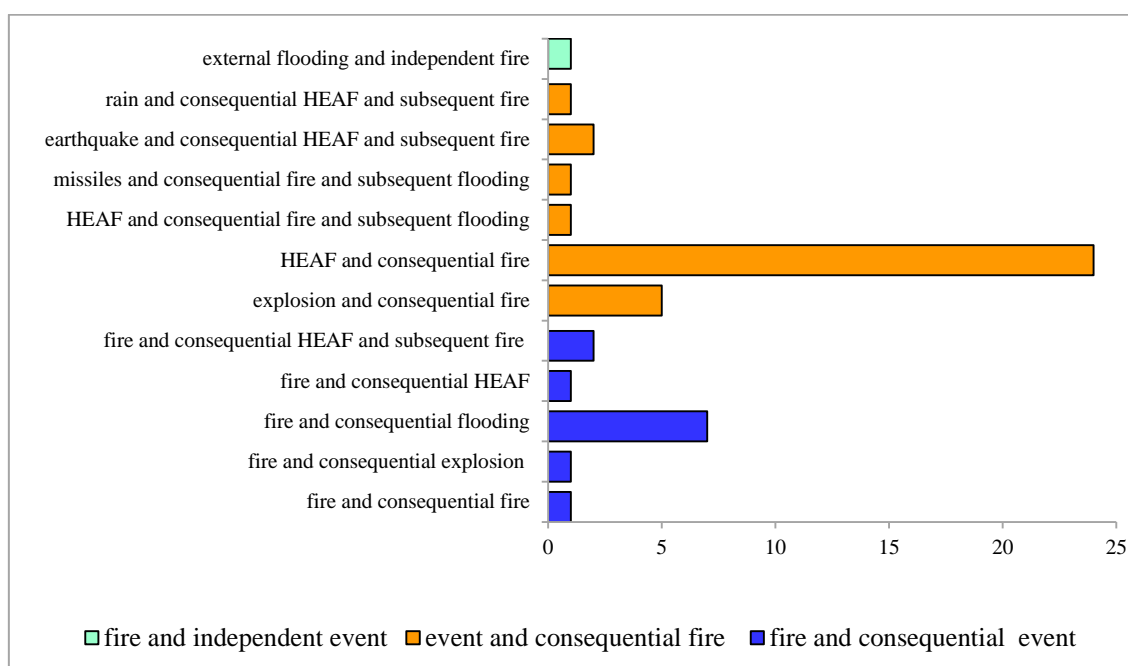


Figure 2. Different types of combinations of fires with other events

The following tables, corresponding to the different types of event combinations reported to the FIRE Database, provide a brief overview on the fire related information with respect to the 47 records of event combinations with fires. The information provided covers plant state, when the event occurred, component where the fire started and the fuel(s) involved, building or plant area where the event occurred, root causes as far as known and coded, the means by which the fire was successfully suppressed, and the fire duration if included in the coding.

In these tables as well as in Figure 3 to Figure 5 and Figure 11 the following abbreviations are used:

PO: power operation
 SD: shutdown mode
 SU: start-up mode
 HS: hot stand-by
 CP: construction phase

E: equipment
 H: human
 P: procedures
 HV: high voltage
 LV: low voltage
 MV: medium voltage

Note: The event titles included in the tables have been taken from the FIRE Database [1]. Since these titles were usually taken from the original national reporting of the corresponding events, which has been done in several countries not for fire reporting purposes but according to the individual reporting criteria, they do sometimes not reflect what happened with regard to fire. The event title may therefore be in a first step misleading; however the narrative parts of the data records clearly reflect the fire events.

4.1. Initial fire and consequential event

The FIRE Database [1] contains in total 12 combinations of fires and consequential events, one of these being a secondary fire being induced by the initial one, one an explosion caused by an initial fire, seven fires resulting in consequential flooding, one fire inducing HEAF, and two fire events resulting in consequential HEAF with subsequent consequential fire. The following tables (Table 1 to Table 5) provide

some brief information from the recent version of the Database [1] on the already observed event combinations of initial fires and consequential events.

Table 1. Fire and consequential fire

Event Title	ID	Plant state before / after fire	Component where the fire started	Fuels	Plant area / building where the event combination occurred	Root causes	Extinguished by (all means involved)	Duration [h:min]
Turbine hall, 254 elevation lube oil purification skid fire – involved combustibles included, lube oil and cable insulation, - resultant damage to the purification skid and 3 local cable trays – no impact on fire safe shutdown	434	SD / SD	oil separator or oil stripper	cable insulation materials; hardly inflammable liquid	turbine building	E, H	external fire brigade; on-site plant fire brigade	00:18

The initial lubricant fire (event ID 434) caused a consequential cable fire on cable trays above the initial fire source in the turbine building.

Table 2. Fire and consequential explosion

Event Title	ID	Plant state before / after fire	Component where the fire started	Fuels	Plant area / building where the event combination occurred	Root causes	Extinguished by (all means involved)	Duration [h:min]
Liquid fuel discharge during a diesel generator fire	319	PO / PO	diesel generator	flammable liquid	auxiliary building	E	external fire brigade; fixed system – automatic actuation, manual actuation; shift personnel	02:35

Event ID 319 was a fire at a diesel generator resulting in an explosion of the motor of the diesel generator lubrication system.

Table 3. Fire and consequential flooding

Event Title	ID	Plant state before / after fire	Component where the fire started	Fuels	Plant area / building where the event combination occurred	Root causes	Extinguished by (all means Involved)	Duration [h:min]
Failure in a ventilation unit with great production of smoke, actuation of fire protection system and leak of water to control room	58	CP / CP	fixed heater	cable insulation materials	electrical building ³	H	fixed system - automatic actuation	00:10

3. The original national coding of “control building” in the Database has been corrected to “electrical building”.

Event Title	ID	Plant state before / after fire	Component where the fire started	Fuels	Plant area / building where the event combination occurred	Root causes	Extinguished by (all means Involved)	Duration [h:min]
Fire in main turbine-generator group no. 2 and flooding of the cellar	82	PO / SD	turbine generator: oil involved	hardly inflammable liquid; hydrogen	turbine building	E	external fire brigade; fixed system - manual actuation	unknown
Manual Reactor Trip due to Rapid Loss of Generator Hydrogen and Subsequent Fire	257	PO / SD	miscellaneous hydrogen containing equipment (e.g. piping)	Hydrogen	turbine building	E, P	fixed system - automatic actuation; on-site plant fire brigade	00:23
Fire on the roof of the auxiliary building and presence of smoke inside the electrical penetration area	294	SU / SU	component (other than cable) ignited by hot work	cable insulation materials; plastics / polymeric materials	auxiliary building	H	fixed system – manual actuation; on-site plant fire brigade	00:10
Fire in main transformer T1, phase A, with reactor scram due to main generator trip (activation of the emergency plan inside the NPP, Category 1 of prealert level)	362	PO / SD	high voltage transformer (voltage \geq 50 kV): oil involved, catastrophic	hardly inflammable liquid	outside the plant	unknown	external fire brigade; fixed system - automatic actuation; fixed system - manual actuation; on-site plant fire brigade	00:57
Fire on an oil plug of a boric acid pump	373	PO / PO	pump (electrically driven or turbine driven)	flammable liquid; plastics /polymeric materials	auxiliary building	E	self-extinguishing	
High Voltage Primary Transformer Fire	402	PO / SD	high voltage transformer (voltage \geq 50 kV): non-catastrophic	cable insulation materials; flammable liquid	switchyard	E	fixed system - automatic actuation; fixed system - manual actuation; on-site plant fire brigade	76:44

All the seven events in Table 7 above are fires resulting in internal flooding. Event ID 58 started with a heater fire in the electrical building resulting in extinguishing water leaking to the control room. The turbine generator fire (event ID 82) caused flooding of the reactor cavity and machine room due fire-extinguishing water being used as well as by components damaged by the fire releasing higher amounts of water. Details can be found in Section 5.1.3. Water from extinguishing a hydrogen fire in the turbine building (event ID 257) entered into electrical cabinets. Event ID 294 was a fire of plastic materials on the roof of the auxiliary building. The large amount of water on this roof flooded the building. In the event ID 362, the water used for extinguishing a high voltage transformer fire outside buildings penetrated into the turbine building and caused flooding. The flooding of 700 l of boric acid which were released due to a fire-induced failure in the boric acid pump is provided in the event with the ID 373. Event ID 402 was a high voltage transformer fire in the switchyard, where the fire-extinguishing water together with transformer oil entered the turbine building.

Table 4. Fire and consequential HEAF

Event Title	ID	Plant state before / after fire	Component where the fire started	Fuels	Plant area / building where the event combination occurred	Root causes	Extinguished by (all means involved)	Duration [h:min]
Loss of 400 kV power supply following a fire in the 6.6 kV AC normal distribution system cubicle	237	SD / SD	electrical cabinet: high or medium voltage (HEAF, ≥ 1 kV)	hardly inflammable liquid; plastics / polymeric materials	electrical building	E	external fire brigade; shift personnel	01:11

In the event ID 237, a circuit breaker cubicle fire resulted in a consequential HEAF of the breaker (electrical cabinet, voltage ≥ 1 kV).

4.1.1. Event chains with fires and more than one consequential event

Table 5. Fire with consequential HEAF and subsequent fire

Event Title	ID	Plant state before / after fire	Component where the fire started	Fuels	Plant area / building where the event combination occurred	Root causes	Extinguished by (all means involved)	Duration [h:min]
Fire in an electrical cabinet in a switchyard room. Converter in cabinet – 2 NXA201 is affected by the fire. Cause is overheating of affected component. An arc started a second fire	59	PO / PO	electrical cabinet: low voltage (non-HEAF, < 1 kV)	other solid material	electrical building ⁴	E	on-site plant fire brigade	> 00:05
Fire at 6.6 kV switchgear	94	PO / SD	electrical cabinet: high or medium voltage (HEAF, ≥ 1 kV)	cable insulation materials; other insulations	electrical building	E, H	on-site plant fire brigade	00:37

Both events (event IDs 59 and 94) were fires of electrical cabinets, resulting in HEAF of the cabinet inducing a consequential fire, in an electrical building

4. The original national coding of “switchyard” in the Database resulting from a mistake in translation has been corrected to “electrical building”.

4.2. Initial event and consequential fire

The FIRE Database [1] contains in total 34 combinations of initial event and consequential fire, five of these representing fires induced by an internal explosion, 24 being fires caused by HEAF, and five representing event chains involving fire. One of these five event chains was an initial HEAF inducing a fire with subsequent internal flooding, another one was a fire caused by missiles resulting in a subsequent flooding. Two seismically induced HEAF resulted in internal fires and another natural external event, heavy rain, caused a HEAF with subsequent fire. In the following tables (Table 6 to Table 11) some brief information from the recent version of the Database [1] on already observed event combinations of initial events and consequential fires is given.

Table 6. Explosion and consequential fire

Event Title	ID	Plant state before / after fire	Component where the fire started	Fuels	Plant area / building where the event combination occurred	Root causes	Extinguished by (all means involved)	Duration [h:min]
Incipient fire in a site communication system room	196	PO / PO	rectifier or inverter, or battery charger	plastics / polymeric materials	other building/area	E	shift personnel	00:15
Hydrogen fire at high pressure hydrogen cylinders	360	PO / PO	hydrogen containing vessel	hydrogen	other building/area	E	on-site plant fire brigade	00:13
Fire due to a hydrogen leak coming from the turbo generator	377	SU / SD	turbine generator: exciter	hydrogen	turbine building	E	fire source isolation; self-extinguished	(00:01) 00:10
Alert declared due to fire affecting access to safety related equipment	411	PO / PO	hydrogen containing vessel	hydrogen	outside the plant	H	on-site plant fire brigade; external fire brigade	00:19
Hydrogen explosion with several fires on the turbine generator (GTA) ⁵	449	PO / SD	turbine generator	hydrogen	turbine building	E	on-site plant fire brigade; external fire brigade	03:20

Event ID 196 was a small smouldering fire of a capacitor consequential to the component's explosive failure. The break of the pressure gauge at a hydrogen supply line at 200 bar pressure (event ID 360) caused an initial hydrogen explosion with consequential fire at the hydrogen cylinders, which self-ignited. Another typical explosion with consequential fire occurred in the event ID 377 when during start-up of the plant a leak at the turbine-generator exciter caused a release of hydrogen, which directly exploded and resulted in a consequential fire with a 5 m high hydrogen flame being observed. In the event ID 411, a leakage of hydrogen from hydrogen storage tanks outside of plant buildings on the plant area resulted in a hydrogen explosion. The explosion initiated by a spark created by a faulty human action. The explosion directly caused a consequential hydrogen fire. The event ID 449 was a hydrogen explosion (deflagration) resulting in consequential fires at the turbine generator.

5. The event occurred within the reporting period of the recent version of the Database [1], but was implemented after its distribution.

Table 7. HEAF and consequential fire⁶

Event Title	ID	Plant state before/after fire	Component where the fire started	Fuels	Plant area/building where the event combination occurred	Root causes	Extinguished by (all means involved)	Duration [h:min]
Short circuit in the 220 kV/380 kV switchgear with consequential loss of offsite power	68	PO / HS	other component	hardly inflammable liquid	switchyard	E	on-site plant fire brigade	00:46
Trip of main transformer, followed by fire in phase "S" due to manufacturing defect. Subsequently, turbine trip and, with permissive P-7, reactor trip (event #1)	71	PO / HS	high voltage transformer (voltage \geq 50 kV): oil involved, catastrophic	hardly inflammable liquid	outside the plant	E	fixed extinguishing system – automatic actuation, manual actuation; on-site plant fire brigade; shift personnel	00:58
Trip of main transformer, followed by fire in phase "S" due to manufacturing defect. Subsequently, turbine trip and, with permissive P-7, reactor trip (event #2)	74	PO / HS	high voltage transformer (voltage \geq 50 kV): oil involved, catastrophic	hardly inflammable liquid	outside the plant	E	fixed extinguishing system – automatic actuation, manual actuation; on-site plant fire brigade; shift personnel	00:15
When energising with sub-critical reactor, main transformer tripped, followed by fire in phase "R" ⁷	75	SU / SU	high voltage transformer (voltage \geq 50 kV): oil involved, catastrophic	hardly inflammable liquid	outside the plant	E	fixed extinguishing system – automatic actuation, manual actuation; on-site plant fire brigade; shift personnel	00:08
Loss of a 6.6 kV emergency switchboard	91	PO / SD	electrical cabinet: high or medium voltage (HEAF, \geq 1 kV)	cable insulation materials	electrical building	E	shift personnel	00:07

6. Some events are coded as HEAF and consequential fire although the categorisation of these events is different in PRA in the respective country.

7. (event #3)

Event Title	ID	Plant state before/after fire	Component where the fire started	Fuels	Plant area/building where the event combination occurred	Root causes	Extinguished by (all means involved)	Duration [h:min]
Fire of a station service load transformer caused by a defect on the power part of the branch lines switch followed by an explosion	123	PO / SD	medium and low voltage transformer (voltage level < 50 kV): oil filled	flammable liquid	switchyard	E	fixed extinguishing system – automatic actuation; on-site plant fire brigade	00:16
Reactor trip due to a failure in a fast switch-over connection function. Failure in a commutator fuse in an electrical cabinet ⁸	130	PO / SD	electrical cabinet: low voltage (non-HEAF, < 1 kV)	other solid material	electrical building	E	shift personnel	< 00:05
Unit main transformer fault and fire	165	PO / HS	high voltage transformer (voltage ≥ 50 kV): oil involved, catastrophic	flammable liquid	other building/area	E	on-site plant fire brigade	00:14
Incipient fire on ultimate emergency diesel generator	211	PO / PO	electrical cabinet: high or medium voltage (HEAF, ≥ 1 kV)	other insulations; plastics / polymeric materials	diesel generator building	E	self-extinguished	00:05
Switchyard fire in 34.5 kV circuit breaker	252	PO / PO	breaker	hardly inflammable liquid	switchyard	E	on-site plant fire brigade	unknown
Failure of start-up transformer ST-20	267	SU / SD	high voltage transformer (voltage ≥ 50 kV): oil involved, catastrophic	flammable liquid	outside plant ⁹	E	fixed system – automatic actuation	< 00:10
Explosion of an oil-filled current transformer leading to a fire in the 400 kV platform *	290	PO / SD	high voltage transformer (voltage ≥ 50 kV): oil involved, catastrophic	hardly inflammable liquid	switchyard	E	external fire brigade; fixed system – manual actuation; shift personnel	00:48
Switchyard device failure results in a reactor trip	303	PO / HS	medium or low voltage transformer (voltage level < 50 kV): dry	unknown	switchyard	E	fire guard/watch	00:34

8. HEAF at a component was coded as non-HEAF-component in the FIRE Database.

9. The original national coding of “other building/area” in the Database has been corrected to “outside plant”.

Event Title	ID	Plant state before/after fire	Component where the fire started	Fuels	Plant area/building where the event combination occurred	Root causes	Extinguished by (all means involved)	Duration [h:min]
Reactor trip due to main transformer fault and fire	328	PO / HS	high voltage transformer (voltage \geq 50 kV): oil involved, catastrophic	flammable liquid	outside the plant	E	fixed extinguishing system – automatic actuation, manual actuation ; on-site plant fire brigade	unknown
Fire in a 6 kV electrical cabinet in room D2.21, cabinet feed power to the pump 725 P1. A breaker in the cabinet is burning	346	SD / SD	breaker	other solid material	turbine building	E, H, P	on-site plant fire brigade	01:05
Voltage transformer fire due to human error during maintenance outage	347	SD / SD	medium and low voltage transformer (voltage level < 50 kV): oil filled	hardly inflammable liquid; other insulations	outside the plant	H	on-site plant fire brigade; self-extinguished	00:05
Fire (explosion like) in local transformer at 00:30. The reactor tripped due to the fire	350	PO / SD	medium and low voltage transformer (voltage level < 50 kV): oil filled	cable insulation materials; flammable liquid; other solid material	outside the plant	E	external fire brigade; fixed system – automatic actuation; on-site plant fire brigade;	~ 01:40
Automatic reactor trip due to circulating water pump surge capacitor failure	351	PO / SD	pump (electrically driven or turbine driven)	other insulations	intake building	E	self-extinguished	00:34
Automatic reactor trip due to a turbine generator trip caused by a fault on the 31 main transformer phase B high voltage bushing	354	PO / HS	high voltage transformer (voltage \geq 50 kV): oil involved, catastrophic	hardly inflammable liquid	other building/area	E	on-site plant fire brigade; fixed system – automatic actuation	00:12
Plant Trip due to Electrical Fault	400	PO / HS	cable run (self-ignited, power cables)	cable insulation materials	turbine building	E, H	on-site plant fire brigade	00:15
Automatic shutdown of the reactor following an explosion and a consequential fire on the main power transformer	405	PO / SD	high voltage transformer voltage \geq 50 kV): oil involved, catastrophic	cable insulation materials; hardly inflammable liquid	switchyard	E	external fire brigade; fixed system – automatic actuation; on-site plant fire brigade	02:45

Event Title	ID	Plant state before/after fire	Component where the fire started	Fuels	Plant area/building where the event combination occurred	Root causes	Extinguished by (all means involved)	Duration [h:min]
Automatic reactor trip due to a turbine generator trip caused by a fault of the 21 main transformer phase B high voltage bushing	407	PO / HS	high voltage transformer (voltage \geq 50 kV): oil involved, non-catastrophic	hardly inflammable liquid	switchyard	unknown	fixed system – automatic actuation	00:02
Arcing in isolated phase bus results in a generator trip, turbine trip, reactor trip and a small fire	429	PO / HS	high voltage transformer (voltage \geq 50 kV): oil involved, catastrophic	cable insulation materials; hardly inflammable liquid	turbine building	E	external fire brigade; on-site plant fire brigade	00:29
Licensee event report (LER) 2013-003-00, Unit 1 turbine trip and subsequent manual reactor trip due to 4 kV cable fault	430	SU / HS	bus duct	cable insulation material; other solid material; plastics / polymeric material	turbine building	E	fixed system - automatic actuation	< 00:05

In the event ID 68 an instrument transducer was destroyed by a HEAF and the spouting oil caught fire. Three events occurred at high voltage transformers of the same plant. Event IDs 71, 74 and 75 correspond to a series of events that took place in the same plant in 6 months' time. In all the three events, the HEAF led to a consequential fire at the main transformer. In the event ID 91 an electric arc occurred at a contactor supplying an essential service water system pump. The HEAF with explosive fault of the whole cubicle resulted in a consequential fire in the emergency switchboard.

In another event (event ID 123) the explosive HEAF at a service load transformer in the switchyard caused a consequential fire at the oil-filled transformer. Event ID 130 was a HEAF induced by the failure of a fuse with short circuit in a low voltage electrical cabinet in a switchgear room of the electrical building. The HEAF resulted in a fire being successfully extinguished by the fire brigade with the initial attack. Event ID 165 is again a HEAF at a unit main transformer with subsequent transformer fire at the oil-filled transformer.

In the event ID 211, a HEAF in a cubicle of a 6.6 kV electrical cabinet in the diesel generator building, for which the staff only observed an explosion type noise, resulted in a consequential fire which self-extinguished. An explosive HEAF at a switchyard output feeder breaker (event ID 252) caused a consequential fire at the breaker. Event ID 267 was another HEAF with consequential fire occurred at a high voltage, oil filled start-up transformer in the transformer yard. In case of event ID 290 an internal electric arc at a high voltage transformer in the switchyard set fire to the transformer oil while in the event ID 303 a HEAF at a dry switchyard coupling capacitor voltage transformer resulted in subsequent transformer fire. Event ID 328 is again a HEAF at a main station transformer with consequential fire of the oil-filled transformer.

HEAF in the breaker inside a cabinet in the process room inside the turbine building (event ID 346) caused overheating of cables and a consequential fire of cables and other insulation material of electric equipment. In the event ID 347, which occurred during the regular refuelling outage of the affected plant, shorts to ground resulting in HEAF at two 15.1 kV transformers close to the main transformer resulted in

transformer fires and an small oil pool fire of released transformer oil. The fire in the event ID 350 was initiated by a HEAF due to short to ground between three phases of a local transformer outside plants buildings which caused a consequential fire of the oil-filled transformer.

An electric arc (HEAF, event ID 351) occurring at the capacitor of an electrically driven pump in the intake building resulted in subsequent fire. Another HEAF event at a main transformer (event ID 354) resulted in consequential transformer fire with the transformer oil being ignited by the arc. The HEAF in event ID 400 occurred at a 4 kV feeder cable power cable in an electrical room of the turbine building caused a consequential cable fire. Event ID 405 is again an explosive HEAF with consequential fire that occurred at the main transformer (high voltage, oil filled) in the switchyard of a multi-unit nuclear power plant. Event ID 407 is also a HEAF at a main transformer with subsequent fire. In the event ID 429, the initial HEAF resulted from a loose damper blade within the isolated phase bus ductwork of the unit auxiliary transformer in the turbine building. As a consequence, a small cable insulation and oil collection pan caught fire. A cable failure occurred in turbine building mezzanine level of one unit of a multi-unit station (event ID 430) resulting in a HEAF at a 4 kV bus duct with subsequent cable fire of the bus supply power cables.

For the majority of the 24 combinations of HEAF and consequential fire more details can be found in [2].

4.2.1. Event chains with fires as one of the consequential events

Table 8. HEAF with consequential fire resulting and subsequent flooding

Event Title	ID	Plant state before / after fire	Component where the fire started	Fuels	Plant area / building where the event combination occurred	Root causes	Extinguished by (all means involved)	Duration [h:min]
Fire causing the loss of the train 6.6 kV normal distribution system and an automatic reactor trip	171	PO / SD	electrical cabinet; high or medium voltage (non-HEAF, ≥ 1 kV)	cable insulation materials	electrical building	E	fixed system, - automatic actuation; shift personnel	00:42

In the event ID 171 an initial HEAF occurred in an electrical cabinet inducing a fire which finally resulted in subsequent flooding by extinguishing water in a room below that where the fire occurred.

Table 9. Missiles with consequential fire and subsequent flooding

Event Title	ID	Plant state before / after fire	Component Where the Fire Started	Fuels	Plant Area / Building Where the Event Combination Occurred	Root causes	Extinguished by (all Means Involved)	Duration [h:min]
A turbine and reactor trip due to a generator breakdown. Turbine trip (TSS 15*D) occurred immediately on signal from 420 K012, differential protection G1. Fire in turbine building	10	PO / SD	turbine generator: exciter	flammable liquid; other flammable material	turbine building	E	on-site plant fire brigade; external fire brigade	> 00:05

In the event ID 10, missiles from the turbine caused a fire in the turbine building which finally resulted in subsequent internal flooding by extinguishing water with leaking oil.

Table 10. Earthquake with consequential HEAF and subsequent fire¹⁰

Event Title	ID	Plant state before / after fire	Component where the fire started	Fuels	Plant area / building where the event combination occurred	Root causes	Extinguished by (all means involved)	Duration [h:min]
House transformer fire induced by the “Niigata-Chuetsu-Oki Earthquake”	361	PO / SD	medium and low voltage transformer (voltage < 50 kV): oil filled	flammable liquid	outside plant ¹¹	E	external fire brigade; fixed system – manual actuation	01:55
Seismic induced arcing fault in non-emergency metal clad (M/C) switchgear cabinet	410	PO / PO	electrical cabinet: high or medium voltage (HEAF \geq 1 kV)	cable insulation materials	turbine building	E	on-site plant fire brigade; fixed system – manual actuation	07:58

In case of the event ID 361 the high seismic acceleration caused a HEAF at a transformer that was installed outside close to the turbine building being separated from the other components by a fire wall. The HEAF resulted in subsequent fire. The ignition mechanism was that the electric arc between the bushing and the bus duct ignited oil leaking from the transformer to the bus duct. In case of event ID 410 the initial earthquake caused a HEAF in a high voltage electrical cabinet which resulted in a fire, mainly of cables affecting the entire ten cabinet cubicles.

Table 11. Weather (rain) induced event with consequential HEAF and subsequent fire

Event Title	ID	Plant state before / after fire	Component where the fire started	Fuel	Plant area / building where the event combination occurred	Root causes	Extinguished by (all means involved)	Duration [h:min]
Fire at the cabinet containing 6.9 kV bus for start-up	46	SD / SD	electrical cabinet: high or medium voltage (HEAF \geq 1 kV)	cable insulation materials	turbine building	E, H	fixed system - manual actuation; external fire brigade	02:14

In the event ID 46 water ingress into the turbine building due to heavy rain caused a consequential HEAF with subsequent fire in an electrical cabinet in the turbine building.

10. The root cause of these two event combinations has been corrected to “E “for equipment as the initial hazard is not the root cause according to the IAEA definition which includes failures of any SSC as equipment failures.

11. The original national coding of “other building/area” in the Database has been corrected to “outside plant”.

4.3. Fire and independent event

The FIRE Database [1] contains one event combination of a fire occurring independently during an external flooding of a few weeks.

Table 12. External flooding and independent fire

Event Title	ID	Plant state before / after fire	Component where the fire started	Fuel	Plant area / building where the event combination occurred	Root causes	Extinguished by (all means involved)	Duration [h:min]
Fire in Safety Related 480 Volt Electrical Bus	413	SD / SD	electrical cabinet: low voltage (non-HEAF < 1 kV)	cable insulation material; other insulations; other solid material	electrical building	E	fixed system – automatic actuation	< 00:01

During external flooding of several weeks a fire (event ID 413) occurred independently in an electrical cabinet in the electrical building.

In the recent version of the FIRE Database [1], 47 out of 448 fire events have been identified as event combinations of fires and other events. This contribution is non-negligible. Among them, seven event sequences represent event chains with more than one consequential event and at least one of these being a fire. 24 out of 47 events combinations are fires consequential to HEAF, additional six event sequences are HEAF induced by an initial hazard (including fire) with subsequent fire.

It has to be mentioned in this context that for most of the different types of combinations, only one or very few events have been reported up to the present time. The vast majority of combinations results from HEAF and consequential fires. The most recent version of the FIRE Database [1] contains in total 31 HEAF events. 30 of these identified as HEAF events have led to consequential fires either solely (24 events, representing 5 % of all events in the Database) or as event chains (six event sequences). These multiple event sequences cover initial fires with consequential HEAF and subsequent fire (two events), HEAF inducing a consequential fire resulting in subsequent internal flooding (one event) and HEAF induced by external hazards (earthquake or rain) with consequential fire (three events). Thus the available operating experience gives some indications that these event combinations may need special attention with respect to preventive measures. A majority of the HEAF events recorded occurred at transformers (66 %) and electrical cabinets (30 %). The trend seems to be increasing for HEAF events at transformers as approximately 60 % of these events occurred between 2000 and 2015 versus 40 % in the period between 1985 and 2000, probably due to ageing effects of transformer windings.

Eight out of 47 event combinations are fire events resulting in an internal flooding, in the majority of these events due to fire-extinguishing activities, one of the 8 was a missiles induced fire. The contribution of these events representing nearly 2 % of all fire events in the recent Database version [1] shows that some improvement could also be made to account for this type of event combination.

One case of an external flooding and a simultaneously, however independently occurring fire event has been reported to the FIRE Database, demonstrating that such combinations are not only academic assumptions although the probability of such an event combination is low.

The only event of rain water causing a high energy arc resulting in a subsequent fire is interesting because of possible lessons learnt from this event combination. More details can be found in Section 5.

With regard to the severity of the events, there are indications either provided by information on how many safety trains were affected or lost and by the change of the plant operational mode according to the

event. In eight of the 47 event combinations recorded in the Database, one safety train and in case of two event sequences more than one safety train was lost. For 30 of the 47 event combinations (64 %) the plant operation mode changed. This contribution is even higher (75 %) when considering that for plants under construction or in shutdown (7 events in total) the plant mode cannot change.

The consequences of the event combinations recorded in the FIRE Database on the plant operation mode are shown in Figure 3 and Figure 4.

In 35 events the plant operated at full power when the initial event occurred, in 9 of these the plant remained at full power, while in case of 10 events the mode changed to hot stand-by and in 16 events to shut down as a result of the fire. The contribution of more than two thirds of all event combinations during power operation mode having resulted in a plant operation mode change is notable. The result differs strongly from that for individual events (no event combinations) in the Database, where for 60 % of the events the plant operational mode stays at full power and changes to hot-stand-by or shutdown for only 37 % of the events. In case of plants in shutdown conditions (six events) or under construction (one event) the plant operation mode of course remained unchanged, while for plants under start-up (in total five events) the operation mode changed to hot stand-by (one event) or shutdown (two events), and remained unchanged only for two events. No event combination involving fire has been recorded to present in the Database for plants in hot stand-by.

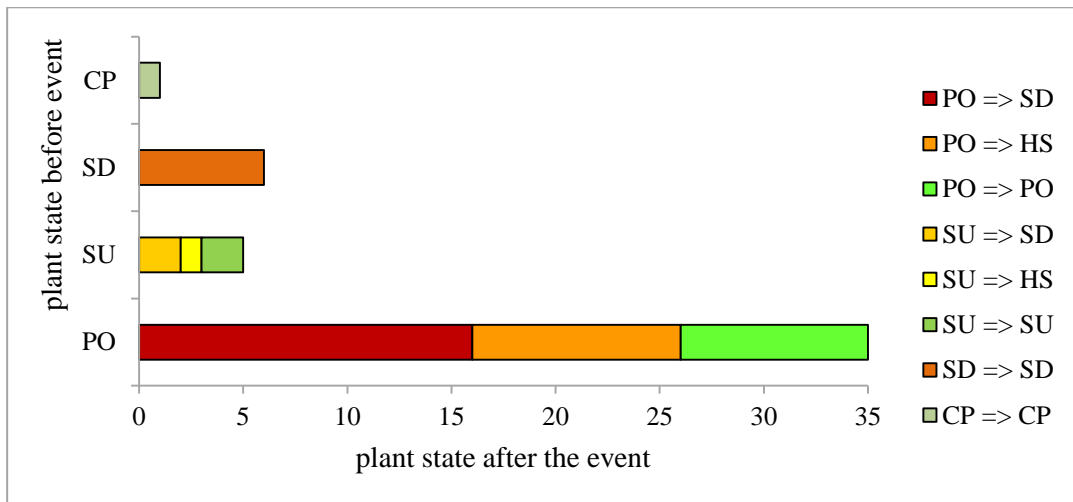


Figure 3. Operational mode before the start of the event combination and after the event

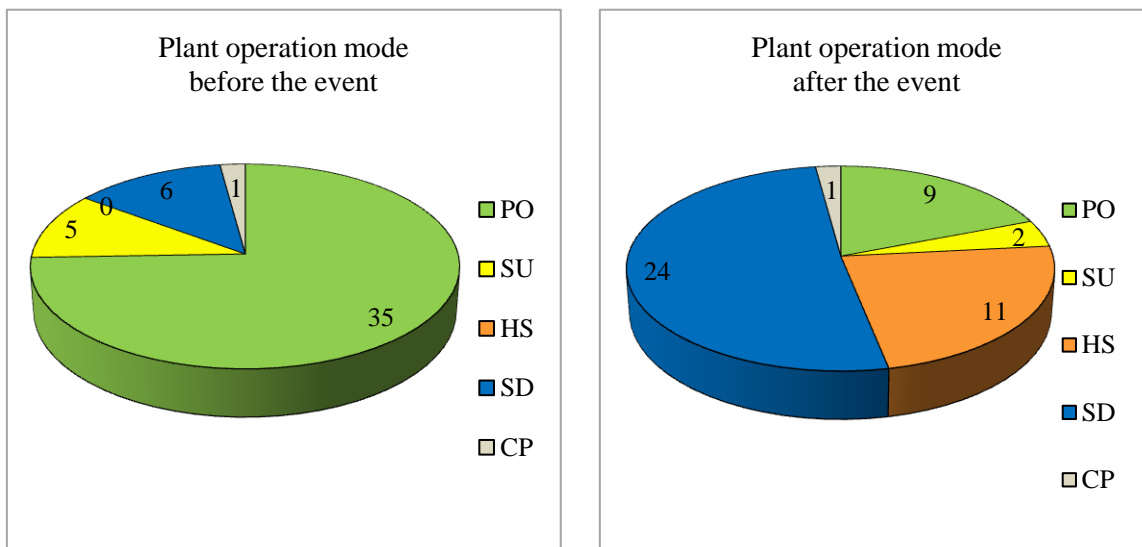


Figure 4. Operational mode changes for the event combinations (left: before the event, right: after the event)

For assessing the severity of events several measures are available. How these compare for event combinations of two or more events versus single events is shown in Table 13 below. For all severity measures considered the percentage contributions from event combinations are notably higher (up to more than 80 %), and those of the measures, relative to the population sizes, are significantly higher event combinations than for individual events, exceeding the individual event’s shares by a factor of about 2 to nearly 4. The observation points out the high safety significance of event combinations and underpins the value of improvements to safety from in-depth investigations of such event combinations involving plant internal fires at NPP. It should also be mentioned that all event combinations were limited to one plant unit in case of multi-unit sites.

Table 13. Measures for severity of single events and event combinations

Number of occurrences of severity measures in single events and event combinations				
Number of events	Significance index* Challenging	Several attacks needed	One or more safety trains affected	Multiple components / compartments, structures affected
Single events: 401	153 (38 %)	81 (21 %)	51 (11 %)	83 (21 %)
Event combinations: 47	39 (83 %)	25 (53 %)	10 (21 %)	29 (62 %)

* to characterise the significance of fire events three severity categories are used. These are challenging, potentially challenging, and non-challenging.

With regard to the components, where the fires involved in the event combinations occurred, Figure 5 shows the distribution of components where fires in case of event combinations started. One observation is that transformers (high voltage as well as low and medium voltage ones) represent the dominating component where the event combination started.

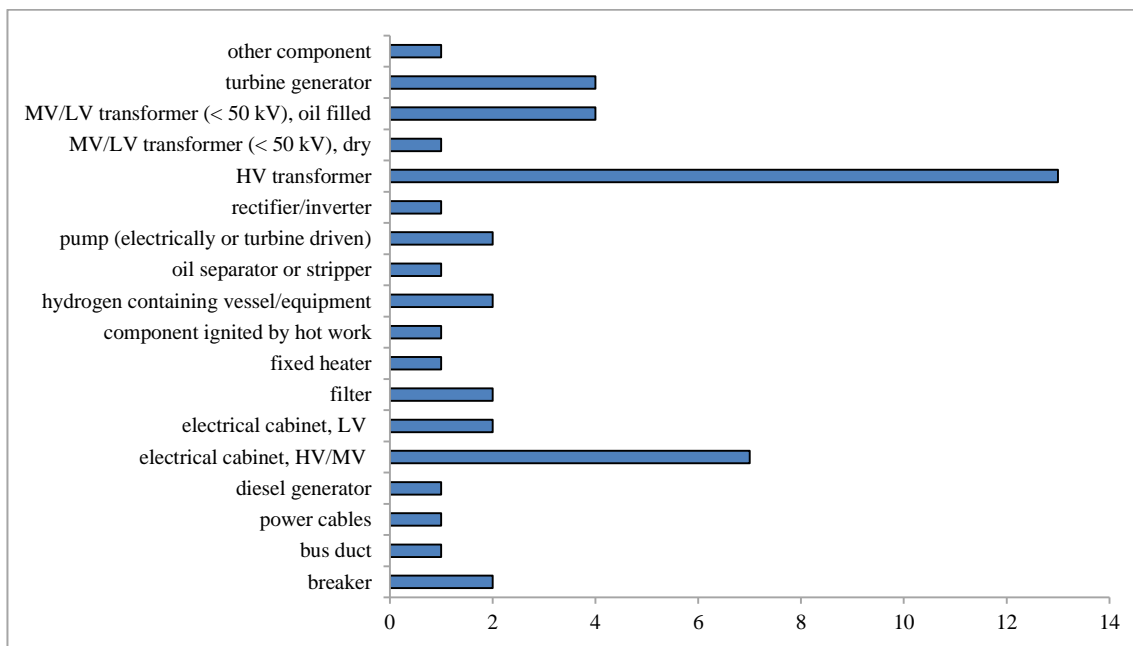


Figure 5. Event combinations - component where the fire started¹²

Details on selected event combinations, their development, consequences and possible corrective actions are provided in the following Section 5.

12. The component category names in Figure 5 have been directly taken from the FIRE Database [1] not specifying the voltage levels for the different types of electrical cabinets. The voltage exceeds 1 kV for medium and high voltage electrical cabinets.

5. IN-DEPTH ANALYSIS OF THE EVENT COMBINATIONS OBSERVED

Basic information regarding the 47 event combinations of fires and other events are provided in Table 1 to Table 12 in Section 4. In the following, the different types of combinations are discussed in more detail and exemplary descriptions of the events and their consequences are provided. As far as possible, corrective actions and changes in procedures as a consequence of the event are also provided.

5.1. Fire and consequential event

For this category of causally related event combination of fires and consequential events the following event combinations have been reported to the NEA Fire Incidents Records Exchange (FIRE) Project Database [1]:

- fire and consequential fire (see Table 1),
- fire and consequential explosion (see Table 2),
- fire and consequential flooding (see Table 3),
- fire and consequential HEAF(see Table 4), and
- fire with consequential HEAF and subsequent fire (see Table 5).

5.1.1. Fire and consequential fire

Only one event has been identified in the FIRE Database [1] for the event combination fire and consequential fire (event ID 434). The initial fire of hardly inflammable lubrication oil at an oil separator in a process room of the turbine hall rapidly developed and caused a subsequent cable fire within three cable trays in a distance of approximately 3.7 meter (12 ft) in the zone of influence above the initial fire source being ignited.

The cause of the initial ignition was a fault of a contactor in a control panel, leading to continued operation of a heating element, which in turn resulted in heating up the stagnant oil in the lubrication oil purification system to above the design temperature of 110 °C. It is assumed that the auto-ignition temperature of 357°C was reached. The heated oil ignited when coming in contact with oxygen from the atmosphere resulting in an ignition of the oil that had already leaked into the systems drip tray. Besides the secondary fire the event resulted in significant damage to the lubrication oil purification skid and its components as well as to minor damage to the surrounding area and a significant amount of soot. Several attacks of manual firefighting with different types of extinguishing media were needed by the plant internal and external fire brigade. Although this next part is technically correct it may not be fully relevant and consideration should be given to removing the detail. The facility could have been safely shutdown

Design modifications to the purification equipment and modifications of procedures have been taken as corrective actions taken against recurrence. The damaged equipment and cables were replaced.

5.1.2. Fire and consequential explosion

Only one event representing a fire with consequential explosion has been identified in the FIRE Database [1]. All the other fires resulting in explosive consequences represent fires with consequential HEAF events.

This event (event ID 319) occurred in one unit of a multi-unit NPP site. The plant was at full power operation when an incipient fire occurred during the test of one specific diesel generator at the site that supplies electricity to a fire pump. This pump is designed to spray water on the walls of the NPP buildings to avoid fire spreading from the neighbouring petrol depot.

The monthly diesel generator test started and 36 min later a fire alarm was signalled in the central room indicating a fire in the essential service water pumping station. The operator immediately stopped the diesel; the fire was confirmed 6 min later. A fire-extinguishing water production system pump was brought into operation since the fire pump was unavailable due to maintenance work. The external fire brigade was called 2 min later. During the same time period two explosions occurred.

To reduce electrical risks the electrical supply of equipment not used was disconnected. About 36 min after the information the external fire brigade and the internal intervention team started to protect the diesel generator fuel tank by injecting water and emulsifier in the tank. Moreover, an automatic device sprayed foam in the diesel room. 15 min later this fuel tank started leaking from the vent and antipollution devices were installed. Some iridescence traces were observed an hour and a half later in the intake channel.

Again 20 min later smoke propagated through a technical gallery located between pump station and turbine hall and intruded into the turbine hall. Fire was declared extinguished one hour later.

The firefighting caused a fuel discharge by the fuel tank vent and the leaking fuel was pumped from the ground beneath the tank.

To avoid a recurrence of this event all identical motors have been checked to verify the fuel dilution in oil. High dilution rates have been encountered. As a result of the investigations a device for collecting the fuel discharged by the tank vent has been installed. Moreover, procedures for stopping the injection of water and foam in the fuel tank before complete filling have been provided.

5.1.3. Fire and consequential flooding

In total seven event combinations of fire and consequential flooding have been observed from the operating experience recorded in the FIRE Database [1]. In this context, it is notable that in the majority of events the water causing the flood came either from fire-extinguishing systems or from portable water-based fire brigade equipment.

In the following, two of these event combinations are outlined in more detail.

In the first case (event ID 82), the nuclear power plant was at full power operation, when a fire in the main turbine-generator group no. 2 was detected due to a failure in the corresponding turbine. The pipes of turbine lubrication oil were broken and hydrogen as coolant of the alternator was released.

As a consequence of the fire, several components were damaged (burned) as shown in Figure 6, including:

- Some electric power cables of the main auxiliary equipment necessary for the working of turbine driven fans no. 3 and 4,
- Some electric power cables of the pumps related with shutdown cooling system function,
- Pump motors related with component cooling system function; part of the control and regulation circuits (48 V),
- Different auxiliary components to the main turbine-generator groups no.1 and 2,
- Expanding compensatory joints placed before and after the condenser in the cooling water pipes.



Figure 6. Damages due to the fire in one of the event combinations of fire and consequential fire

The available analyses conclude that the root cause of the start of the incident was the opening of the meshing groove of wheel 8 of the high pressure disc. The break was caused by the formation of a crack of considerable size as a consequence of the appearance over a period of time of multiple fissures along the entire groove on both sides.

The appearance of this large crack at the level of the disc of high pressure wheel 8 provoked the detachment of a packet of blades, which caused a tremendous imbalance in the high pressure body, and which was transmitted throughout its length to the rest of the machine. This caused friction between rotor and stator in all sections of the turbine, particularly in the high pressure, with the consequential deformation of bearings by both axial and radial forces. This resulted in a break in the external lubrication tubes of the high pressure bearing in both its connections before and after the bearing and in the interior in the low pressure bearing, the shearing of three of the four steam admission pipes and the fracture of the expansion joint flanges between the high pressure and low pressure. All the above facts caused oil and hydrogen leakages representing the main combustibles in this fire.

The fire quickly affected the cable channels under the lower slab of the turbine generator and as a consequence of the leaking oil, which was directly feeding the fire, it spread rapidly to the rest of the installation along the cable channels, seriously affecting the compressed air network, and consequently a large part of the control functions.

One of the most important consequences of the fire which only affected the conventional area of the facility was the flooding of the reactor cavity. The root cause of the flood was the fire which affected the expanding compensatory joints placed before and after the condenser in the cooling water pipes, there subsequently being observed an orifice of approximately 0.06 m^2 at the entry, and another of 0.09 m^2 at the exit.

If one takes into account the flows of the circulatory pumps and postulate a velocity of 10 m/s through an orifice of 0.06 m^2 and with an adjusted restriction coefficient of 0.6, one obtains a volume of circulatory water of 2600 m^3 which poured out of the building during a time period of two hours.

As a direct consequence of the spillage, plus the leaks in certain demineralised water circuits caused by valves remaining open due to the lack of compressed air, as well as water used to put out the fire, the water dripped into the machine room located in the reactor cavity and in reached a level of about 80 cm. The high level reached by the water is explained by the fact that only two pumps with an extraction capacity of $60 \text{ m}^3/\text{h}$ remained, since the control power to other pumps had been cut by the fire.

There is no complete physical separation between the turbine building and the reactor cavity owing to the existence of several communicating doors which do not close hermetically. This is the reason why the water level in the reactor cavity reached the same level as that in the turbine building.

The only cause of the flood is that the fire affected the expanding compensatory joints placed before and after the condenser in the cooling water pipes. This is not generally considered in the fire analysis but should be taken into account.

After the event, the affected nuclear power plant was shut down and did not operate anymore. Therefore, corrective actions were not taken.

Another event (event ID 58) took place while a plant was under construction. In that phase, work was performed in order to repair some detectors. A station of the spray water deluge system was actuated in the room located just above the control room due to the presence of thick smoke from a ventilation unit. The fire started in the electrical heater unit of a vent unit in the room for ventilation. The smoke originated from the electrical heater having been overheated which resulted in a release of a large amount of smoke from the insulation material. The overheating was caused by a discrepancy between the real cable layers composition and the wiring diagrams resulting in a failure in disconnecting the power source from the electrical heater.

Seconds after the fire alarm signalled in the control room, water from the spray water deluge system in the room leaked into the control room below.

As soon as the cause of the fire protection system actuation had been identified, the spray water deluge system was stopped. During the time of system operation, approximately 10 m^3 of water were sprayed. As a result of this release of water, cabinets and racks of some systems got wet; however neither operational panels nor consoles were affected.

The water leakage to the control room was due to the fact that the mounting of cables between both elevations was still underway and, as a result of these activities, some penetrations were still open and others leaked as they were not completely installed.

As a result of the event, the licensee carried out a review of the cables that led to the failure in disconnecting the power source from the electrical heater, as well as a review of all the ventilation units similar to the one affected by the fire. Additionally, the regulatory body required a safety demonstration of the leak-tightness of the control room before reaching criticality.

As a conclusion, in all the cases, independently of the source of the flood, it can be observed that the floods have not been prevented due to one or more of the following reasons:

- Failure of seals or other protective measures resulting in leakages to other areas.
- Drain obstruction prior to the fire or apparently caused by some “fire products” or deficiency in the drain capacity.
- Existence of water escape routes having not been analysed.
- Fire leading to the failure of other pipes.

- The same equipment failure having caused the fire caused a pipe failure. The flooding resulted from the contributions of water from fire extinguishing and from other affected pipes.

One of the root causes of most of these event combinations is a lack of a specific analysis that takes into account the drainage system capacity, the failure of pipes originated by fires (for example in rubber expansion joints) and flood paths of the water used to extinguish the fires. It would be meaningful to analyse in detail during the design of the fire protection systems and before establishing fire management strategies the flood paths of the fire-extinguishing media.

5.1.4. Fire and consequential HEAF

One event (event ID 237) has been identified as combination of a plant internal fire with a consequential HEAF. This event occurred when the reactor was in shutdown mode because of refuelling as the first primary coolant pump was started up. Immediately, the alarms concerning the 6.6 kV AC normal distribution system's switchboard and the 6.6 kV AC normal distribution system's over-current defaults were signalled. A few minutes later fire alarms regarding three areas (7 m level, switchboard of trains A and B) started. After confirmation of the fire the fire-fighting team of the plant and the external fire brigade were called. The plant team tried to extinguish the fire with three CO₂ fire extinguishers which they finally achieved with the help of the external firemen using a dry chemical fire extinguisher.

The fire occurred due to the roller and cage assembly ensuring the electric mobile contact: the contact degradation led to a short circuit current in the circuit breaker and the oil vaporisation caused the cubicle's fire resulting in a HEAF destroying the breaker explosion like. In addition, fire doors were damaged by the blast. The 400 kV power supply became unavailable which caused a switch-over to the 225 kV power supply

In order to avoid a similar event a contact resistance measurement will be systematically performed after each maintenance inspection.

5.1.5. Event chains with fires and more than one consequential events

The most recent version of the FIRE Database [1] covers two event sequences where a fire induced a HEAF as consequential event which resulted in a consequential fire.

The Database contains one event sequence of low safety significance but interesting from the point of view that this was an event chain of an initial incipient fire resulting in HEAF with consequential fire. In this event case (event ID 59), a sequence of steps of the fire event can be observed: a smouldering fire started inside an electric cabinet causing an electric arc and a high energetic explosion like electrical failure (HEAF event) which finally resulted in a real fire.

The second example of this type of combination (event ID 94) occurred during power operation. Initially, the power measurement of one 6.6 kV house load switchgear indicated a faulty value and the personnel started to examine the reasons. Some damaged terminal blocks / overheated connections were detected in the secondary circuit of the current transformer. As the terminal block replacement was started, the equipment in the switchgear cubicle started to release smoke (see Figure 7) and the fire brigade was alerted. An electrician informed the main control room about the situation and all house load switchgears were connected to the 110 kV grid and shutdown of the plant was prepared.

Due to the smoke generated inside the switchgear cabinet an electric arc occurred and caused a fire. The overload protection device opened the circuit breaker feeding the switchgear. The plant transformer's overload protection tripped the generator relay protection, which led to a turbine trip. One diesel generator started up as designed and provided power to the associated safety related bus bar, which had lost normal power supply via the damaged 6.6 kV switchgear. Later on, the fire/smoke spread to the neighbouring cubicle containing the cable terminal from the start-up transformer (the breaker itself was opened due to the overload protection) and caused a short circuit by arcing: the differential protection device of the start-

up transformer opened all circuit breakers still supplying the 6.6 kV house load bus bars and also the breaker in the primary side of the start-up transformer, leading to total loss of supply from the grid. The turbine's condenser system was no longer available under these conditions resulting in the reactor scram. After loss of power supply from the grid, three additional diesel generators started and provided power to the safety related switchgears, as designed.

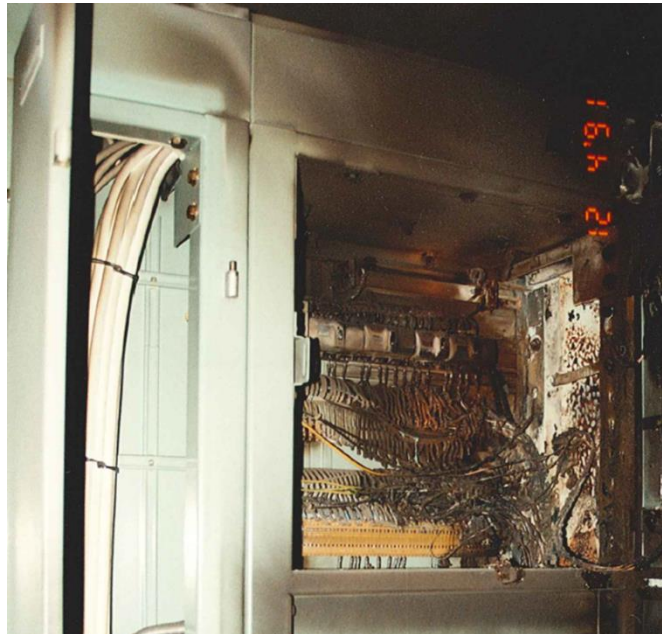


Figure 7. Component where the fire started in the event “fire and consequential HEAF”

The fire brigade extinguished the fire using manual extinguishers, within about 30 min. The extinguishing was hampered by the uncertainty about potential voltage inside the switchgear cubicles. Furthermore, the closed structure of the cubicles hampered extinguishing. Three cubicles were destroyed almost totally and one cubicle was destroyed partially (see Figure 7 above and Figure 8 to Figure 10 below).

Figure 8 shows the lower part of the 6 kV cubicles no. 2 and 3. Details regarding the holes are provided in Figure 9. The breaker for power supply from the plant transformer was located in the cubicle no. 2 (on the left side), which was destroyed by an electric arc and fire. Holes were created by the HEAF on both sides of the cubicle walls. The power supply cables coming from the start-up transformer to the switchgear are seen in the lower part of the cubicle no. 3 (on the right side).



Figure 8. Lower part of the 6 kV cubicles no. 2 and 3 damaged by fire and HEAF

Due to the failure of the component, a hole in the wall arose, which should separate the cubicles no. 1 and 2 (on the left) and no. 2 and 3 (on the right) as provided in Figure 9.



Figure 9. Damage of a fire with consequential HEAF: hole in the wall separating the cubicles no. 1 and 2 (left), the hole in the wall separating the cubicles no. 2 and 3 (right)

It can be observed from Figure 10, the other switchgears in the room (on the right side) did not suffer any damages. Only cleaning was needed before re-energising.



Figure 10. Switchgear room with damaged and undamaged switchgears

After the fire had been extinguished, efforts to regain external supply from the 110 kV to the three not affected 6.6 kV house load switchgears were started. Before regaining voltage, the failed bus bar had to be separated from the transformers by opening the terminals of the connecting cables at the transformers (the cable terminal was destroyed inside the ignited switchgear). This activity took approximately 6.5 h including cleaning of the one switchgear which was located in the same room with the ignited one. Then the two house load switchgears were re-connected to the 110 kV grid.

The following corrective actions were performed in that case after this event combination:

- The damaged switchgear cubicles and power supply cables coming from the transformers were replaced with new ones.
- The maintenance of switchgears was improved.
- A second start-up transformer was installed and disconnections were mounted in the supply connections to reduce vulnerability of the power supply from the start-up transformer.
- Fixed CO₂ extinguishing systems were installed at the switchgears. However, the fixed CO₂ extinguishing system is no longer present in the switchgears, because the switchgears have been equipped with electric arc relay protection systems.
- Separation walls between the switchgear cubicles were improved.
- The generator breaker was replaced.

5.2. Event and consequential fire

In general, the category of causally related event combinations of initial events and consequential fires may include nearly all types of events from external or internal hazards resulting in a consequential fire. This also covers chains of more than two events including fire at least as one of the consequential events. However, so far only very few of these event combinations have been reported to the FIRE Database [1] including the following types of combinations:

- explosion and consequential fire (see Table 6),
- HEAF and consequential fire (see Table 7),
- event chains of an initial internal hazard with consequential fire and subsequent internal hazard:
 - HEAF with consequential fire and subsequent flooding (see Table 8),,
 - missiles and consequential fire and subsequent flooding (see Table 9),
- event chains of an initial external hazard with consequential HEAF and subsequent fire:
 - earthquake with consequential HEAF and subsequent fire (see Table 10), and
 - weather induced event (rain) with consequential HEAF and subsequent fire (see Table 11).

HEAF events give the highest contribution to the category “event and consequential fire” with 28 records. Moreover, several of these events were more severe ones, a loss of safety trains occurred in case of eight event sequences. For 20 of the entire 31 event combinations involving HEAF in the event sequence a change of the plant operational mode from power operation was observed.

5.2.1. Explosion and consequential fire

Five events have been identified for this type of event combination. In all cases no safety train was lost. The majority of the initial explosions were hydrogen explosions.

In the example provided for this event combination (event ID 360) the affected NPP unit was operating at full power, while a periodic test of the fan and the recombiner of the containment building gas treatment system were carried out. The pressure gauge at the hydrogen supply line broke at the pressure of 200 bar when a new set of hydrogen cylinders was prepared for operation. The released hydrogen self-ignited (hydrogen explosion) and the personnel being present was mildly hurt by fragments of the measuring device. The personnel escaped and contacted the guard who manually actuated the fire alarm. The on-site fire brigade arrived 3 min later and isolated the area. The fire brigade got advice how to deal with the event from external organisations (e.g. hydrogen supplier).

Then the fire brigade prepared the closing of the hydrogen cylinder shut-off valves. A thermographic camera was used to analyse the flame height and to ensure the safety of the action needed at the hydrogen cylinders. The fire self-extinguished after closure of the hydrogen cylinder isolation valves.

The hydrogen station where the fire occurred contains two sets of hydrogen cylinders with 12 cylinders per set. The fire was limited to a small area, two measuring instruments failed after the fire.

As a result of the explosion and the consequential fire certain procedures were improved relating to the hydrogen station: a new procedure for replacement of hydrogen cylinders and procedures for ensuring personal safety. Moreover, the replacement of the hydrogen station has been initiated.

5.2.2. HEAF and consequential fire

As already explained, combinations of HEAF and consequential fire represent the highest contribution of event combinations with fires with 24 combinations of HEAF and fire only, one event sequence with additional subsequent flooding, three HEAF induced by external hazards (seismic, weather) with subsequent fire and two combinations of fire, consequential HEAF and subsequent fire. In 17 of the 24 HEAF with consequential fire event sequences the operational mode changed from full power to hot standby or shutdown mode respectively.

Figure 11 shows the distribution of components where the HEAF induced fires started. As one can see transformers (high voltage as well as low and medium voltage) represent the dominating component where the event combination started.

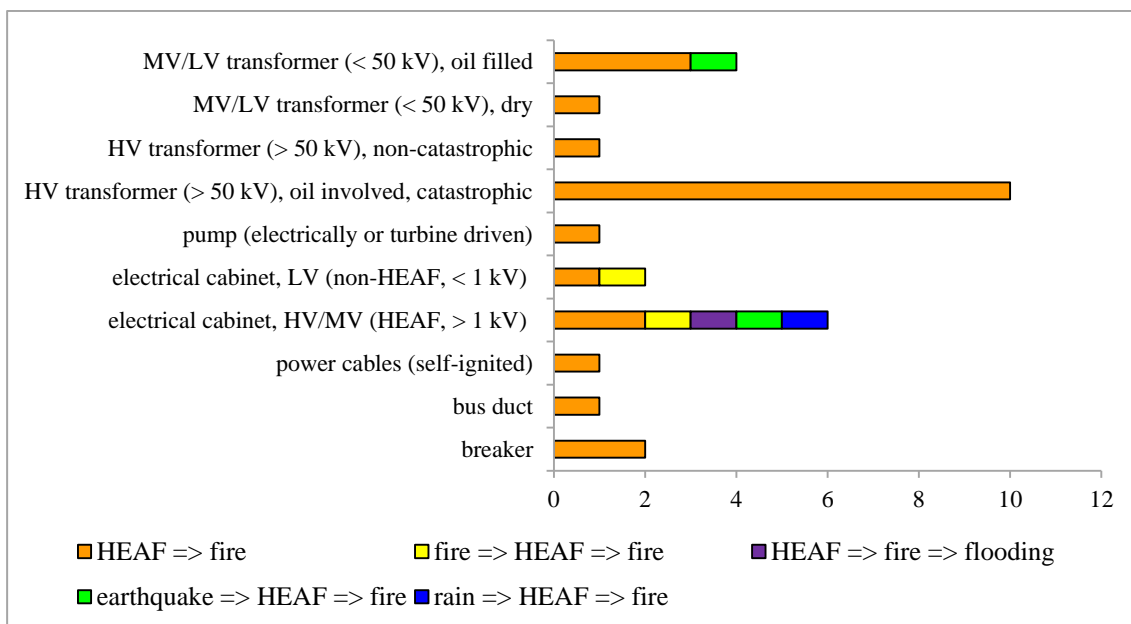


Figure 11. Event combinations involving HEAF and consequential fire- component where the fire started

In the first example discussed in more detail (event ID 400), a feeder cable to the 4 kV non-vital bus 5 failed. Specifically, the cable insulation on the feeder cable failed at the 4 kV bus 5 cabinet entry point. When the fault occurred, circuit breaker 52/24 did not clear the fault as expected, and the breaker remained closed for the duration of the event. The circuit breaker failed to open because of a mechanical flaw in the trip circuit fuse, which was intended to disable the control power to the trip circuit. Failure of the breaker to open led to internal damage to the unit auxiliary transformer (UAT) and a lockout of the UAT on fault pressure that caused the main generator lockout relay (86P) to operate.

The initial fault on the 4 kV bus 5 also resulted in electrical fires at the 4 kV bus 5 and at the breaker 52/24 on 4 kV bus 4 (see

Figure 12).



Figure 12. Damage at bus 5 (on the left) and 4

The fires were extinguished by fire brigade and security personnel using dry chemical fire extinguishers. Damage to the 4 kV bus 4 was initially limited to the 52/24 cubicle. Damage to 4 kV bus 5 was limited to the incoming line compartment along with the feeder cables. Moreover, the failure of a bus-tie breaker to open and isolate the fault resulted in a loss of power to reactor coolant pump (RCP) B and a subsequent reactor trip.

Subsequent to the reactor trip, an automatic safety injection actuation occurred due to an uncontrolled reactor coolant system (RCS) cool-down. Plant response was complicated by equipment malfunctions and failure of the operating crew to diagnose plant conditions and properly control the plant.

During plant restoration a relay was reset which re-initiated the electrical fault and caused a second fire and significant damage to surrounding equipment, including grounds on both safety related 125 V DC battery buses.

The event involved a number of equipment failures including:

- A feeder cable failure leads to an arc fault and initial fire causing the failure of the UAT and non-vital bus 5.
- Breaker 24 failed to open causing the loss of non-vital bus 4.
- Alternate charging valve CVC-310A opened due the Phase A containment isolation and air leaks within the valve. This caused seal injection flow to be diverted away from the RCP seals.
- The charging suction source failed to automatically switch over from the volume control tank to the refuelling water storage tank due to instrumentation failure.
- Operator action deficiencies also contributed to the complexity of the event:
 - Failed to control the RCS cool-down caused by the opening of the drain valves.
 - Failed (initially) to recognise the closure of component cooling water flow return valve from the RCPs.
 - Failed to recognise the RCP seal injection had become inadequate.
 - Failed (initially) to diagnose the failed charging suction switch over resulting in a loss of charging flow.

- After the plant was stabilised, operators re-initiated the electrical fault causing a second fire because they failed to understand the current status of the electrical system and failed to follow procedures.

Specific corrective actions in case of this event combination in particular included several procedure and process revisions and enhancements:

1. Implementing a procedure for monitoring and improving the performance of operations crews.
2. Revising a procedure for performance planning and monitoring to require organisational effectiveness reviews.
3. A suite of related corrective actions that, in general are designed to monitor and improve leadership skills and accountability among managers and supervisors.
4. Revising a procedure to ensure that crew and individual training performance evaluations are reviewed during shift management review meetings.
5. Revising procedures for simulator and remedial training to require complete evaluation and documentation of underlying performance deficiencies.
6. Revising processes to ensure effective use of the Corrective Action Programme.

This event combination also covers safety culture aspects (leadership evaluation, reconstitution of operating crews) and review of work processes and procedures.

In addition, as part of a larger procedure upgrade project, the licensee is converting certain emergency operating procedure flowcharts to a two column format that is recognised as an improved format for presenting complex event response procedures.

This event combination has been taken in [10] as a basis for discussing current limitations of probabilistic risk assessment (PRA):

“Perhaps the most obvious and unsettling observation from a PRA methodology point of view is that an event of this type is unlikely to survive probability-based screening of PRA. The large number of seemingly independent contributors would push the scenario to practically zero in a typical PRA. Additionally the event highlights some important human performance features that are not captured by the way human reliability assessments are done now. These include the fact that simulator training did not match actual plant response, emergency operating procedures were deficient in regards to verifying RCP seal injection, and command and control within the control room was poor. During the event crew supervisors were distracted from oversight of the plant including the awareness of major plant parameters. In addition, supervisors failed to properly manage the frequency and duration of crew updates/briefs during the early portion of the event leading to interruption in the implementation of emergency procedures and distraction the operators.”

Another example of this type of event combination is a fire event in the main transformer (event ID 71). The event combination started with a short circuit in the high voltage terminal (400 kV) due to an isolation failure between this terminal and the phase box. The corresponding high energy arcing event had immediate consequences. The box oil exploded and ejection and spillage of the box oil occurred.

The unit was at 100 % power when the main transformer that was installed outside caught fire (see Figure 13 and Figure 14). The area has got 3 h fire resistant rated walls at both sides because the affected transformer is located between two further transformers. Immediately after the transformer explosion, the turbine trip occurred due to protection actuation and, consequently, reactor trip. The response of plant systems was adequate, particularly transfers of electrical buses and start-up of diesel generator. The plant remained under control in hot stand-by. The fire protection system of the area was signalled as being activated in the control room. The control room manager ordered visual inspection of the

transformers area to the control room. As soon as the plant field operator had confirmed the fire, the on-site fire brigade was alerted and the external fire brigade co-operated with the on-site fire brigade and the operation personnel in the last phase of fire extinguishing. Some hot points of flames were also extinguished on the roof of the turbine building that is close to the transformer area, where oil had been ejected to after the transformer burst. The fire lasted only about one hour.

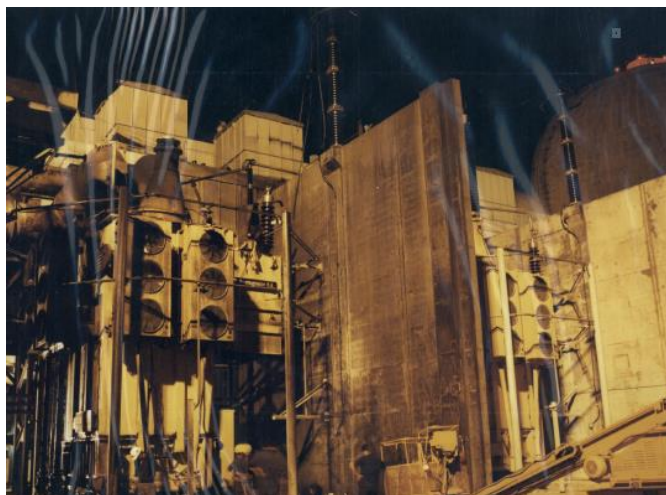


Figure 13. Damage of a transformer after HEAF and consequential fire



Figure 14. Damage due to fire

After the occurrence of similar events a thorough investigation was initiated in order to unveil the root cause of the failures. As a result, some screws, made of steel poor in carbon, were found to be employed to hold the wooden support pad of low voltage bus bar system as shown in Figure 15. The wooden supports in contact with the screws were carbonised. Calculations have shown that peak temperatures higher than 300 C may have been reached at some points of the screws, temperature high enough to degrade the wooden supports.



Figure 15. Screws of steel employed to hold the wooden support pad of low voltage bus bar system

At some time in the event sequence, the steel screws began to transmit the current, appearing as arcing between the low voltage coil windings. The rapid formation of gases caused the swelling of the oil box and the low voltage bus bar system. These gases were being collected but impossible to be drained by the Buchholz relay, leaving the high voltage terminal without dielectric material (poor conductor of electricity), triggering an arcing ground and bursting of the porcelain terminal.

In another example (event ID 290), the respective unit of the affected multi-unit plant site was at full power operation, when arcing occurred between the primary and the body of the oil-filled current transformer, which is located on the 400 kV platform at the principal transformer outlet. The internal electric arc set fire to the oil, the resulting gas formation increased the pressure in the transformer, leading to the cover ejection, and subsequent oil combustion caused fire. The fault at the voltage regulation of the alternator induced a turbine trip and an automatic reactor scram. The NPP was unavailable for a period of two weeks for repair.

The electric fault was detected by the 400 kV energy evacuation surveillance protections. By switching to the 225 kV power supply, the reactor state changed to shut down. According to this incident the unit was unavailable for two weeks and it might have hurt some people because of fire and ceramic fragments projectiles due to the explosion. The fire lasted about 45 min. It was extinguished by the shift personnel and the external fire brigade.

Following the incident, the ground area covered by oil had to be excavated, the three current transformers of the unit and a circuit breaker's pole had to be replaced, and the 24 kV coaxial skirts had to be repaired.

In order to avoid another similar incident, a control programme of the unit 1 transformers was implemented and the unit alternator voltage regulation was controlled. The transformer explosion is probably a precursor to PSA analysis.

Another example is an event combination at a multi-unit site with four reactor units (event ID 123). The respective unit was in full operation at that time. Again, a HEAF event with explosion followed by a fire occurred on the transformer which supplies house load of one plant during full power operation. The transformer failure caused an outage of the 400 kV power line with the subsequent unit transient. The unit was then powered from the reserve. Firefighting was performed by the on-site fire brigade. The probable cause was the fault of the power contacts of the branch switch of the transformer.

The high energy arcing fault was created before total short circuit. As a result, a large volume of gases was generated within a very short time period, which caused the explosion of the switch power part and subsequent rupture of the transformer vessel, ejection of oil in the adjacent area, and oil fire. The accident led to the discharge of approximately 32 t of oil from the collecting tank underneath the transformer and subsequently into the aeration channel and to the cable ducts. The transformer which was damaged by the explosion was replaced by a new one.

The fifth example (event ID 347) is an event combination which started with a short circuit, an electric arc and an explosion occurred, affecting voltage transformers connected to the 15 kV bus bars between generator and main transformer and the voltage transformer oil as well insulation material caught fire. Moreover, missiles resulting from the explosion were found 30 m away.

Refuelling outage of the unit was ongoing (cold shutdown). Therefore, the electric power was supplied via the reserve auxiliary transformer (110/6 kV). After the maintenance, the main transformer no. 2 was connected to the 400 kV grid; the auxiliary transformer no. 2 became energised as well. Approximately 30 s prior to this, several signals on shorts to ground came up and were gone during one second until the short to ground protection triggered. The short to ground protection aims to disconnect the main transformer only from the generator's side; it worked as designed. However, the generator breaker was not needed to be disconnected, as it was already in the open position. Further on, short to ground alarm and protection came up and went away during the next 2 min. Finally, the differential protection was actuated and the main transformer no. 2 was disconnected from the 400 kV grid, which also de-energised the auxiliary transformer no. 2. Disconnection of the main transformer generated an automatic fire warning and triggered an alarm for the on-site fire brigade.

One minute after the automatic alarm the fire brigade received a fire alarm from the plant's security centre. Plant personnel arriving to the site had notified the security centre on a fire near the auxiliary transformer. On arrival to the fire location 2 min later, the firemen noticed smoke and flames between the main and auxiliary transformer. The flames died out quickly and after assuring the main transformer was de-energised, the firemen extinguished a small oil pool fire using a portable CO₂ fire extinguisher. The extinguished fire was located on one of the three protective casings containing the voltage transformers below the generator bus bars (the bus bars' voltage level is about 15 kV), the fire occurred approximately 4 m above the ground level. The firemen isolated the area and protective foam was laid on the oil, which had leaked down on the yard (approximately 20 l). Some oil remained also inside the protective casings and it was absorbed.

Two out of the three voltage transformers had exploded and transformer oil as well as insulation material had caught fire. All three voltage transformers and part of the capacitors and overvoltage protectors located inside the protective casings were badly damaged. The protective casings made of thin steel plate suffered mechanical damages due to the explosion caused by an electric arc. Some smithereens of the insulators of the overvoltage protectors were found approximately 30 m away from the protective casings. The main and auxiliary transformers are located just a few metres away from the scene, but they were not damaged. No damages occurred due to smoke or secondary effects. The incident did not affect power supply of the unit, because a reserve auxiliary transformer was in use.

The cause for the incident was a human error during the maintenance outage (the ground wire was mounted erroneously in the voltage transformer of the phase R forming a short circuit in the secondary side of the voltage transformers, which caused overheating of the equipment and finally, a high voltage short circuit / electric arc / explosion occurred and the differential protection actuated). As corrective actions, procedures were modified accordingly and the importance of adequate post-maintenance inspections was highlighted. The area to be isolated around the main transformer was decided to be enlarged due to the smithereens being found 30 m away (this refers to the situation when the main transformer is to be energised after maintenance).

There are two main transformers and two auxiliary transformers per unit located on the yard next to the turbine building. These are equipped with an automatically actuated fixed water extinguishing system. However, the location of the failed components and fire is not covered by any fire detection or fire-extinguishing system.

Another HEAF event (event ID 354) occurred when an automatic reactor trip occurred due to a turbine-generator trip as a result of a fault on one main transformer. All control rods fully inserted and all required safety systems functioned properly. The plant was stabilised in hot stand-by with decay heat being removed by the main condenser. There was no radiation release. The emergency diesel generators did not start as adequate offsite power remained available. Two of three 138 kV offsite power substation feeders tripped as a result of the event. The auxiliary feed water system automatically started as expected due to steam generator low level from shrink effect. Control room operators were notified of a fire at the main transformer with the fire protection deluge system actuated. The plant fire brigade responded to the fire and applied foam; the fire was extinguished within 12 min.

The control room was notified approximately 20 min later that a visible explosion had previously occurred. The direct cause of the reactor trip was due to the actuation of the relays that sensed a fault from the failure of main transformer 345 kV phase B bushing. The most probable cause was a design weakness associated with the type bushing used in the Phase B bushing. Significant corrective actions included replacement of the affected main transformer, and inspection, repair and replacement of damaged components as required associated with the second main transformer, the UAT, and high voltage components.

The most probable cause was a design weakness associated with condenser type high voltage bushings used in Phase B whose design develops problems affecting dielectric insulation. Documented design weaknesses included:

1. design flaw where gaps existed at the ends of the internal insulation paper/core allowing for the formation of gas bubbles leading to partial discharge and increased dielectric losses,
2. the bushing condenser design incorporated alternate paper layers printed and plain where the ink developed capacitance properties allowing for voltage tracking across the paper causing corona action and burning,
3. the bushing flex seal design for thermal cycling would move and crack resulting in compromise of the seal, and
4. age of the phase B bushing which was an original early design with 30 years of operation.

Another HEAF event to be reported in more detail (event ID 430) occurred when a unit was operating at 47 % power a refuelling outage (start-up-mode). The control room received multiple unexpected alarms, including turbine trip, main transformer differential protection generator trip, unit station service transformer BV-TR-1C fire, and turbine room fire. The generator tripped on "BV-TR-1C" transformer differential protection. The reactor operator manually tripped the reactor due to the receipt of these multiple unexpected alarms. An automatic reactor trip signal was not generated nor expected to be generated because the reactor was operating at a power level less than the turbine trip.

Reports from the fire brigade declared that an explosion had occurred in a cable tray in the turbine building mezzanine. A cable failure had occurred in the turbine building mezzanine level where the 4 KV bus supply cables pass through the wall into the service building to the electrical switchgear room. The failure resulted in an arc flash (explosion) and fire in the "B" 4 kV bus supply cabling causing catastrophic failure of the cables and significant damage to adjacent bus cabling. The fire protection deluge system activated and suppressed the fire. The operational mode due to the fire changed to hot stand-by.

An investigation has determined that the B" 4 kV bus supply cables faulted an arc flash and fire. The cables experienced a diminished service life due to long term ohmic heating within the cable tray enclose.

The heating occurred because these cables are normally in service and loaded. The cable monitoring programme was not effective in identifying the degradation.

The PRA risk associated with this event is modelled as a turbine trip and subsequent reactor trip. The plant risk associated with the turbine trip and subsequent reactor trip due to the 4 kV bus supply cable fault, explosion, and fire in the turbine building mezzanine is considered to be very low. This is based on the conditional core damage probability and conditional large early release probability for this event when considering the actual plant conditions that were present at the time of the event.

The following corrective actions have been taken:

- A visual examination of the accessible portions of the Unit 1 offsite 4 kV bus supply cables was performed. These cables did not exhibit the degradation noted on the failed on-site supply cables.
- Thermography inspections of the Unit 1 offsite supply cables were performed. Temperatures were consistent along their entire length. No hot spots were identified on any of the cables surveyed.
- The Unit 1 on-site 4 kV bus supply cables will be replaced under an engineering change package (ECP).
- The Unit 1 offsite, Unit 2 offsite and Unit 2 on-site 4 kV bus supply cables will have additional inspections performed for signs of cable degradation or ageing.
- The results of laboratory inspection and testing of the failed cables will be reviewed and documented in the corrective action programme.
- The cable management programme will be revised based on lessons learnt from this event and mitigating strategies will be implemented in the interim.

Completion of the above and other corrective actions is being tracked through the BVPS corrective action programme.

In the last example in the context of HEAF and consequential fire (event ID 68), a current-to-voltage transducer (instrument transducer) on the high voltage side of the 220 kV generator transformer failed according to an arc. The plant unit was under shutdown conditions because of the annual outage. The 380 kV main connection line to the 3external grid was disconnected. Energy supply was provided via the 220 kV back-up connection. High energy arcing caused an explosive fault of the 220 kV current-to-voltage transducer in the switchyard. The ionisation and ejected particles caused damage to various electrical equipment. The instrument transducer was destroyed and the spouting oil (100 to 200 l) caught fire.

The part of the affected 380 KV line to the external grid routed approximately 5 to 6 m above the faulty transducer in the switchyard was ionised causing a short circuit. According to the short circuit the line was taken from the grid.

The event was immediately signalled in the unit control room and the on-site plant fire brigade was called directly after the alarm. Three fire brigade members started to fight the fire with portable extinguishers (dry chemical). Later on, additional fire fighters (in total 22) were involved suppressing successfully the fire by keeping the component, where the fire restarted again and again, covered by foam.

Because of the failure of the instrument transducer the 220 kV line was disconnected in the switchyard (breaker opening). As a result, the auxiliary transformer lost voltage and the unit experienced a loss of offsite power. Three of the unit's diesel generators started as designed, one was out of service for maintenance. The failed converter is also integrated in the protection of the 220 kV generator transformer of the other unit (differential protection) resulting in the loss of offsite power at the second unit, too. The main coolant pumps tripped and a reactor scram was initiated automatically.

The cause for the loss of the last connection to the 380 kV grid was arcing between the phases R and S of this line resulting from the original HEAF and explosive destruction of the transducer.

After localisation of the failure and isolation of the faulty line, the 220 kV line was re-energised after approximately 30 min, the diesels were subsequently taken out of service. The 380 kV main grid was re-connected to the unit after 90 min. The 220 kV line of the unit to the 220 kV grid remained out of service until repair work on the line had been finished.

More information on this type of events is provided in [2].

5.2.3. Event chains with fires as a consequential event

In the following, some examples of event chains involving more than one consequential event including fire as contained in the FIRE Database [1] are outlined.

5.2.3.1. HEAF with consequential fire and subsequent flooding

In the recent version of the FIRE Database [1] one event (event ID 171) was identified representing an event chain of HEAF with consequential fire and subsequent internal flooding. An electrical fault occurred at the 380 V emergency supplied distribution system in the circulating water pumping station. The over-current caused a HEAF at the train A 6.6 kV normal distribution system (busbar LGA) in the electrical cabinet room at the level four of the electrical building as well as a melt of the sprinkler head in a cable room in the level three of the electrical building, which caused an internal flooding in the levels below.

Lessons learnt from this event combination were: a common cause failure could initiate two simultaneous electric faults resulting in two fires starting in different remote areas. Therefore, as corrective action, a procedure has been established to cope with cases of several simultaneous fires starting in different areas. This procedure has been implemented at various nuclear power plants and is seen as a good practice to efficiently prevent events developing to such event sequences (as well as the event of two independent fires) in the future.

5.2.3.2. Missiles with consequential fire and subsequent flooding

There is one example of this type of event combination (event ID 10) in the FIRE Database [1], an initial missile having occurred at a turbine with resulting fire and reactor trip due to a generator break-down which finally resulted in internal flooding.

A metal ring around the generator rotor cracked, most probably due to stress corrosion. The break-down caused imbalance and heavy vibrations in the generator. The generator was totally destroyed and, as a consequence, the generator break-down generated missiles inside the turbine building. Turbine trip occurred immediately. The reactor was also tripped on signal indicating heavy vibrations in the oil lubrication system.

The break-down also generated projectiles (missiles) of loosened parts. The missiles damaged both the bearing/gasket oil pipes as well as the water sprinkler system. The loss of lubricating oil in the turbine very quickly caused temperature increase due to metal-metal friction.

Oil leaked from the turbine and was ignited when hitting hot surfaces. Water from the affected sprinkler system helped the oil to float the oil leaked also on the sprinkler water on the turbine floor, forming oil pools which contributed to the spreading of the fire. The water spread over large parts of the floor in the turbine building and therefore also to widely spreading the fire.

This observation demonstrates the significance of passive flooding barriers and of the availability of means to divert leaked (oil) in a controlled manner to other areas. Moreover it shows that a fire can be controlled and prevented from spreading to other areas.

5.2.3.3. *Earthquake with consequential HEAF and subsequent fire*

Earthquake with consequential events, such as HEAF or fires, or HEAF and resulting fire are well-known hazard combinations. However, in the FIRE Database [1] only the latter, fire events resulting indirectly from the earthquake induced by a HEAF have been recorded so far.

Two examples of this type of event combination can be found in the FIRE Database. In both cases a sequence of steps of the fire event can be observed for the combination of an earthquake and consequential fire. Not surprisingly the earthquakes have caused high energy arcing faults which resulted in a fire. Corrective actions have been plant specifically taken, e.g., plant-specific design modifications and, in one case, providing an additional fire engine (chemical) and full time operators for this fire engine.

In the first case (event ID 361), an earthquake occurred and the reactor was automatically tripped from full power to shut down mode by high seismic acceleration signal prior to the fire, and was cooled down to the cold-shutdown mode without suffering any effects from the fire. The fire started at the (main) station transformer (see Figure 16.) installed outside buildings on the plant site and isolated from other components by a fire wall. The damaged transformer is shown in



Figure 17.



Figure 16. Seismically and HEAF induced fire at a station transformer



Figure 17. Damaged transformer after the fire

The ignition mechanism was the electrical arcing between the bushing and the bus duct igniting the insulation oil leaking from the transformer to the bus duct. The analysis of the current and voltage records of the generator circuit revealed that the arc discharge was caused by the three-phase short circuit due to the contact of the bushing terminal contactor with the secondary side of the bus duct, which failed due to the large scale seismic motion (see Figure 18).

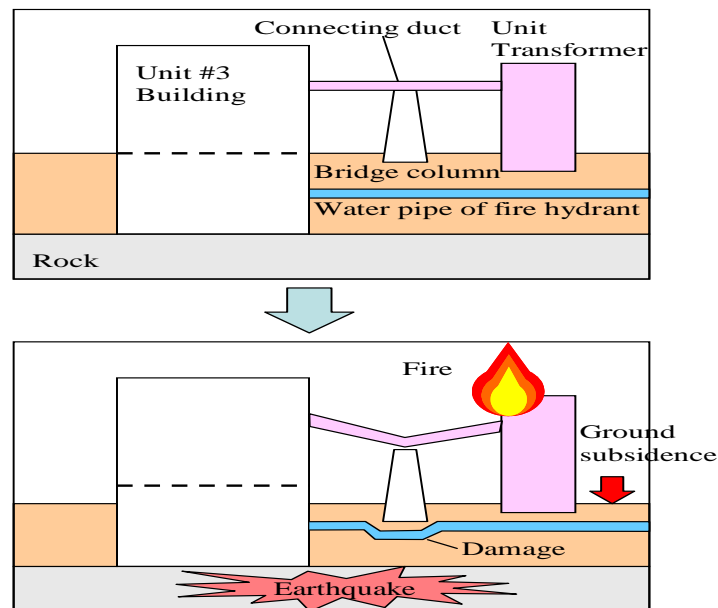


Figure 18. Earthquake first causing a HEAF resulting in a consequential fire

The fuel involved was insulation oil leaked from the transformer. The transformer contained about 17 m³ of insulation oil during normal operation. The fire was detected by post-earthquake patrol of plant personnel. The fire was extinguished by pouring chemical hydrate from the regional fire engine because the underground water pipes to the hydrants were broken by the seismic ground motion and could not deliver enough water (see Figure 19).

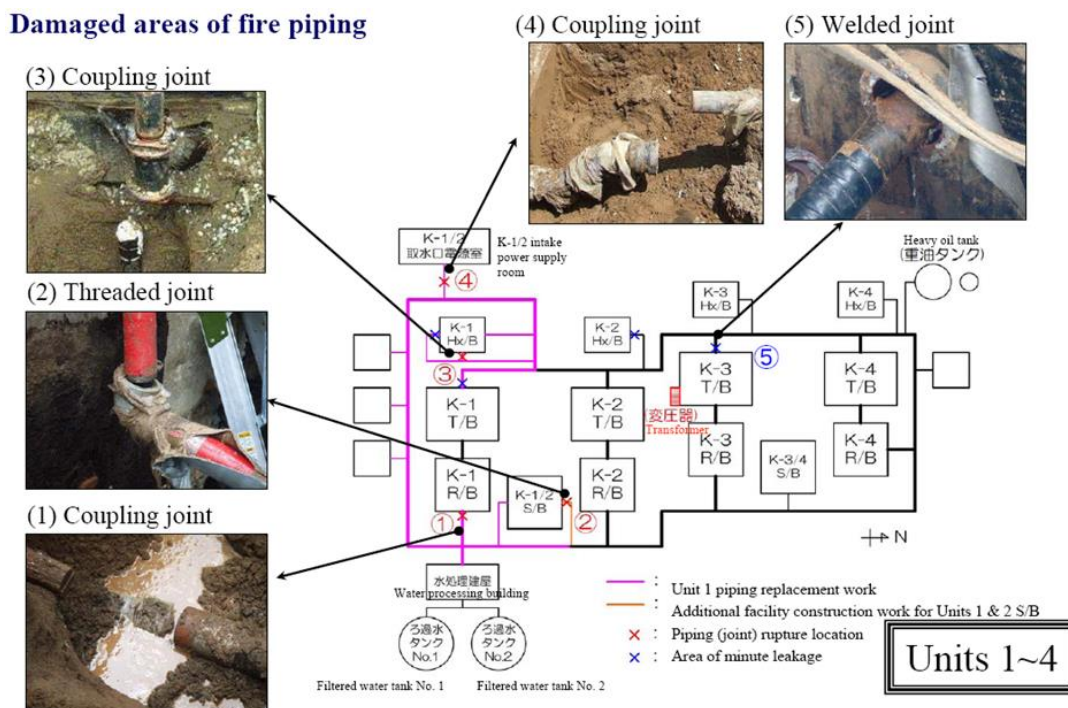


Figure 19. Damage of the water pipes to hydrants

In case of the second event (event ID 410), the earthquake caused an arcing fault in two of the non-emergency switchgear cabinets No. 7 and No. 8 (see Figure 20). The cabinet was installed in the underground floor of the turbine building.



Figure 20. Electric cabinet with the sector on the left where the fire started

In this switchgear cabinet, all ten units were completely damaged by the fire. Cabinet No. 8 (see the third cabinet from the left in Figure 21.) was mostly damaged because high energy gas in the section where the fire started could propagate to other sections through the penetration of control cable bundle (control duct – Figure 22.) located at the upper portion of the cabinet. Moreover, jackets and insulators of cables above the cabinet were also affected by the fire.



Figure 21. The ten connected cabinets with damage after the event



Figure 22. Damage after the event in the control duct

Prior to the earthquake, the plant was at full power operation, it was automatically shut down due to the signal of high seismic acceleration.

The cause of the event combination was presumed to be a suspended breaker inside the high-voltage power distribution panel that had swung widely due to the seismic vibration and damaged the disconnecting parts of the pertinent breaker, resulting in the short circuit and such like by touching the surrounding structures inside the high voltage power distribution panel. Subsequently, the cable insulation coating inside the high voltage power distribution panel melted because of the heat induced by arc discharge and smoke was emitted.

The fire was detected by an optical fire detector, although the on-site fire brigade could not identify the fire location due to heavy smoke at first. Therefore, they actuated the fixed carbon dioxide extinguishing system (main oil tank room, EHC (*electro-hydraulic controller*) system, control oil unit room, exciter room) after instructing operators to evacuate from the turbine building and confirming that evacuation had been completed. As a precautionary measure, the hydrogen gas used for the generator was replaced by nitrogen gas.

Additionally, the public external fire brigade was called which was not able to support the on-site fire brigade because of damage of the access ways to the site by the earthquake and tsunami.

As a result of the event combination one safety train was lost. The fire duration was nearly eight hours, one of the highest fire durations observed from events in the recent version of the FIRE Database [1].

5.2.3.4. Weather (rain) induced event with consequential HEAF and subsequent fire

One event of extreme weather conditions causing HEAF and consequential fire (event ID 46) has been found in the FIRE Database [1]. Even if this event sequence with more than one consequential event represents only a negligible contribution to the total number of event combinations studied in this Topical Report, some lessons could be learned from this combination. The event sequence was as follows: rain water penetrated through the gap of a cable duct located at the outside of the turbine building. The rain water intrusion seems to be caused by a typhoon. The water caused a HEAF in the 6.9 kV bus leading to a fire in the electric equipment room. This room was filled with smoke. The fire was observed at the upper part of the 6.9 kV switchgear cabinet. As corrective actions, fire-proof seals and drain functions were installed at the cable duct. Moreover, cables with fire retardant insulation materials will be used.

It is known that other events resulting from rain water coming through building ceilings have occurred in NPP of at least one other member country. These events have not caused a fire and for this reason are not included in the FIRE Database [1]; however they could have had the potential to lead to the same combination of events. However, these events have been a trigger to really take care of such unlikely situations and resulted in some preventive actions taken in all NPP of the country to avoid this type of events in the future. In at least one of these not reported events rain water coming from the turbine building ceiling also affected the 6.9 kV bus of a nuclear power plant (but no fire was induced due to a prompt actuation). Corrective actions consisted in repairing the ceiling and, in addition, in installing a kind of roof that covers the 6.9 kV bus. This type of cover was extended to other important electrical equipment that could be potentially affected by this type of failure.

5.3. Fire and independent event

5.3.1. External flooding and independent event

Up to the time being, the FIRE Database [1] contains only one example of a fire and an independently, but simultaneously occurring event (event ID 413) - in this case an external flooding (see Figure 23). At the time when the internal fire started, the plant was in cold shutdown and had already reported the impacts of the flood.



Figure 23. External flooding situation of the plant affected by simultaneous flooding and fire

The fire occurred in electrical switchgear that distributes power to vital systems and components needed for the safe shutdown of the plant. This fire affected two independent trains of the system.

The fire started in a replacement electrical breaker that was modified to fit inside the existing electrical switchgear. The replacement breaker was installed and in service for about 18 months before the fire occurred.

Licensee fire brigade personnel as well as personnel of the local fire department responded to the fire. The fire was extinguished after 40 min. The fire resulted in a loss of power to six of nine safety related 480 V AC buses and two of four safety related 4160 V AC buses leading to the complete loss of the spent fuel pool cooling function for approximately 90 min, resulting in a 3 °C temperature rise in the pool. This could have resulted in the loss of a safety function or multiple failures in systems used to mitigate an event in case the event would have occurred at power.

As a cause for the event poor alignment between electrical components and inadequate cleaning of the connections (hardened grease at the interface) has been identified, which increased the electrical resistance at their junction. These conditions created a build-up of heat that caused a fire affecting one train; electrically conductive soot and smoke spread past a barrier and tripped the breaker on the opposing train. This electrical fault resulted in the above explained loss of spent fuel pool cooling.

An analysis has been performed to calculate the change in core damage frequency for each postulated fire at a breaker. The sum of the change in core damage frequencies (CDF), $2.7 \cdot 10^{-5}$ per reactor year, is the best estimation of the fire-induced risk for single fire scenarios caused by the subject performance deficiency. The change in CDF for each of the postulated fire combinations has been calculated. The sum of the change in CDF, $8.1 \cdot 10^{-5}$ per reactor year, is the best estimation of the fire-induced risk for multiple fire scenarios caused by the subject performance deficiency. This represents the risk from common cause failures of the subject breaker cubicles. Although there is some overlap in the quantification of single and multiple fires, the analyst determined that this dependence was negligible in the final result. The sum of the fire-induced change in CDF is $1.1 \cdot 10^{-4}$ per reactor year.

This combination of events shows the need to be aware of the possibility of a fire and an independently occurring event. In case of the external flooding the accessibility of the plant even under such extreme circumstances is necessary and should be assessed within PSA to ensure technical support from outside, in this case by the local fire department.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. General conclusions

Forty-seven out of 448 fire events have been identified as event combinations of fires and other events in the recent version of the NEA Fire Incidents Records Exchange (FIRE) Project Database [1]. This contribution is non-negligible. In nearly all member countries (as shown in Appendix A) national regulations/recommendations addressing event combinations of fires and other events and how to manage them are already in force or under development.

Notably, 24 out of 47 events combinations are fires consequential to HEAF. Thus, HEAF events resulting in fires are the most important contributors to event combinations, among them HEAF at transformers and at electrical cabinets representing the highest contributions.

The FIRE Database [1] contains in total 31 HEAF events, 24 of these HEAF events have led to consequential fires; one further HEAF event resulted from an initial fire. Two HEAF events resulted from earthquakes and one HEAF resulted from impact of heavy rain. The entire fire events correlated to HEAF are presented in the set of event combinations. A majority of such correlations of HEAF and fire have resulted in more severe consequences and a change of the plant operational mode. One of the lessons learnt from this result is that HEAF phenomena were not well known when a majority of the existing nuclear power plants (NPP) were designed. According to the recent insights safety improvements to adequately consider potential HEAF events in the design and operation of nuclear installations are needed.

The experience from event combinations recorded in the FIRE Database also indicates that only a few explosions caused a consequential fire and that most of these did not cause a change in the plant operational mode indicating that the plant design against internal explosions has already considered the possibility of such consequential fires.

Seven out of 46 fire events in the recent FIRE Database version [1] resulted in an internal flooding. In most of the cases the flooding was due to fire-extinguishing activities. The non-negligible contribution of event combinations finally resulting in subsequent internal flooding events indicates that some improvements may be possible in the plant design regarding the protection against fire and consequential flooding.

One example of a fire and a simultaneously occurring event independently of the fire has been observed from the FIRE Database underlining that such combinations are not only academic assumptions even if the probability of such an event combination is low.

Five event sequences show a domino effect: fire with consequential HEAF causing another fire, missiles causing a fire resulting in subsequent flooding, two event sequences with seismically induced HEAF and subsequent fires, and, last but not least, rain causing HEAF and subsequent fire.

It has also to be mentioned that none of event combinations observed in the FIRE Database resulted in a loss of all safety trains. Moreover, they were limited to one plant unit in case of multi-unit sites. However, this may result from the fact that a majority of the event records in the Database represent events without safety significance and that passive fire protection means in the most cases ensure that fires occurring inside buildings are at least limited to the building.

One general conclusion is that event combinations of events from internal as well as external hazards with fires need to be more systematically analysed. Moreover, they should be addressed in the site-specific plant design. This was also one of the lessons learnt from the post-Fukushima reactor accident analyses. The investigations of FIRE Database carried out in this Topical Report clearly underpin this lesson learned.

6.2. Recommendations

The following recommendations can be derived from the investigations carried out for this Topical Report:

The operating experience has provided some essential insights from which improvements can be derived. Equipment failures representing at least one of the root causes in nearly all event combinations involving HEAF and fire indicate that the prevention of such high energetic arcs should be improved. Based on the number of event combinations of HEAF and fire and their at least partly more severe consequences, prevention of the HEAF has been recognised to be highly important.

Further analyses of the failure mechanisms as well as corresponding improvements in the plants are needed. The results of the ongoing experimental NEA HEAF Project “Joan of Arc” are expected to provide further support in this direction. As an already implemented practical example of plant-specific improvements with respect to HEAF prevention, switchgears can be provided with arc protection systems to minimise equipment damage due to potential arcing faults and to ensure the safety of the plant and its personnel. Moreover, the consequences of event combinations involving HEAF and fire need further investigations which may result in plant modifications including improved procedures in the future.

While combinations of a majority of internal hazards and those external hazards not exceeding the design basis have already been accounted for in the plant fire safety concepts and are also addressed in the regulations of several Project member countries, some consequences of fires, in particular flooding from extinguishing activities may warrant a more systematic consideration. In this context, it might be meaningful to analyse in detail the potential secondary effects from fire-extinguishing media during the design of the fire protection features and before establishing fire management strategies.

In addition, the in-depth investigation of event combinations of fires and other events has clearly demonstrated that some improvements in the Database, particularly for statistical use, but also for consistency in coding and a harmonised understanding of complex event scenarios is needed (e.g. regarding the consideration of fire spread or consequential fire). The already identified potential improvements will be implemented in the next version of the Database to be distributed in the first year of the Phase Five of the FIRE Database Project.

REFERENCES

- [1] Organisation for Economic Cooperation and Development (OECD) Nuclear Energy Agency (NEA) Committee on the Safety of Nuclear Installations (CSNI): *OECD FIRE Database, OECD FIRE DB 2014:1*, Paris, France, August 2015.
- [2] Organisation for Economic Co-operation and Development (OECD) Nuclear Energy Agency (NEA), Committee on the Safety of Nuclear Installations (CSNI): *OECD FIRE Project - Topical Report No. 1, Analysis of High Energy Arcing Fault (HEAF) Fire Events*, NEA/CSNI/R(2013)6, Paris, France, June 2013, www.oecd-nea.org/documents/2013/sin/csni-r2013-6.pdf.
- [3] Organisation for Economic Co-operation and Development (OECD) Nuclear Energy Agency (NEA), Committee on the Safety of Nuclear Installations (CSNI): *OECD FIRE Project - Topical Report No. 2, Fire Specific Regulations on OECD FIRE Member Countries*, Paris, France, draft.
- [4] Organisation for Economic Co-operation and Development (OECD) Nuclear Energy Agency (NEA), Committee on the Safety of Nuclear Installations (CSNI): *FIRE Project Report: Collection and Analysis of Fire Events (2010-2013) – Extensions in the Database and Applications*, NEA/CSNI/R(2015)14, Paris, France, 2015, www.oecd-nea.org/nsd/docs/2015/csni-r2015-14.pdf.
- [5] Darbra, R. M., A. Palacios, J. Casal: *Domino effect in chemical accidents: main features and accident sequences*, Journal of Hazardous Materials Volume 183 (1-3), pp. 565-73, November 2010.
- [6] Hemmatian, B., B. Abdolhamidzadeh, R. M. Darbra, J. Casal: *The significance of domino effect in chemical accidents*, Journal of Loss Prevention in the Process Industries, Volume 29, pp. 30–38, May 2014.
- [7] Khakzad, N., F. Khan, P. Amyotte, V. Cozzani: *Domino effect analysis using Bayesian networks*, Risk Analysis, Vol. 33, No. 2, pp. 292–306, 2013.
- [8] International Atomic Energy Agency (IAEA): *Safety of Nuclear Power Plants: Design, Specific Safety Requirements*, IAEA Safety Standards Series No. SSR-2/1, Vienna, January 2012, www-pub.iaea.org/MTCD/publications/PDF/Pub1534_web.pdf.
- [9] International Atomic Energy Agency (IAEA), *Development and Application of Level 1 Probabilistic Safety Assessment for Nuclear Power Plants*, IAEA Safety Standards Series No. SSG-3, STI/PUB/1430, ISBN 978-92-0-114509-3, Vienna, Austria, April 2010, www-pub.iaea.org/MTCD/publications/PDF/Pub1430_web.pdf.
- [10] Mosleh, A.: *PRA: A perspective on strengths, current limitations, and possible improvements*, Nuclear Engineering and Technology, Vol. 46, No. 1, February 2014.
- [11] Canadian Nuclear Safety Commission (CNSC): *Design of Reactor Facilities: Nuclear Power Plants*, REGDOC-2.5.2, May 2014, <https://cnsccsn.gc.ca/eng/acts-and-regulations/regulatory-documents/history/regdoc2-5-2.cfm>.
- [12] Canadian Nuclear Safety Commission (CNSC): *Deterministic Safety Analysis*, REGDOC-2.4.1, May 2014, <https://cnsccsn.gc.ca/eng/acts-and-regulations/regulatory-documents/history/regdoc2-4-1.cfm>.

- [13] Canadian Nuclear Safety Commission (CNSC): *Probabilistic Safety Assessment (PSA) for Nuclear Power Plants*, REGDOC-2.4.2, May 2014, <https://cnsccsn.gc.ca/eng/acts-and-regulations/regulatory-documents/history/regdoc2-4-2.cfm>.
- [14] Canadian Centre for Occupational Health and Safety: *Fire protection for nuclear power plants*, CSA N293-12, 2012.
- [15] P002h - Fires, Operational Procedure for NPP Dukovany, Revision V05, CEZ a.s., 2012.
- [16] P003h – Liquidation of Emergency Conditions, Operational Procedure for NPP Dukovany, Revision V01, CEZ a.s., 2004.
- [17] Government Decree on the Safety of Nuclear Power Plants 717/2013, www.finlex.fi/en/laki/kaannokset/2013/en20130717.pdf.
- [18] Safety design of a nuclear power plant, STUK Guide YVL B.1, www.finlex.fi/data/normit/41774-YVL_B.1e.pdf.
- [19] Provisions for Internal and External Hazards at a Nuclear Facility, STUK Guide YVL B.7, www.finlex.fi/data/normit/41791-YVL_B.7e.pdf.
- [20] Fire Protection at a Nuclear Facility, STUK Guide YVL B.8, www.finlex.fi/data/normit/41792-YVL_B.8e.pdf.
- [21] Probabilistic Risk Assessment and Risk Management of a Nuclear Power Plant, STUK Guide YVL A.7, www.finlex.fi/data/normit/41813-YVL_A.7e.pdf.
- [22] ETC-F, *EPR Technical Codes for Fire Protection*, Edition 2013, www.afcen.com/en/publications/etc-f.
- [23] Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, *Safety Requirements for Nuclear Power Plants*, as amended and published on November 22, 2012 and revised version of March 3, 2015, www.bfs.de/SharedDocs/Downloads/BfS/EN/hns/a1-english/A1-03-15-SiAnf.pdf.
- [24] Nuclear Safety Standards Commission (KTA, German for Kerntechnischer Ausschuss): *Fire Protection in Nuclear Power Plants, Part 1: Basic Requirements*, KTA 2101.1, Safety Standards of the Nuclear Safety Standards Commission (KTA), 2015-09, draft for approval by KTA General Assembly, September 2015.
- [25] Nuclear Safety Standards Commission (KTA, German for: Kerntechnischer Ausschuss): *Explosion Protection in Nuclear Power Plants with Light Water Reactors (General and Case-specific Requirements)*, KTA 2103, Safety Standards of the Nuclear Safety Standards Commission (KTA), 2015-09, draft for approval by KTA General Assembly, September 2015.
- [26] Nuclear Safety Standards Commission (KTA, German for: Kerntechnischer Ausschuss): *Design of Nuclear Power Plants against Seismic Events; Part 1: Principles*, KTA 2201.1, Safety Standards of the Nuclear Safety Standards Commission (KTA), 2011–11, www.kta-gs.de/e/standards/2200/2201_1_engl_2011_11.pdf.
- [27] Nuclear Safety Standards Commission (KTA, German for: Kerntechnischer Ausschuss): *Design of Nuclear Power Plants against Damaging Effects from Lightning*; KTA 2206, Safety Standards of the Nuclear Safety Standards Commission (KTA), 2009–11, www-pub.iaea.org/MTCD/publications/PDF/Pub1186_web.pdf<http://www.kta-gs.de/>.
- [28] Nuclear Regulation Authority (NRA): *Standard for the Examination of Practical Power Generation Nuclear Reactors and Associated Facilities Regarding their Fire Protection*, NUCREGTEC1306195, June 2013 (only Japanese).

- [29] Nuclear Regulation Authority (NRA): *Guide for Evaluating the Effects of External Fires at Nuclear Power Stations*, NUCREGTEC13061912, June 2013 (only Japanese)
- [30] International Atomic Energy Agency (IAEA): *Protection against Internal Fires and Explosions in the Design of Nuclear Power Plants*, Safety Guide No. NS-G-1.7, Vienna, Austria, 2004, www-pub.iaea.org/MTCD/publications/PDF/Pub1186_web.pdf.
- [31] Nuclear Safety Standards Commission (KTA, German for: Kerntechnischer Ausschuss): *Fire Protection in Nuclear Power Plants, Part 1: Basic Requirements KTA 2101.1 (12/2000)*, Safety Standards of the Nuclear Safety Standards Commission (KTA), December 2000, www.kta-gs.de/e/standards/2100/2101_1e.pdf.
- [32] Nuclear Safety Standards Commission (KTA, German for: Kerntechnischer Ausschuss): *Explosion Protection in Nuclear Power Plants with Light Water Reactors (General and Case-specific Requirements)*, KTA 2103 (12/2000), Safety Standards of the Nuclear Safety Standards Commission (KTA), December 2000, www.kta-gs.de/e/standards/2100/2103e.pdf.
- [33] Dutch Safety Requirements for Nuclear Reactors: *Fundamental Safety Requirements*, 19.03.2015, www.oecd-nea.org/nsd/docs/2015/csni-r2015-15.pdf.
- [34] Nuclear Safety Council (CSN): *The Nuclear Safety Council's Instruction on the requirements of the fire protection programme at nuclear power plants*, IS-30, Rev. 1, 21, Madrid, February 2013.
- [35] Swedish Radiation Safety Authority: *The Swedish Radiation Safety Authority's Regulations and General Advice concerning Safety in Nuclear Facilities*, SSMFS 2008:1, ISSN 2000-0987, published on 30 January 2009.
- [36] Swedish Radiation Safety Authority (SSM): *The Swedish Radiation Safety Authority's Regulations concerning the Design and Construction of Nuclear Power Plants*, SSMFS 2008:17, ISSN 2000-0987, published on 30 January 2009.
- [37] Eidgenössisches Nuklearsicherheitsinspektorat ENSI (Swiss Federal Nuclear Safety Inspectorate): *Probabilistic Safety Analysis (PSA): Quality and Scope, Guideline for Swiss Nuclear Installations*, ENSI-A05/e, http://static.ensi.ch/1391415729/ensi-a05_e.pdf.
- [38] Hauptabteilung für die Sicherheit der Kernanlagen (HSK), Eidg. Kommission für die Sicherheit von Kernanlagen (KSA): *Auslegungskriterien für den Schutz von sicherheitsrelevanten Ausrüstungen in Kernkraftwerken gegen die Folgen von Flugzeugabsturz*, Richtlinie für schweizerische Kernanlagen HSK-R-102/d, Dezember 1986, Neudruck 1983 (in German), http://static.ensi.ch/1314014379/r102_d.pdf#
- [39] United States Nuclear Regulatory Commission (NRC): *10 CFR 50 Domestic Licensing of Production and Utilisation Facilities; 10 CFR 50.48 Fire Protection*, August 2007, www.nrc.gov/reading-rm/doc-collections/cfr/part050/part050-0048.html.
- [40] National Fire Protection Association (NFPA): *NFPA 805, Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants*, 2001 Edition, Quincy, MA, USA, 2001.
- [41] United States Nuclear Regulatory Commission (NRC): *Appendix A to Branch Technical Position (BTP) APCSB 9.5-1, Guidelines for Fire Protection for Nuclear Power Plants*, 1976, www.nrc.gov/reading-rm/doc-collections/nuregs/brochures/br0361/s1/apcsb95-1.pdf.
- [42] United States Nuclear Regulatory Commission (NRC): *B.5.b – Mitigation Strategies Requirements from Order EA-02-026, Section B.5.b, the Subsequent License Conditions, and 10 CFR 50.54 (hh)*, August 2015, www.nrc.gov/reading-rm/doc-collections/cfr/part050/part050-0054.html.

- [43] United States Nuclear Regulatory Commission (NRC): Recommendations for Enhancing Reactor Safety in the 21st Century; *The Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident*; July 12, 2011, <http://pbadupws.nrc.gov/docs/ML1118/ML111861807.pdf>.

APPENDIX A: NATIONAL REGULATIONS REGARDING EVENT COMBINATIONS OF FIRES AND OTHER EVENTS

In the following national regulations regarding event combinations involving fires are outlined. It is important to note that not all members of the FIRE Database Project have already included this aspect in their regulations (Korea and USA).

A.1. Canada

In Canada, nuclear power plants (NPPs) are regulated via a Power Reactor Operating License (PROL). The PROL contains high-level requirements for meeting the Nuclear Safety and Control Act and is supported by a license condition handbook (LCH) which includes compliance verification criteria and guidance on how the requirements of the PROL can be met. The compliance verification criteria in the LCH references codes, standards and regulatory documents (e.g. REGDOCs) which the licensee is required to comply with. Consideration of combination events are addressed in the following REGDOCs and standards.

REGDOC-2.5.2, Design of reactor facilities: Nuclear power plants [11]

REGDOC-2.5.2 [11] establishes design requirements and expectations for new nuclear power plants. It also includes high-level requirements and expectations related to Design extension Conditions (DECs).

REGDOC-2.5.2 indicates that the safety objectives of DECs are to prevent core damage, mitigate accident consequences and protect containment integrity.

DECs may take into account accidents involving the reactor core, spent fuel pools and, where appropriate, multiple units at a site. Such accidents could be triggered by multiple failures of equipment, operator errors, internal or external events and, most probably, by a combination of events and failures. When major accidents occur they are complex with many contributing factors.

REGDOC-2.5.2 establishes the “plant design envelope” which comprises normal operation (NO), anticipated operational occurrences (AOO), DBAs and DECs. The corresponding Figure is taken from REGDOC-2.5.2 [11]. It shows the relationship of DECs to the other plant states.

As indicated in the Figure below, DECs are considered a subset of beyond design basis accident (BDBA) conditions. The rationale for this is that BDBA conditions extend to include accidents that, due to their extremely low probability of occurrence, are considered to be “practically eliminated”. It is important to note that DECs would not include conditions that are considered to be “practically eliminated”.

Operational states		Accident conditions		
Normal operation	Anticipated operational occurrences	Design-basis accidents	Beyond-design-basis accidents	
			Design-extension conditions	Practically eliminated conditions
			No severe fuel degradation	Severe accidents
Design basis		Design extension	Not considered as design extension	
Reducing frequency of occurrence →				

REGDOC-2.5.2 specifically addresses combinations of events as follows:

“Definition

Design extension conditions

A subset of beyond design basis accidents that are considered in the design process of the facility in accordance with best-estimate methodology to keep releases of radioactive material within acceptable limits. Design extension conditions could include severe accident conditions.

7.4 Postulated initiating events

7.4.1 Internal hazards

SSCs important to safety shall be designed and located in a manner that minimises the probability and effects of hazards (e.g. fires and explosions) caused by external or internal events.

The possible interaction of external and internal events shall be considered, such as external events initiating internal fires or floods, or that may lead to the generation of missiles.

7.4.3 Combination of events

Combinations of randomly occurring individual events that could credibly lead to AOOs, DBAs, or

DECs shall be considered in the design. Such combinations shall be identified early in the design phase, and shall be confirmed using a systematic approach.

Events that may result from other events, such as a flood following an earthquake, shall be considered to be part of the original PIE.

Guidance

Where the results of engineering judgement, deterministic safety assessments and probabilistic safety assessments indicate potential combinations of events, such combinations of events should be considered to be AOOs, DBAs or DEC, depending on their likelihood of occurrence.”

REGDOC-2.4.1, Deterministic safety analysis [12]

REGDOC-2.4.1 [12], *Deterministic Safety Analysis*, sets out requirements and guidance for the preparation and presentation of a safety analysis that demonstrates the safety of a nuclear facility. REGDOC-2.4.1 specifically addresses combination events as follows:

“4. Requirements for deterministic safety analysis

4.2 Events to be analysed

4.2.1 Identification of events

The licensee shall use a systematic process to identify events, event sequences, and event combinations (“events” hereafter in this document) that can potentially challenge the safety or control functions of the NPP. The licensee shall also identify events that may lead to fission product releases, including those related to spent fuel pools (also called irradiated fuel bays) and fuel-handling systems.

Guidance

The safety analysis is performed for a set of events that could lead to challenges related to the NPP’s safety or control functions. These include events caused by SSC failures or human error, as well as human-induced or natural common cause events.

The events considered in safety analysis could be single PIEs, sequences of several consequential events, or combinations of independent events.”

REGDOC-2.4.2, Probabilistic safety assessment (PSA) for nuclear power plants [13]

REGDOC 2.4.2 sets out requirements and guidance for the preparation and presentation of a probabilistic safety assessment (PSA).

REGDOC 2.4.2 requires consideration of all potential initiating events (internal and external). It is the first paragraph of Section 4.8 which aims at considering these events separately.

In addition, REGDOC states that potential combinations of external hazards shall be included.

“4.8 Site-specific initiating events and potential hazards

Include all potential site-specific initiating events and potential hazards, namely:

- *Internal initiating events and internal hazards*
- *External hazards, both natural and human-induced, but non-malevolent*

Include potential combinations of the external hazards.”

REGDOC 2.4.2 was the result of amendments to the previous PSA standard (S-294) and included specific consideration of potential combination of external events following the Fukushima accident.

CSA N293, Fire protection for nuclear power plants [14]

CSA N293 provides the minimum fire protection requirements for the design, construction, commissioning, operation, and decommissioning of NPP, including structures, systems, and components (SSCs) that directly support the plant and the protected area. CSA provides guidance for the consideration of event combinations in relation to seismic events, the effects of fire suppression water and smoke from a fire – some clauses are provided below. CSA N293 also requires that a fire hazard assessment (FHA) and fire safe-shutdown analysis (FSSA) be performed for the facility. The guidance provided for the FHA (included in Appendix B of the standard) requires consideration of the effects of a fire and fire suppression while that provided for the FSSA includes valid assumptions for not considering some event combinations in the FSSA (Section 11.5). Select text is included below.

“5.7.7.1*

Fires that are caused by an earthquake and have an impact on nuclear safety shall be assessed and addressed. These fires shall be prevented, suppressed, or contained such that sufficient SSCs remain available to meet the nuclear safety criteria in Clause 5.4, taking into account the potential failure of structures and systems that are not qualified to withstand earthquakes. Fire suppression systems and fire separations credited for earthquakes shall be designed to remain functional following an earthquake.

5.7.7.2*

Where the failure (both direct and consequential) of fire protection systems or fire separations can cause the failure of the plant SSCs required to perform nuclear safety functions after an earthquake, these fire protection systems and fire separations shall be seismically qualified to prevent such failures.

5.7.7.3*

Regardless of the results of the assessment required by Clause 5.7.7.1, manual fire suppression shall be provided for fires that might occur following an earthquake but are not a direct result of an earthquake.

5.7.7.4*

Fire suppression systems that are designed to function after an earthquake shall be provided with services (e.g., power, water, compressed air) that are qualified to remain functional following the design-basis earthquake defined for the plant.

5.7.7.5

Where manual activation of fire suppression and smoke control systems is credited in the assessment required by Clause 5.7.7.1, control areas and the paths leading to them shall be seismically qualified to remain accessible.

7.3.3.6*

Diking, drainage, a combination of both, or other means of containment shall be provided to limit the spread of flammable and combustible liquids (including fire-fighting water contaminated with flammable and combustible liquids) and to divert liquid from equipment that, when damaged by water, becomes inoperable and affects nuclear safety.

7.4.1 General

All fire protection systems shall be seismically designed to satisfy the requirements of NFPA 13 and NBCC, except for fire protection systems specified in Clauses 7.4.2 and 7.4.3.

The design and installation of fire protection systems specified in Clause 7.4.2 and 7.4.3 shall comply with CSA N289.3. The following seismic categories shall be used to identify the extent to which SSCs are required to remain operational after an earthquake:

- (a) Seismic Category A — SSCs that must retain their pressure boundary integrity, structural integrity, or passive function (i.e. equipment that does not have an active mechanical function but might have an electrical or load-bearing function) during and following an earthquake.*
- (b) Seismic Category B — SSCs that must retain their pressure boundary integrity, structural integrity, or active function and in addition must remain operable during and following an earthquake.*

Category B includes equipment that is not part of the pressure boundary but must operate during and following an earthquake.

11.5 Valid assumptions

Assumptions used and not specified in Clause 11.5, Items (a) to (f), shall be clearly stated and justified in the documentation.

When assessing fire hazards and consequences of fires, the following are considered acceptable assumptions:

- (a) Fires need not be postulated coincident with independent, low-frequency events or accidents in the plant.*
- (b) Two or more simultaneous, independent fires in a plant or adjacent plant units need not be postulated.*
- (c) In a fire safe-shutdown analysis, failure of a single component need not be postulated coincident with failures caused by fire.*

B.3.5.5.6 Fixed fire-extinguishing systems

A list should be drawn up of the fixed fire-extinguishing systems installed in each fire zone.

The list should include

- (a) fixed water-based fire-extinguishing systems, and should specify the type of system, area of coverage, design density, and whether the system has manual or automatic actuation; and*

Note: The adequacy of drainage or collection of the water discharge may be evaluated separately from the FHA, such as in a plant-wide flooding assessment.

B.3.6.4.6 Calculation results

The determination of adverse fire conditions in and across fire zones should be stated in terms that can be readily compared to the vulnerability of plant structures and systems, in particular, the fire safe-shutdown systems. Where appropriate, results should report vulnerability to heat, smoke, water spray, and moisture, or any combination of these.

B.3.8.2.5 Direct, indirect, and secondary effects of a control measure

In the FHA, fire is assessed as a single, independent hazard in order to determine its effect on the ability to achieve the objectives of the standard. It is assumed that such a hazard does not occur simultaneously with other low-frequency independent hazards or initiating events. It should also be recognised that fire control measures can have unintentional and undesirable effects on other plant systems, and that these effects can have a safety significance that might not be obvious.

Examples of the undesirable effects that can result from the installation and actuation of a fixed fire-extinguishing system include the following:

- (a) Actuation of a water spray or sprinkler system can result in damage to electrical control cubicles elsewhere in the fire compartment, leading to failure of redundant fire safe-shutdown systems or components.”*

Note:

The above includes selected text only and therefore cannot be considered to be complete. The applicable REGDOC or Standard should be consulted for a comprehensive understanding of the requirements and guidance provided.

A.2. Czech Republic

The fire regulation P002h [15] (at the Dukovany NPP, similar regulation exists with other designations at the Temelin NPP) contains Abnormal Operating Procedures (AOPs) and addresses two groups of combinations of events associated with fires. These are:

1. Fire threatening the integrity of the primary circuit:
 - fire in the room of the MCP (Main Circulation Pump);
 - fire involving the packing of MCP.
2. Fire threatening the operation of the unit (turbine hall and rooms/spaces with electrical equipment):
 - fire of the turbine oil system;
 - fire of the oil system of the main feed water pumps;
 - fire/explosion at the hydrogen cooling system of the generator;
 - fires in selected areas of cable and switching stations;
 - fire of the main transformers 400 kV and 110 kV;

- fire of the main control room (MCR) and emergency control room;
- fire of a diesel generator.

The operating regulations P003 [17] (at the Dukovany NPP, similar regulation exists with other designations at the Temelin NPP), which contains symptomatic oriented Emergency Operating Procedures (EOPs), focuses on events related to failures of the technological equipment and does not cover combinations of events.

In the PSA for the Dukovany NPP, three groups of combinations of fire and other events are considered:

1. Fire and consequential initiating event (IE) - in the PSA from two groups:
 - PL – internal fires leading to a LOCA (corresponding to group 1 in P002h)f;
 - PT – internal fires leading to the loss of secondary circuit (corresponding to group 2 in P002h);
2. Initiating event and consequential fire - typically it has to be considered in the seismic PSA. For other IEs the PSA does not distinguish between failure of components, hydrogen leakage or human factors.

As a consequence, event combinations are covered by minimal cut sets (MCS), the last group being fire and independent IE.

In fact, such combinations are not considered in the PSA (there is no support in the manuals for PSA from Czech Nuclear Authority and the IAEA). For this group, the crucial question is at what time after the occurrence of the first event occurrence of another IE, i.e. the period overlapping of events (2 h, 24 h, 72 h) has to be considered - this is essential for determining the frequency of a combination of events and their screening.

A.3. Finland

High-level requirements are given in the Nuclear Energy Act (990/1987), the Nuclear Energy Decree (161/1988) and the Government Decree on the Safety of Nuclear Power Plants (17.10.2013/717). Detailed requirements on nuclear safety are given by STUK in specific YVL Guides. The English versions of STUK YVL Guides can be found on the website:

<http://plus.edilex.fi/stuklex/en/lainsaadanto/luettelo/ydinvoimalaitosohjeet/>

Requirements for event combinations are not strictly specified. However, PRAs cover the most meaningful event combinations.

Some sections from the Finnish regulation are collected below, considering the scope of events, failures and their consequences.

Government Decree on the Safety of Nuclear Power Plants (717/2013, in force 25.10.2013)[17]

“Section 2, Design extension condition:

- *Design extension condition shall refer to e.g. an accident caused by a rare external event and which the facility is required to withstand without severe fuel failure.*

Section 17, Protection against external hazards:

- *External hazards that may endanger safety functions shall be taken into account in the design of a nuclear power plant. Systems, structures and components shall be designed, located and protected so that the impacts of external hazards deemed possible have only a minor impact on plant safety.*

- *External hazards shall include exceptional weather conditions, seismic events, impact of accidents taking place in the plant's vicinity and other factors resulting from the environment or human activity. The design shall also consider unlawful actions with the aim of damaging the plant and a large commercial aircraft crash.*

Section 18, Protection against internal hazards:

- *The design of a nuclear power plant shall take account of any internal hazards that may challenge safety functions. Systems, structures and components shall be designed, located and protected so that the probability of internal hazards remains low and impacts on plant safety minor.*
- *Internal events to be considered include at least fire, flood, explosion, electro-magnetic radiation, pipe breaks, container breakages, drop of heavy objects, missiles due to explosions or component failures, and other possible internal hazards.”*

Safety design of a nuclear power plant (STUK Guide YVL B.1, in force 1.12.2013) [18]

Design bases of systems performing safety functions:

- **414.** *The nuclear power plant design shall take into account events that may cause a deviation of the plant parameters from normal values, as well as events that may threaten the availability of components or systems performing safety functions. Such events may be caused, for example, by a rupture in pressure equipment or piping; a component failure; a fault in the plant's operation or automatic control; or an internal or external threat.*
- **415.** *Internal threats to be considered shall include at least fires breaking out inside the plant; floods resulting from component or pipe failures; impact and jet forces; explosions; overvoltage; and the potential for malicious damage.*
- **416.** *External threats to be considered shall include at least extreme weather conditions; a fire in the neighborhood of the plant; high and low sea levels; seismic phenomena; clogging of the heat sink for reasons other than freezing or seismic phenomena; an aircraft crash; electromagnetic phenomena; an explosion or the presence of toxic gases within the plant site; an oil spill in the surrounding sea area; and unauthorised entry to the plant site or unauthorised access to information systems.*

Strength of individual levels of defence in depth:

- **437.** *The safety divisions hosting redundant parts of safety systems shall be located in different buildings or housed in dedicated compartments to separate them from the other safety divisions in the same building in order to prevent faults from spreading from one redundant system part to another as a result of internal events (e.g. fire, flood or dynamic effects) or external events.*

Specific requirements for systems needed for achieving and maintaining a controlled state:

- **447.** *In events involving a combination of failures (DEC B) and in rare external events (DEC C), it shall be possible to shut down the reactor and keep it subcritical in a controlled state in such a way that the limits set forth for fuel integrity, radiological consequences and overpressure protection in design-basis category DEC are not exceeded.*

Provisions for Internal and External Hazards at a Nuclear Facility (STUK Guide YVL B.7, in force 1.12.2013) [19]

Layout design:

- **311.** *Provisions shall be made in the design of the nuclear facility to protect the facility against internal hazards. This can be done by means of layout design, for example. Internal hazards to be*

taken into account in design shall be determined on a facility-specific basis. At least the following phenomena shall be analysed as internal hazards:

- fires and the spread of smoke and hazardous gases as well as explosions generated in consequence of a fire;*
- explosions and chemical reactions of materials handled at the facility;*
- release of dangerous gases and liquids;*
- arcing;*
- electro-magnetic interference;*
- consequent effects of the failure of components, piping and tanks containing liquids or gases (missiles, jet forces, pipe whips, pressure waves);*
- missiles caused by the failure of rotating machines and other equipment;*
- falling of heavy loads;*
- floods;*
- unnecessary operation of the fire water and extinguishing system;*
- loss of the cooling, heating and ventilation of rooms as well as their unnecessary operation.*

Fire protection at a nuclear facility (STUK Guide YVL B.8, in force 1.12.2013) [20]

Failure criteria during fire situations:

- **315.** *Nuclear power plant design shall make provision for fire-induced initiating events and safety functions whose actuation is required during fire situations. A fire may cause an initiating event such as a turbine trip or a reactor scram as well as consequential failures. Even if a fire at the nuclear power plant does not directly lead to an initiating event involving an automatic initiation of safety functions, provision shall always be made for promptly bringing the facility to a safe state during a fire situation in accordance with the operating procedures for anticipated operational occurrences and accidents.*
- **319.** *In addition to an initiating event possibly caused by a fire, to be taken into account during fire situations are fire-induced consequential failures irrespective of which the accomplishment of safety functions must be possible in accordance with the failure criteria of Guide YVL B.1. In analysing the scope of consequential failures, the effects of smoke and other combustion gases shall be taken into account. It shall be possible to bring the nuclear power plant into a safe state even if a fire causes consequential failures in safety functions, in addition to the initiating event, and even if safety functions are affected by a single failure that is independent of the fire.*

Protection against fire-load induced explosions:

- **355.** *Explosions and arcs as well as their consequent effects such as missiles shall be taken into account in designing fire protection arrangements at nuclear power plants. Protection shall be provided against explosions occurring in consequence of fires.*
- **356.** *The nuclear power plant's design shall provide protection against the risk of explosions and arcs in accordance with the defence in depth approach to fire protection so as to:*
 - prevent explosions and arcs by monitoring and protection systems;*
 - minimise the risk for plant safety from explosions and arcs;*
 - limit the spread of the effects of an explosion and arc.*
- **360.** *The possibility of arcing shall be taken into account in the design of rooms containing electrical equipment and in the choice of the equipment (instrumentation, circuit breakers).*

- *Switch cabinets important to safety shall be provided with arc barriers, which limit the duration of arcs and the amount of total energy generated and released*
- *Design shall consider the possibility of smoke causing an arc flash in the switchgear room*
- **361.** *In addition to fires, to be taken into account in transformer positioning and protection is the possibility of an arc or a rapid, explosive energy discharge.*
 - *During a high energy discharge, the rapid release of gas as well as the mixing and expansion of air and gas could cause a powerful fire and explosion.*
 - *Large oil-cooled transformers shall be equipped with monitoring and protection systems (hydrogen monitors, gas relays) to prevent fires and arcs (arc flashes).*
 - *Transformers containing large amounts of oil shall be placed sufficiently far from buildings and protected with structures and fire-extinguishing systems.*

Probabilistic Risk Assessment and Risk Management of a Nuclear Power Plant (STUK Guide YVL A.7, in force 1.12.2003) [21]

Contents and documentation of the PRA:

- **401.** *In the PRA, the following shall be analysed as initiating events: the plant's internal failures, disturbances and human errors, loss of offsite power supply, fires, flooding, hoisting of heavy loads, abnormal weather conditions, seismic events and other environmental factors as well as external factors caused by human activities.*

A.4. France

A combination of events is the occurrence of several events that affect a single installation at the same time. If there are no links between these events, they are considered as independent. Otherwise, depending on their correlation, the events share a proven or simply potential dependence.

The events may be internal events caused by the failure of safety related equipment or hazards (of internal or external origin).

As a general rule, combinations must be explicitly considered whenever there is a proven dependence with no design solution that “practically eliminates” the dependence. Each dependence “practically eliminated” by complementary design provision must be justified.

The following dependent combinations are notably to be examined: lightning and fire, airplane crash and fire, explosion and fire, earthquake and fire, earthquake and explosion.

Furthermore, an independent fire must be considered:

- in conjunction with each event of high occurrence frequency that is likely to affect the fire protection provisions (e.g. frost, loss of external power supply, etc.),
- after an internal initiating event taken into account in the design-basis accident (DBA) over a sustained period without compensatory provisions (e.g. large break LOCA).

For possible combinations of events, all direct and indirect effects brought about by the initial event are to be studied. Therefore, the effects of initial events on fire protection provisions and associated back-up elements as well as the possible intervention of the external emergency services are to be assessed. If necessary, these fire protection provisions will have to be protected themselves against associated events and qualified on the basis of the specific conditions induced.

The EPR Technical Code for fire protection (ETC-F) [22] provides the following principles:

External hazards and consequential fire

- *In buildings which are designed against external hazards, it shall be avoided that due to these events the equipment can release combustible materials or create an ignition source. This shall*

be demonstrated by an appropriate selection of materials and an appropriate design of this equipment.

- *If the equipment has not been correspondingly designed, structural and equipment-related fire protection measures shall be taken which shall themselves be designed to resist the effects of these hazards by an appropriate selection of materials and an appropriate design.*

Internal hazards and consequential fire

- *The structural and equipment-related fire protection measures shall be designed such, that in case of any fire which has to be assumed as a direct consequence of an internal hazard, basically the following requirements have to be ensured :*
 - *It shall be ensured that a fire cannot have an inadmissible effect on redundant and on non-redundant safety related equipment, such as the reactor coolant pressure boundary, the containment, the piping with break preclusion.*
 - *The functional failure of all the equipment within the fire compartment or fire cell where the fire is postulated shall be assumed.*

A.5. Germany

The German “Safety Requirements for Nuclear Power Plants” as issued recently [23] include high-level requirements with regard to combinations of internal hazards, such as fires, with other hazards.

It is required that all the plant specifically possible internal hazards and their potential combinations with internal or external hazards including emergency cases have to be considered.

For each hazard or combination of hazards, their consequences to nuclear plant safety including their consequential effects have to be analysed. In particular, the following consequential effects have to be specifically addressed:

- internal flooding,
- internal fires,
- internal explosions,
- increased radiation level,
- chemical reactions,
- functional failures of mechanical, electrical, or I&C components,
- pressure increase and differences,
- temperature and/or humidity increase,
- missiles, and
- jet and reaction forces.

Nuclear fire protection is addressed in detail in the revised German Nuclear Safety Standard KTA 2101.1 [24] on fire protection which covers event combinations with fires. This standard, does consider this aspect systematically and exhaustively in a specific paragraph 3.3 as outlined in the following.

“3.3 Combinations of fires with other anticipated events

3.3.1. Basic Principles

(1) Combinations of fires with other anticipated events have to be assumed, if the events to be combined are causally related or if their occurrence at the same time has to be accounted for due to their occurrence frequency and the extent of damage.

(2) Combinations of fires with other anticipated events have to be solely considered with respect to meeting the goals mentioned in Section 1, Paragraph (2) item a). For the combinations to be considered

fire protection measures have to be implemented unless effective and reliable precautionary measures have already been taken.

Note:

This requirement substantiates the extent of damage mentioned in 3.3.1 (1).

(3) The following combinations have to be distinguished:

- a) Combinations of causally related events:*
 - aa) Fire and consequential event,*
 - ab) Anticipated event and consequential fire,*
- b) Combinations of independently events occurring events*

3.3.2 Combinations of causally related events

3.3.2.1 Fire and Consequential Event

(1) The following combinations of fires and consequential events have to be considered:

- a) Fires and consequential component failure:*
 - aa) Failure (including high energy faults) of electrical components and equipment,*
 - ab) Failure of mechanical components (e.g. fast rotating parts, pre-tensioned springs),*
 - ac) Failure (including high energy faults) of pressure retaining pipework and vessels, whose own intrinsic failure cannot be excluded.*

aca) For pressure retaining vessels and systems, structures and components (SSC), for which their own intrinsic failure can be excluded because of their quality characteristics or for which their failure modes are limited, either measures for preventing a fire in the area of pressure retaining vessels or components have to be implemented or protection measures against fire impact have to be taken. Otherwise it has to be demonstrated that in case of fire the quality characteristics that preclude a failure or limit a failure mode will not be not be inadmissibly impaired.

acb) For pressure retaining vessels and systems, structures and components (SSC) for which their own intrinsic failure cannot be excluded, either measures for preventing a fire or measures to protect them shall be implemented. Alternatively, measures have to be taken to protect the safety system against the simultaneous impact of a fire and a consequential anticipated event on the above mentioned vessels and SSCs.

b) Fires and consequential internal explosion including explosions of radiolysis gases in systems and components.

3.3.2.2 Anticipated Event and Consequential Fire

The following event combinations of anticipated events and consequential fire have to be considered:

- a) component failure and consequential fire;*

Note: Such pressure retaining vessels and components are e.g. the reactor containment, the steam generators, the pressuriser, the main coolant pumps and the accumulators in nuclear power plants with pressurised water reactors and the reactor pressure vessel and the reactor scram vessel in nuclear power plants with boiling water reactors respectively. The corresponding SSCs are e.g. the containment, safety related support structures and structural elements as well as the spent fuel pool. Such quality characteristics may be e.g. the voltage exploitation. A limited failure mode is given in case of e.g. a design ensuring basis safety according to the "Safety Requirements for Nuclear Power Plants."

- aa) *high energy faults (including arcing) of electrical components and equipment (e.g. switchgears, breakers, transformers, high voltage cables);*
- ab) *high energy faults of mechanical components (e.g. fast rotating parts, pre-tensioned springs);*
- ac) *high energy faults of pressure retaining pipe work and vessels whose own intrinsic failure cannot be excluded;*
- b) *Plant internal explosions and consequential fire An explosion as consequential event to a fire inadmissibly impairing the required safety functions has to be excluded. Safety functions are presumed not to be inadmissibly impaired if the provisions provided in KTA 2103 [25] are considered.*
- c) *Earthquake and consequential fire*
 - ca) *In safety related buildings, which have to be designed against earthquakes according to the requirements of the nuclear seismic standard KTA 2201.1 [26], it has to be ensured that the required safety functions are not inadmissibly impaired by a fire consequential to the earthquake. This requirement is met if either those plant components releasing combustibles in case of loss of their integrity or those enabling an ignition are designed against earthquake by suitable materials and construction. If a fire cannot be excluded it has to be ensured by structural fire protection means that those safety functions required after an earthquake are not inadmissibly impaired. If this is not possible according to needs from systems technology or use, an equal protection has to be ensured by suitable technical fire protection means (e.g., fire detection and alarm system) or a combination of such measures. The aforementioned structural and technical fire protection means have to be designed accordingly, applying suitable building construction and other materials and construction designed against earthquake. Due to the short duration of strong earthquakes in Germany it can be assumed that a consequential fire will be effective only after the earthquake.*
 - cb) *If the plant is designed against an earthquake with a maximum intensity of $I = VI$ (EMS-98), the required function of the structural fire protection means as well as those of the technical fire protection features are presumed without any specific design provisions.*
- d) *Lightning and consequential fire:*

Any fire consequential to lightning inadmissibly impairing the required safety functions has to be excluded. Safety functions are presumed not to be inadmissibly impaired if the provisions provided in KTA 2206 [27] are considered.

3.3.3 Combinations of independent events

- (1) *In principle, no measures have to be taken for combinations of an anticipated fire and an independently occurring anticipated event.*
- (2) *Measures have to be taken for combinations of an anticipated fire with one of the anticipated events listed in the following:*
 - a) *Plant internal flooding,*
 - b) *Plant internal or external electro-magnetic interference (EMI), (except lightning),*
 - c) *Earthquake (including consequential effects),*

Note:

In this context, it has been assumed that:

- a) the occurrence frequency of combinations of independently occurring events is less than 1×10^{-5} per year,
- b) such event combinations are excluded by suitable precautionary measures, or that
- c) an event occurring independently from the fire does not inadmissibly impair the fire protection means.

- d) *Flooding, or*
- e) *Other site related external hazards.*

Note:

For a grace period of one week the occurrence frequency of the combination of an anticipated fire and one of the anticipated events listed in (2) is less than $1 \times 10^{-5}/a$.

- (3) *Those fire protection means needed in case of a combination of an anticipated event listed in (2) and an independently occurring fire for ensuring the fire protection goals according to Par. 1 (2) have to be made available again or be replaced by suitable other measures within one week after the occurrence of the event combination. (4) For the combinations of an anticipated fire with one of the anticipated events listed in (2) it is assumed that the measures mentioned in (3) can be taken within one week.*

A.6. Japan

Three major requirements regarding event combination of fires and other events are provided in the NUCREGTEC1306195 [28] “Standard for the Examination of Practical Power Generation Nuclear Reactors and Associated Facilities Regarding their Fire Protection” and one in the NUCREGTEC13061912 [29] “Guide for Evaluating the Effects of External Fires at Nuclear Power Stations”.

1. Prevent fires caused by natural phenomena

The design shall employ appropriate fire protection measures to prevent fires at structures, systems and equipment of the nuclear reactor facilities caused by natural phenomena such as lightning strikes and earthquakes in accordance with the following subparagraphs:

- (1) *As a measure to prevent fires caused by lightning strikes, lightning rods shall be installed on buildings etc.*
- (2) *Structures, systems and equipment equipped with safety functions shall be installed on a ground that has sufficient bearing capacity, and measures shall be taken to prevent fires caused by destruction or collapse of structures, systems and/or equipment equipped with safety functions.*

2. Design of the fire detection and fire extinguishing

The fire detection equipment and fire-extinguishing equipment shall be so designed that the fire detection and fire-extinguishing performance and functions will be retained even in the event of earthquakes or other natural phenomena in accordance with the following subparagraphs:

- (1) *The design of the fire-extinguishing equipment that may be frozen shall incorporate freezing-prevention measures.*
- (2) *The design of the fire-extinguishing equipment shall be such that its performance will not be significantly deteriorated by wind, storms, floods, etc.*
- (3) *The design of the fire-fighting piping shall incorporate measures to deal with ground displacements during earthquakes.*

3. Protection against internal flooding

The structures, systems and equipment equipped with safety functions shall be so designed that their safety functions will not be lost as a result of damage to or malfunctioning or incorrect operation of the fire-extinguishing equipment.

4. Fires of the premises of power stations that should be considered

The types of fires listed below which occur off the premises of power stations should be considered. In the case where a fire can be caused by an aircraft crash into the premises of a power station, it should be deemed that the ignition point of the fire is on the premises of the power station.

(1) Forest fires

The design should be such that appropriate protection measures are put in place to ensure that the nuclear reactor facilities of the power station will be unaffected by forest fires approaching the power station whose ignition points are off the premises of the power station and within 10 km from the power station and the safety of the nuclear reactor facilities against the effects (including the secondary effects) of such fires will be secured.

(2) Fires and explosions at nearby industrial facilities

A.7. Korea

The fire protection activities in nuclear facilities are regulated in Article 14 (Protection against Fire Protection, etc.) and Article 59 (Fire Protection Programme) of Regulations on Technical Standards for Nuclear Reactor Facilities, Etc. which contain the high-level requirements to meet Enforcement Decree of Nuclear Safety Act as shown in below.

“Regulations on Technical Standards for Nuclear Reactor Facilities, etc.

Article 14 (Protection against Fire Protection, etc.)

(1) Structures, systems, and components important to safety shall be designed and located in conformity with each of the following requirements in order to minimise the probability and the effects of fires and explosions:

- 1. The capability for reactor safe shutdown, residual heat removal, and confinement of radioactive materials shall not be impaired significantly at the occurrence of a fire in any area within reactor facilities;*
- 2. Non-combustible and fire-proof/heat-resistance materials shall be used wherever practical throughout the plant. Fire detection and fire-fighting systems of appropriate capacity and capability shall be installed for minimising the adverse effects of fires on structures, systems, and components important to safety, commensurate with the importance of the structures, systems, and components.*
- 3. Fire-fighting systems shall be designed and arranged to ensure that their failure, damage or malfunction does not significantly impair the safety performance of the structures, systems, and components important to safety.*

(2) As regards reactor facilities, a fire hazard analysis shall be performed in consideration of each of the following:

- 1. Classification of fire protection areas;*
- 2. Types and size of combustible materials;*
- 3. Categories of design bases fires;*
- 4. Fire detection and fighting facilities;*
- 5. Fire hazard assessment; and*
- 6. Capability to perform safe shutdown, residual heat removal, fire detection and prevention of*

radioactive release.

(3) *Technical standards as regards the fire hazard analysis as provided in the foregoing Paragraph (2) shall be determined and publicly notified by the Nuclear Safety and Security Commission.*

Article 59 (Fire Protection Programme)

According to Article 41 (1) 4 of the Decree, the operator of a nuclear power reactor shall establish and implement a fire protection programme for preventing, detecting, and suppressing fires as determined and publicly notified by the Nuclear Safety and Security Commission”

“Notice of the Nuclear Safety and Security Commission

No.2015-01 (Regulation on Establishment and Implementation of Fire Protection Programme)

The purpose of this notice is to specify the regulation on establishment and implementation of fire protection programme in accordance with Articles 26 (1) and 34 of the Nuclear Safety Act, and Article 41 of the Enforcement Decree of the Act and Article 59 of the Regulations on Technical Standards for Nuclear Reactor Facilities, etc.

No.2014-28 (Technical Standards for Fire Hazard Analysis)”

The purpose of this notice is to specify the technical standards for fire hazard analysis in accordance with Subparagraph 2 of Article 11, Subparagraph 2 of Article 21 and Article 30 (3) of the Nuclear Safety Act and Article 14 of the Regulations on Technical Standards for Nuclear Reactor Facilities, etc.”

There are no specific rules on combinations of events in the Korean nuclear regulation.

With any other regulation related to deterministic and probabilistic safety analysis, there are no specific requirements on the combination of events related to fire in the Korean nuclear regulations. However, the event combinations associated with fires have been considered in the stress test for operating plants under the stress test implementation guideline which is the internal policy in KINS. Fire consequential to a beyond design basis seismic event is considered only in the stress test as combination of events.

A.8. The Netherlands

In principle, all nuclear facilities in the Netherlands, including the Borssele nuclear power plant, operate under license, authorised after a safety assessment has been carried out. The license is granted by the regulatory body under the Nuclear Energy Act. In the Netherlands, the (modified) requirements and guides of the International Atomic Energy Agency (IAEA) are the basis of the regulation, including the Western European Nuclear Regulators Association (WENRA) Reference Levels for the existing NPP. These are coupled to the license requirement. Recently, the license requirement has been updated, including the WENRA RHWG Reference Levels of 2008.

Combinations of fires and other anticipated events are treated according to IAEA Safety Guide NS-G-1.7 “Fires and Explosions in the Design of Nuclear Power Plants” [30], par. 2.20 to 2.24, stating:

“2.20. A random combination of events may represent an extremely unlikely scenario that should be shown in the probabilistic safety analysis to be sufficiently rare as to be able to be discounted, rather than being taken as a postulated accident (paras I.14–I.18 in Appendix I of ...

2.21. In the design of fire protection systems and equipment, some combinations of fire and other postulated initiating events likely to occur independently of a fire should be taken into account, by the method given in paras I.14–I.18 of Appendix I of Ref. [1], and appropriate provisions should be made. For example, concerning the combination of a loss of coolant accident and an independent fire, the post-event recovery period should be taken into account while the near-term period, including the occurrence of the event and the start-up of mitigation systems, may be excluded.

2.22. *A postulated initiating event should not lead to a fire with consequences for safety systems. Possible causes of fires, such as severe seismic events or the disintegration of a turbine, should be addressed in the fire hazard analysis, and special design provisions (e.g. use of cable wraps, detection systems and suppression systems) should be made as necessary. In the fire hazard analysis, special attention should be paid to hot equipment and/or to the potential failure of circuits conveying flammable liquids and gases.*

2.23. *Fire protection systems and equipment that need to maintain a functional capability (their integrity and/or their functional capability and/or their operability) despite the effects of the postulated initiating event should be identified, adequately designed and qualified.*

2.24. *Fire protection systems that do not need to maintain a functional capability following a postulated initiating event should be designed and qualified so as not to fail in a way that threatens nuclear safety.”*

In addition, the German KTA fire and explosion protection standards are considered, providing guidance on combinations of fires and other anticipated events in KTA 2101.1 [31] and on explosions and other anticipated events in [32].

The most recent Dutch regulation for the design of new NPPs, the so-called “Dutch Safety Requirements for Nuclear Reactors: Fundamental Safety Requirements” as from March 19, 2015 [33] address such event combinations more systematically. They contain high-level comprehensive requirements regarding combinations of internal hazards, in particular fires, with other hazards. The following requirements are provided there with respect such event combinations:

“4.4 Internal and external hazards

4.4 (1) *The protection of structures, systems and components against internal and external hazards according to subsection 2.5 shall be based on the following:*

- a) the relevant internal and external hazards and*
- b) other external hazards to be postulated at the site under consideration;*
- c) the special characteristics of external hazards of long duration;*
- d) combinations of several natural or human-induced external hazards (e.g. earthquake, flooding, storm, lightning, fire, human-induced hazards) or combinations of these hazards with plant internal events (e.g. pipe break, loss of offsite power) or internal hazards (e.g. internal fires, internal flooding). These combinations shall be considered if the combined events or hazards are related or if their simultaneous occurrence has to be assumed due to their probability and degree of damage.*

4.4 (2) *All structures, systems and components shall be classified according to their safety significance in case of internal or external hazards. The classification shall take into account all possible effects of internal and external hazards, the role of the respective structures, systems and components in ensuring the safety functions, their location, and possible interactions with items important to safety. For each specified class the requirements for the level of protection applicable to the items in this class shall be defined in a way to ensure that the requirements of subsection 2.5, 2.1 (5a) and 2.1 (5b) are met.*

...

Annex 2 Requirements for provisions and protection against hazards 19.3.2015

1 Basic Requirements on Protection Concepts for Plant Internal and External Hazards

...

1 (3) *The design of systems, structures and components against internal and external hazards shall be based on*

- a) *those natural hazards with the most severe consequences or other external hazards to be postulated at the site under consideration;*
- b) *the special characteristics of external hazards of long duration;*
- c) *combinations of several natural or human-induced external hazards (e.g. earthquake, flooding, storm, lightning, fire, human-induced hazards) or combinations of these hazards with plant internal events (e.g. pipe break, loss of offsite power) or internal hazards (e.g. internal fires, internal flooding). These combinations shall be considered if the combined events or hazards show a causal relationship or if their simultaneous occurrence has to be assumed according to its probability and the expected degree of damage.*

1 (4) Preventive measures shall ensure that internal or external hazards inadmissibly impairing the required function of items important to safety shall be,

- *either reliably prevented;*
- *or sufficiently limited in their effects (see “Dutch Safety Requirements for Nuclear Reactors” 2.1 (5)).*

1 (5) The effectiveness and reliability of a preventive measure shall be commensurate to the occurrence frequency and the potential effects of the hazard against which the respective measure provides protection.

1 (6) If preventive measures as described in Sections 3 and 4 are in place, analyses of event sequences due to the corresponding internal and external hazards are not required in general. In this case, the safety demonstration focuses on compliance with the requirements for effectiveness and reliability of the preventive measures.

However, the requirements according to Annex 1 of the “Dutch Safety Requirements for Nuclear Reactors” do apply for analyses of event sequences that have to be postulated notwithstanding existing preventive measures and for event sequences for which preventive measures only limit the effects according to 1 (3) .

1 (7) Radiological consequences shall be determined for hazards originating from internal and / or external hazards leading to a radiological representative event at levels 3 or 4 of defence in depth.

Note: Radiological representative events on level 3 of defence in depth are listed in Annex 1 of the “Dutch Safety Requirements for Nuclear Reactors”.

...

3 Requirements for Internal Hazards

3.1 Basic requirements

3.1 (1) Plant specifically postulated internal hazards and their possible combinations or their combinations with other external hazards that may occur due to the plant-specific conditions shall be fully considered.

Note: Sections 2.5 and 4.2 of the “Dutch Safety Requirements for Nuclear Reactors” and subsections 3.2.1 (3) and (4) in Annex 4 of the “Dutch Safety Requirements for Nuclear Reactors” shall be considered.

...

3.1 (2) For each hazard or combination of hazards according to subsection 3.1 (1), the safety related impacts on the plant shall be determined considering the consequential impacts to be expected. In particular, the effects listed in the following shall be considered:

- *plant internal flooding;*

- plant internal fires and explosions;
- increased radiation level;
- chemical reactions;
- electrical, I&C or process related malfunctions/failures;
- pressure build-up, pressure differences;
- temperature and humidity increase;
- fragments (debris / missiles) flying around and falling;
- jet and reaction forces;
- collapse of structures and non-structural elements.

3.1 (3) Features for protection against internal hazards shall preferably be installed close to the potential source of an internal hazard unless another location is more advantageous with regard to safety.

...

Annex 4 Requirements on safety demonstration and documentation 19.3.2015

...

3.2.1 (3) Combinations of several external hazards or combinations of these hazards with internal events and hazards shall be postulated in accordance with the “Dutch Safety Requirements for Nuclear Reactors”.

The accidental impacts and the impacts resulting from the accident consequences are combined with the “normal external operational loads” (incl. snow and wind loads) and the “forced reactions under normal operational loads”. Consideration of the time-dependent progression of events is admissible for these combinations.

3.2.1 (4) The following shall be considered as possible consequential events occurring as a result of external hazards, unless the corresponding plant components have been designed to withstand these events:

- a) impacts from pressure blast waves upon the failure of vessels with high energy content;*
- b) consequential mechanical damage upon the failure of plant equipment;*
- c) flooding due to a failure of plant equipment and*
- d) fires*

and the following shall be taken into account:

- e) malfunctions of structures, systems and components in plant areas that are not correspondingly designed, with consideration of instrumentation and control installations, and*
- f) the occurrence of a loss of offsite power.”*

A.9. Spain

In Spain the NPPs have several requirements as their license basis. The general requirement issued by the CSN is the IS-30 [34]. In this instruction, there are two requirements related to combinations of events:

- The requirement presented below, that would prevent the combinations of fire and subsequent flooding caused by fire-extinguishing mechanisms, is included:

SSCs important to safety which do not require protection by means of water suppression systems but might be affected by the water ejected upon opening the latter must be protected by means of shields or screens. Appropriate drains shall be installed in areas containing SSCs important to safety to avoid potential damages due to the discharge of said water systems.

- The following requirement takes into account implicitly combinations of seismic events and fires.

Even though fires or fire protection-system failures concurrent with design-basis accidents or the most severe natural phenomenon have not been postulated, in the event of a safe-shutdown earthquake (SSE), there must be an extinction system (seismic subsystem) capable of supplying water to equipped fire hose in those fire areas containing equipment necessary to shut down the plant in a safe manner (either located indoors or with supply).

Besides, after the Fukushima event, several Complementary Technical Instructions (ITC) were issued by the CSN. In those ITC there are requirements to perform the analyses detailed below that are related to the combinations of events. These analyses have already been made by the utilities.

- Perform an analysis to identify those additional measures needed to mitigate the consequences of events caused voluntarily or involuntarily by human intervention which might involve the occurrence of fires or explosions that might lead to the loss of large areas of the plant.
- Perform an analysis of the possible indirect effects induced by an earthquake inside the facility; for this purpose, consideration has been given to explosions and fires, as well as to internal flooding caused by pipe breaks. The scope expected by the CSN for the analysis, related to fires and explosions is as follows: identification of the design basis of the facility as regards protection against fires and explosions caused by an earthquake; identification of combustible or explosive materials stored at the plant, including the performance of an analysis of the corresponding seismic capacity and definition of feasible actions to improve seismic performance where possible. In those cases in which it is not possible to justify an adequate seismic margin, a check is made to ensure that the potential effects do not impact the capacity to reach and maintain safe plant shutdown conditions and that they do not cause any unacceptable radiological consequences offsite.

A.10. Sweden

SSMFS 2008:1 (Swedish Radiation Safety Authority's Regulations and General Advice concerning Safety in Nuclear Facilities) [35] addresses high-level requirements for the safety analyses. In the context of combination of events it requires that the safety analyses shall be based on a systematic inventory of events, event sequences and conditions which can lead to a radiological accident. The general advice on the application of SSMFS 2008:1 [35] prescribes that probable as well as improbable design-basis events should be specified. Identified events that are not subject to further analysis should be specified in the safety analysis. Furthermore the advice states that the safety analyses should take into account reasonable combinations of independent events. Events that are consequences of other events should however be considered as a part of the initiating event.

SSMFS 2008:17 (The Swedish Radiation Safety Authority's regulations and general advice concerning the design and construction of nuclear power reactors) [36] addresses requirements concerning internal and external hazards. It requires that the nuclear reactor shall be dimensioned to withstand natural phenomena and other events that arise outside or inside the facility and which can lead to a radiological accident. In general reasonable technical and administrative measures shall be taken in order to counteract common cause failures. The general advice clarifies what should be taken into account on the topic of fire hazard analysis. Regarding combinations of events following are stated:

- "When analysing fire as an initiating event, an additional fire need not be assumed in the facility.
- When analysing initiating events other than fire, which in turn can result in a fire, a fire should be assumed to occur as a possible consequential failure from the initiating event.

- When analysing events other than fire, which in turn cannot result in a fire, a fire should nonetheless be assumed to occur no earlier than 12 hours after the initiating event. This event sequence need not be combined with a single failure.”

A.11. Switzerland

Some general aspects are provided in ENSI-A05 “Probabilistic Safety Analysis: Quality and Scope” [37].

Turbine missiles

- Targets that, if hit, have the potential to lead directly or indirectly (e.g., by wall failure, flooding, or fire) to damage of a PSA component shall be identified.
- The consequences of the four most adverse independent turbine missiles shall be analysed. At the same time the PSA components’ unavailability caused by an induced turbine fire (e.g., due to ignition of hydrogen or seal and lube oil) shall be considered in the PSA model. In addition, the effects of hydrogen explosion and smoke shall be discussed.

Fragility Analysis

A comprehensive and systematic walk-down of the plant and plant vicinity shall be performed according to international standards in order to:

- identify components and structures potentially compromising PSA equipment in case of earthquake (e.g., due to mechanical interaction, seismically induced fires, floods, and explosions).

For each structure or component vulnerable to the indirect effects of vibratory ground motion, the fragility parameters shall be determined as follows:

- The conditional failure probability of structures or components affected by seismic-induced fires, explosions and floods shall be estimated as a function of ground motion or assumed to be 1.0 (guaranteed failure).

Aircraft

Indirect Effects of an Aircraft Crash (Missiles and Fire/Explosion Effects)

- The effects of collateral mechanical loads and of fire/explosion resulting from a crash either on a building or on the remaining plant area shall be analysed and the failure probabilities of the buildings shall be assessed taking into account the variability in aircraft type.
- For buildings designed against missile impact (see also [38], paragraphs 3.4, 4.6, and 4.7 for analogous design requirements), only fire effects shall be assessed taking into account fire and explosion sources, (e.g., amount of fuel from the aircraft, gas and oil storage in the plant area), pathways for smoke and hot gas (e.g., air intakes of emergency diesel generators) and pathways for fuel run-off on and into plant structures and along plant grades.

A.12. USA

In the United States NPPs have several requirements as their license basis. The general requirement issued by the NRC is 10 CFR part 50.48 [39]. In this instruction, there is no explicit guidance requiring combination of accident events for fire related scenarios. 10 CFR part 50.48 (b) states: Appendix R to this part establishes fire protection features required to satisfy Criterion 3 of Appendix A to this part with respect to certain generic issues for NPPs licensed to operate before January 1, 1979. The regulation states fire protection features proposed or implemented by the licensee have been accepted by the NRC staff as

satisfying the provisions of Appendix A to Branch Technical Position (BTP) APCS 9.5-1 reflected in NRC fire protection safety evaluation reports issued before the effective date of February 19, 1981; or fire protection features that were accepted by the NRC staff in comprehensive fire protection safety evaluation reports issued before Appendix A to Branch Technical Position APCS 9.5-1 was published in August 1976. Additionally, 10 CFR part 50.48 (c) states that a licensee can maintain a fire protection programme that complies with NFPA 805 [40] as an alternative to meeting 10 CFR, part 50.48 (b).

Branch Technical Position (BTP) APCS 9.5-1 [41]

In the Branch Technical Position (BTP) APCS 9.5-1 [41], combination of fire event scenarios is specifically addressed with the following instructions: Postulated fires or fire protection-system failures need not be considered concurrent with other plant accidents or the most severe natural phenomena, e.g., LOCA and fire. However, in the event of the most severe earthquake, namely, the safe-shutdown earthquake (SSE), the fire protection system should be capable of delivering water from manual hose stations located within hose reach of areas containing equipment required for safe plant shutdown. The water supply for this condition may be obtained by manual operator actuation of valve(s) in a connection to the hose standpipe header from a normal seismic Category I water system, such as the essential service water system. Thus, at least manual hose and portable fire protection capability must be provided for all postulated design bases events requiring plant shutdown. The fire protection systems should, however, because of the higher probability of occurrence, retain their original design capability for (1) natural phenomena of less severity and greater frequency (approximately once in 10 years) such as tornadoes, hurricanes, floods, ice storms or small intensity earthquakes which are characteristic of the site geographic region and (2) for potential man-created site related events such as oil barge collisions, aircraft crashes which have a reasonable probability of occurring at a specific plant site. The effects of lightning strikes should be included in the overall plant fire protection system. Fire protection starts with design and must be carried through in all phases of construction and operation. Furthermore, quality assurance (QA) programmes are needed to identify and rectify errors in design, construction, and operations, and are an essential part of defence-in-depth. The guidelines in this position are intended to implement the philosophy of defence-in-depth protection against the hazards of fire and its associated effects on safety-related equipment.

NFPA 805 [40]

NFPA 805 [40] is incorporated by reference by 10 CFR part 50.48 (c). If a licensee is utilising a performance-based approach within NFPA 805, Section 2.3 states: *“The following assumptions are provided to perform a deterministic analysis of ensuring the nuclear safety performance criteria are met. (Performance-based information (i.e. equipment out of service, equipment failure unrelated to the fire, concurrent design-basis events) are integral parts of a PSA and shall be considered when performance-based approaches are utilised.)*

- (1) Independent failures (i.e. failures that are not a direct consequence of fire damage) of systems, equipment, instrumentation, controls, or power supplies relied upon to achieve the nuclear safety performance criteria do not occur before, during, or following the fire. Therefore, contrary to other nuclear power plant design-basis events, a concurrent single active failure is not required to be postulated.*
- (2) No abnormal system transients, behaviour, or design-basis accidents precede the onset of the fire, nor do any of these events, which are not a direct consequence of fire damage, occur during or following the fire.”*

Aircraft threats

The NRC has also contemplated the possibility of an aircraft threat to a NPP. The requirements for licensees in detailed in 10 CFR part 50.54 (hh) [42]:

- “(1) Each licensee shall develop, implement and maintain procedures that describe how the licensee will address the following areas if the licensee is notified of a potential aircraft threat:*
- (i) Verification of the authenticity of threat notifications;*
 - (ii) Maintenance of continuous communication with threat notification sources;*
 - (iii) Contacting all on-site personnel and applicable offsite response organizations;*
 - (iv) On-site actions necessary to enhance the capability of the facility to mitigate the consequences of an aircraft impact;*
 - (v) Measures to reduce visual discrimination of the site relative to its surroundings or individual buildings within the protected area;*
 - (vi) Dispersal of equipment and personnel, as well as rapid entry into site protected areas for essential on-site personnel and offsite responders who are necessary to mitigate the event; and*
 - (vii) Recall of site personnel.*
- (2) Each licensee shall develop and implement guidance and strategies intended to maintain or restore core cooling, containment, and spent fuel pool cooling capabilities under the circumstances associated with loss of large areas of the plant due to explosions or fire, to include strategies in the following areas:*
- (i) Firefighting;*
 - (ii) Operations to mitigate fuel damage; and*
 - (iii) Actions to minimise radiological release.*
- (3) This section does not apply to a nuclear power plant for which the certifications required under § 50.82(a) or § 52.110(a)(1) of this chapter have been submitted.”*

The Near-Term Task Force Review of Insights from the Fukushima Daiichi

After the nuclear accident at Fukushima, the NRC established the Near-Term Task Force in response to Commission direction to conduct a systematic and methodical review of NRC processes and regulations to determine whether the agency should make additional improvements to its regulatory system and to make recommendations to the Commission for its policy direction, in light of the accident at the Fukushima Daiichi nuclear power plant. The Task Force appreciates that an accident involving core damage and uncontrolled release of radioactive material to the environment, even one without significant health consequences, is inherently unacceptable. The Task Force also recognises that there likely will be more than 100 NPPs operating throughout the United States for decades to come. The Task Force developed its recommendations in full recognition of this environment. In examining the Fukushima Daiichi accident for insights for reactors in the United States, the Task Force addressed protecting against accidents resulting from natural phenomena, mitigating the consequences of such accidents, and ensuring emergency preparedness. The accident in Japan was caused by a natural event (i.e. tsunami) which was far more severe than the design basis for the Fukushima Daiichi nuclear power plant. As part of its undertaking, the Task Force studied the manner in which the NRC has historically required protection from natural phenomena and how the NRC has addressed events that exceed the current design basis for plants in the United States

One of the results of the Near-Term Task Force was a set of Recommended Orders [43]. The Task Force recommended that the Commission use orders to ensure that licensees take the near-term actions described below. In some cases, these are interim actions to be taken until requirements associated with

future rulemakings can be implemented. The recommendations are currently being reviewed and contemplated by the Commission.

Recommended Orders

1. Order licensees to re-evaluate the seismic and flooding hazards at their sites against current NRC requirements and guidance, and, if necessary, update the design basis and SSCs important to safety to protect against the updated hazards.
2. Order licensees to perform seismic and flood protection walk-downs to identify and address plant-specific vulnerabilities and verify the adequacy of monitoring and maintenance for protection features such as watertight barriers and seals in the interim period until longer term actions are completed to update the design basis for external events.
3. Order licensees to provide reasonable protection for equipment currently provided pursuant to 10 CFR 50.54 (hh) (2) from the effects of design-basis external events and to add equipment as needed to address multi-unit events while other requirements are being revised and implemented.
4. Order licensees to include a reliable hardened vent in boiling water reactor (BWR) Mark I and Mark II containments.
5. Order licensees to provide sufficient safety-related instrumentation, able to withstand design-basis natural phenomena, to monitor key spent fuel pool parameters (i.e. water level, temperature, and area radiation levels) from the control room.
6. Order licensees to provide safety-related ac electrical power for the spent fuel pool makeup system. Order licensees to revise their technical specifications to address requirements to have one train of on-site emergency electrical power operable for spent fuel pool makeup and spent fuel pool instrumentation when there is irradiated fuel in the spent fuel pool, regardless of the operational mode of the reactor.
7. Order licensees to have an installed, seismically qualified means to spray water into the spent fuel pools, including an easily accessible connection to supply the water (e.g., using a portable pump or pumper truck) at grade outside the building.
8. Order licensees to modify the Emergency Operating Procedures (EOP) technical guidelines to (1) include EOPs, **Severe Accident Management** Guidances (SAMG), and **Extensive damage mitigation guidelines** (EDMGs) in an integrated manner, (2) specify clear command and control strategies for their implementation, and (3) stipulate appropriate qualification and training for those who make decisions during emergencies.
9. Order licensees to modify each plant's technical specifications to conform to detailed recommendation 8.2.¹²
10. Order licensees to do the following until rulemaking is complete: determine and implement the required staff to fill all necessary positions for responding to a multi-unit event, conduct periodic training and exercises for multi-unit and prolonged SBO scenarios, ensure that Emergency Preparedness (EP) equipment and facilities are sufficient for dealing with multi-unit and prolonged SBO scenarios, provide a means to power communications equipment needed to communicate on-site and offsite during a prolonged SBO, and maintain Emergency Response Data System (ERDS) capability throughout the accident.
11. Order licensees to complete the ERDS modernisation initiative by June 2012 to ensure multi-unit site monitoring capability.

12. Recommendation 8.2: Modify Section 5.0, "Administrative Controls," of the Standard Technical Specifications for each operating reactor design to reference the approved EOP technical guidelines for that plant design.

Recommended actions for long-term evaluation

The Task Force recommends that the staff pursue the longer term review activities described below to further evaluate insights from the Fukushima event and to enhance the safety of United States plants.

1. Evaluate potential enhancements to the capability to prevent or mitigate seismically induced fires and floods.
2. Re-evaluate the need for hardened vents for other containment designs, considering the insights from the Fukushima accident. Depending on the outcome of the re-evaluation, appropriate regulatory action should be taken for any containment designs requiring hardened vents.
3. Identify insights about hydrogen control and mitigation inside containment or in other buildings as additional information is revealed through further study of the Fukushima Daiichi event.
4. Analyse current protective equipment requirements for emergency responders and guidance based upon insights from the accident at Fukushima.
5. Evaluate the command and control structure and the qualifications of decision makers to ensure that the proper level of authority and oversight exists in the correct facility for a long-term SBO or multi-unit accident or both.
6. Evaluate ERDS to do the following: determine an alternate method (e.g., via satellite) to transmit ERDS data that does not rely on hardwired infrastructure that could be unavailable during a severe natural disaster, determine whether the data set currently being received from each site is sufficient for modern assessment needs, and determine whether ERDS should be required to transmit continuously so that no operator action is needed during an emergency.
7. Study whether enhanced on-site emergency response resources are necessary to support the effective implementation of the licensees' emergency plans, including the ability to deliver the equipment to the site under conditions involving significant natural events where degradation of offsite infrastructure or competing priorities for response resources could delay or prevent the arrival of offsite aid.
8. Work with the Federal Emergency Management Agency (FEMA), States, and other external stakeholders to evaluate insights from the implementation of EP at Fukushima to identify potential enhancements to the United States decision-making framework, including the concepts of recovery and re-entry. Study the efficacy of real-time radiation monitoring on-site and within the EPZs (including consideration of ac independence and real-time availability on the Internet).
9. Conduct training, in co-ordination with the appropriate Federal partners, on radiation, radiation safety, and the appropriate use of KI in the local community around each nuclear power plant.