IAEA-TECDOC-1421

Experience gained from fires in nuclear power plants: Lessons learned

IAEA
International Atomic Energy Agency

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FOREWORD

In 1993, the IAEA launched a programme to assist Member States in improving fire safety in nuclear power plants (NPPs). Since then, a number of publications relating to fire safety in NPPs have been issued and a framework for a data collection and reporting system on fire relevant incidents has been initiated.

The review of fire safety assessment in many plants has shown that fire is one of the most important risk contributors for NPPs. Moreover, operational experience has confirmed that many events have a similar root cause, initiation and development mechanism. Therefore, many States have improved the analysis of their operational experience and its feedback.

States that operate NPPs play an important role in the effort to improve fire safety by circulating their experience internationally — this exchange of information can effectively prevent potential events. When operating experience is well organized and made accessible, it can feed an improved fire hazard assessment on a probabilistic basis. The practice of exchanging operational experience seems to be bearing fruit: serious events initiated by fire are on the decline at plants in operating States. However, to maximize this effort, means for communicating operational experience need to be continuously improved and the pool of recipients of operational experience data enlarged.

The present publication is the third in a series started in 1998 on fire events — the first two were: Root Cause Analysis for Fire Events (IAEA-TECDOC-1112) and Use of Operational Experience in Fire Safety Assessment of Nuclear Power Plants (IAEA-TECDOC-1134). The present report includes a detailed analysis of the most recent events compiled with the IAEA databases and other bibliographic sources. It represents a technical basis for the recently revised IAEA Safety Guide on Fire Protection for new and existing plants and highlights lessons learned that may be useful for practical fire safety enhancement in operating plants.

The IAEA is grateful to the experts who contributed to this publication, in particular to the members of the Technical Committee Meeting (TCM) on Fire Experience in NPPs and Lessons Learned, held in Vienna in July 2001, the Chairmen of the Working Groups (R. Bacellar-Brasil, P.J. Barends, Netherlands, G. Jones, United Kingdom and R. Lojk, Canada) and the General Chairman (H.P. Berg, Germany) of this TCM. The IAEA officers responsible for this publication were H. Tezuka and P. Contri of the Division of Nuclear Installation Safety.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

Fire safety assessments and operational experiences gained from events in nuclear power plants have shown that fires and explosions have a high potential to strongly affect the safety of an NPP. As a fire can occur anytime in a plant, fire protection of an NPP is important throughout its lifetime i.e., from the design stage to operation through to its decommissioning.

Fire safety in NPPs has been addressed in IAEA safety standards publications covering the design [1, 2] and the safe operation of NPPs [3, 4]. Other IAEA publicalitons give further guidance for fire safety assessments [5–9] and for fire safety reviews [10,12]. In these documents the analysis of fire experience is mentioned as an essential tool to meet the following objectives:

- To drive a safety review of the procedures in force in operating plants (operational safety objective).
- To drive a periodic safety review of the fire safety issues in design and operation.
- To support a probabilistic analysis for fire hazards for new and existing plants aimed at a better quantification of fire safety aspects and at a prioritization of the safety improvement tasks.

To meet these objectives, a broad record of experience drawn from fire events at plants around the world is strongly encouraged to construct a reliable database that will enable fire safety experts to make recommendations for current and future plants and can be used for statistical purposes. Events should be collected and analysed by fire safety experts to derive recommendations for current and future plants.

In this connection, the IAEA has initiated a systematic event data collection in the framework of the scheme proposed in Ref. [13]. The objectives of this task are: to collect and assess the operational experience on fire and explosions in plants in a systematic manner to gain the necessary information for a thorough safety analysis; to use lessons learned from past events for operational feedback; and to apply them successfully in the plants to avoid or, at least, minimize, the recurrence of events.

This TECDOC has been developed in order to update the analysis of the well known events recorded in the past with the evidence gained from the most recent ones. The fire event data collection scheme given in [13] has also been revised and improved as a second outcome of this activity. While the analysis of the relevant fire events is part of the mandate of the IAEA, completion of the data collection is left to other organizations at the national and international levels. The implementation of the fire safety review services by the IAEA will represent an other chance to improve the document content through its application.

1.2. OBJECTIVE

This TECDOC summarizes the experience gained and lessons learned from fire events at operating plants, supplemented by specific Member State experiences. In addition, it provides a possible structure of an international fire and explosion event database aimed at the analysis of experience from fire events and the evaluation of fire hazard. The intended readership of this is operators of plants and regulators.

1.3. SCOPE

The present publication focuses on existing NPPs and new NPPs; it supplements the Safety Guides on Fire Protection [2] and Fire Safety and the Operation of Nuclear Power Plants [4]. This TECDOC includes an analysis of the lesson learned from recent fire and explosion events described in the IAEA event database IRS [18] and in other bibliographical references identified in the attached papers.

Economical consequences as a result of fires and explosions are outside of the scope of this TECDOC.

1.4. STRUCTURE OF THE TECDOC

Section 2 discusses the lessons learned derived from the most recent fire experience in worldwide NPPs. Section 3 provides a reviewed proposal of incidents reporting criteria for an international fire and explosion event database as well as detailed recommendations on how to get the necessary input for such a database.

Annexes I to XIII contain papers submitted to the IAEA Technical Committee Meeting (TCM) on Fire Experience in NPPs and Lessons Learned held in Vienna in July 2001, These submissions contain important and updated information on the most recent experience in selected countries.

2. LESSONS LEARNED FROM FIRE EXPERIENCE IN NPPS

2.1. DATA SOURCES

This section discusses the lessons learned derived from fire experience in NPPs, using the following sources:

(1) The IRS (IAEA/NEA Incident Reporting System) events database [18];
(2) The papers in Annexes I–XIII (national contributions to the TM held at the IAEA headquarters in Vienna in 2001);
(3) Proceedings of recent international conferences on fire safety in NPPs.

2.2. ANALYTICAL METHOD

To evaluate the lessons learned from the reports and existing events databases different analytical approaches are possible. In this TECDOC the following 6-step approach has been applied.

Step 1. Preparation of data — the followings sources have been used for this TECDOC:
- Relevant fire events in NPPs from the IRS database;
- Papers presented in Annexes from I to XIII; and
- Relevant papers in proceedings of Refs [14–17].

Step 2. Categorization of fire events according to event characteristics such as deficiencies in:
- Design;
- Construction;
- Operation, maintenance, and surveillance;
- Quality assurance; and
- Safety evaluation.

Step 3. Classification of above categorized fire events according to the degraded safety related functions such as:
- Degradation of reactor coolant boundary;
- Degradation of rector containment integrity;
- Failure or significant degradation of the reactivity control;
- Failure or degradation of heat removal capability; and
- Degradation of essential support systems.

Step 4. Screening of the fire events throughout above mentioned Steps 2 and 3. The outcome of this screening will be used for the next step.

Step 5. Deriving lessons learned from each category of the events.

Step 6. Categorizing the lessons learned as fire protection of NPPs such as:
- Prevention;
- Mitigation;
- Detection;
- Suppression.

2.3. ANALYSIS OF THE IRS DATABASE

Although several databases are available on events in NPPs, only the IRS database provides consolidated information from a wide variety of sources, including fires and explosions, reflecting a broad range of experiences and containing the potential for obtaining valuable information and lessons learned for the purpose of this TECDOC.

Concerning the extraction of the lessons learned, the methodology explained in Section 2.2 has been applied to the relevant events in the IRS. The results are shown in the following sections and Tables I to III.

2.3.1. Observations by using the IRS database

The IRS database contains more than 2200 safety related events in NPPs and provides a quite valuable tool for reviewing fire and explosion events.

The IRS database was searched under the reporting categories A5168 (Fire, Burning, Smoke, Explosion) or A5170 (Other External Environmental cause- Fire, Toxic, Explosive gases) and 119 events were extracted. Further manual sorting was achieved on the extracted events and 66 events ware found actually describing fire and explosions.

The selected 66 events were analysed, applying the methods shown in Section 2.1, and grouped according to; the principal causes of fire and explosion events (shown in Table I); to the fire protection and fire fighting (shown in Table II); and to the consequences of the event (shown in Table III).

Through the using experience of the IRS database, the following observations can be derived:

- There is a broad variety of detail and completeness of the event;
- A great deal of information is provided, but it is limited to more safety significant events whereas a lot of lessons learned can be derived from minor events;
- The current reporting criteria appears too high to capture all events of interest for deriving lessons learned;
- Fire was not necessarily the main reason for some of the events though fire was defined as the cause of the event;
- The IRS search criteria also resulted in non-fire/explosion events being selected;
- Near misses were not reported;
- The event reports contained multiple fire events (generic);
- Lessons learned from fires and explosions were not consistently reported for all events.

2.3.2. Principal causes of the fire and explosion events

Table I shows the principal causes (identified in the IRS reports) of the events. As for causes of the events, items such as deficiencies in design, operation (rules and procedures for plant operation), construction, quality assurance, and in lack of emergency procedures have been chosen. The following observations can be derived from the Table I:

- Many of the events had multiple causal factors;
- Design and human factors were major contributors;
- The table confirmed commonly agreed and understood causes;
- Only a few external hazards, e.g. storm, flooding, forest fire etc. caused some internal fire events;
- In some cases, sometimes significant ones, the same type of event recurs in the same NPP;
- In several cases, plant modifications contributed to fire events because theses modifications have not been checked against fire safety needs before their implementation; this underlines that a careful planning of modifications is necessary taking into account fire safety aspects;
- More fires were reported during operation than during shutdown states, although practical experiences in the NPPs show a high amount of fires occurred during shutdown states, in particular in outage phases.

TABLE I. CAUSES OF THE FIRE AND EXPLOSION EVENTS

IRS Event Number	Plant Status	Deficiencies in design	Deficiencies in operation	Deficiencies in construction	Deficiencies in QA	Lack of Procedures
5				X		
19		X	X	X		
52	X			X		
116	X	X	X			
124		X	X		X	X
148		X	X			
149		X	X		X	X
192	X	X	X	X	X	X
272	X	X	X		X	
312		X			X	
359				X		
366			X		X	X
385		X	X			
393		X		X		
409	X	X		X		
433			X			
452		X	X			X
471			X			
473		X				
503			X			
517			X		X	
523			X	X		
600		X				
621	X		X		X	
623	X	X	X		X	
691	X	X	X		X	X
702		X		X	X	X
634			X		X	
739		X	X			
748		X	X	X	X	
1008		X	X		X	X
1013		X	X			
1021		X	X			
1025		X	X		X	X
1035			X			
1183		X	X			X
1207				X	X	
1225	X				X	X
1281				X		
1427			X			
1509	X	X	X		X	X
5302		X				
6095		X	X		X	X
6164		X	X	X	X	X

6227		X	X		X	X
6248		X	X	X	X	X
6263		X			X	
6267		X	X			X
6301		X			X	
6310		X	X		X	
6314	X		X			
6325		X	X			
6341		X	X	X	X	X
7006		X	X			
7162			X		X	
7346		X	X			X
0853A	X	X	X			
0853B	X	X	X			
0853C	X	X	X			
1015A		X	X		X	X
1015B		X	X		X	X
1023A	X		X			
1023B	X		X			
651A	X	X	X			
651B	X		X			
7376A		X	X	X		
7376B		X	X	X		
66	18	46	52	17	29	21

Note to TABLE I ***"Causes of the Fire and Explosion Events"***

Plant Status	X; Shutdown No entry = Normal operation or insufficient information
Design	X; Deficiencies in design, e.g. incorrect plant and equipment layout (steam pipes located adjacent to cables) and incorrect modifications to plant and components and incorrect design data used. No entry = Adequate provisions or insufficient information.
Operation	X; Deficiencies in applying rules and procedures, including plant surveys, maintenance rules, operating procedures and common sense. No entry = Adequate provisions or insufficient information.
Construction	X; Deficiencies in construction of plant and equipment, e.g. incorrect assembly of pipe work resulting in leakage of flammable material and No entry = Adequate provisions or insufficient information.
QA	X; Deficiencies in the application of QA e.g. failure to carryout checks and inspections. No entry = Adequate provisions or insufficient information.
Lack of Emergency Procedures	X; Lack of an emergency procedure in case of hazards such as a fire. No entry = Adequate provisions or insufficient information.

2.3.3. Effectiveness of fire protection means and fire fighting

Table II shows the effectiveness of the fire protection means at the plant and that of fire fighting during the events. As fire protection includes items such as Fire Detection and Fire Barriers were selected. Also, Safety Analysis was chosen to see its adequate contribution to prevent a risk. Fire Extinguishers, Emergency Response Team and Main Control Room Operators were picked up as key items of the effectiveness of the fire fighting.

The following observations can be derived from the Table II:

- The emergency response teams (in particular fire fighting brigades) were generally effective when available, however there was one case that the team staff made matters worse;
- The lack of emergency response teams was sometimes a contributor to the fire;
- The lack of, or failure of, detection and suppression systems and equipment appeared significant and were contributors to some fires;
- Human factors, besides of control room operator actions, featured general failure to perform required maintenance, surveillance and verification reflecting the lack of operational procedures or rules noted in Table I;
- Lack of, or deficiencies in, fire barriers were significant contributors;
- In some cases the non-safety related equipment was the main event contributor to affect the safety related equipment.

2.3.4. Consequences of the fire and explosion events

The event data were analysed with regard to their consequences. The following generic observations were made during the data analysis:

- A substantial number of the reported fires and explosions resulted in an undesired change of plant status (e.g. reactor scram);
- Failure of safety related items, such as off site power and diesel generators, led to an undesired change in plant status;
- Fires and explosions affected the functions important to nuclear safety such as “core heat removal” and “confinement of radioactive material” even when the fire started in a room where any safety related items do not exist;
- In a few cases, nuclear safety was indirectly affected by fire extinguishing agents (as for secondary effects); and
- Fires/ explosions caused common mode failures, mainly due to design deficiencies.
-

Table III shows the summary of consequences of fire and explosion events.

TABLE II. EFFECTIVENESS OF FIRE PROTECTION MEANS AND FIRE FIGHTING

IRS EVENT No.	**Automatic Detection and/or Alarm**		**Fire Barriers**		**Safety Analysis**		**Fixed Extinguishing Systems**		**Manual Fire Extinguishment**		**Emergency response**		**Control Room Operators**		**Human Factors**	
Effective	**Y**	**N**	**Y**	**N**	**Y**	**N**	**Y**	**N**	**Y**	**N**	**Y**	**N**	**Y**	**N**	**Y**	**N**
52		N		N				N	Y		Y		Y		Y	
106	Y					N			Y		Y		Y		Y	
116	Y		Y						Y		Y			N		N
124			Y										Y			
148	Y			N	Y			N			Y		Y			N
149	Y					N			Y				Y			N
192																N
272		N				N		N		N	Y			N		N
312				N					Y		Y					
359	Y		Y		Y			N		N	Y		Y			N
366						N			Y		Y		Y			N
385	Y		Y		Y		Y		Y		Y		Y			N
393								N	Y		Y		Y		Y	
409	Y				Y								Y			
433	Y															
452		N		N		N	Y			N			Y		Y	
471	Y										Y					
473	Y	N									Y		Y			
503	Y								Y		Y		Y			
517						N										
523			Y				Y				Y		Y			
600	Y								Y		Y					
623	Y				Y				Y				Y		Y	
691		N		N		N			Y			N	Y			N
702	Y			N		N			Y				Y			N
734		N		N		N		N	Y					N		
739	Y								Y		Y			N		
748		N		N	Y			N		N				N		N
1008	Y			N		N	Y			N			Y			N
1013	Y			N	Y			N			Y		Y		Y	
1021	Y			N	Y		Y		Y							N
1025	Y		Y			N	Y		Y		Y		Y			N
1035	Y			N	Y		Y			N		N	Y			N
1183	Y		Y		Y			N			Y		Y			N
1207	Y						Y				Y		Y			

1225	Y	N											Y			N
1427			Y					N	Y		Y		Y			
1509	Y			N		N		N	Y					N		
5302	Y										Y					
6095	Y			N		N		N	Y		Y			N		
6164	Y			N		N	Y				Y		Y		Y	N
6227		N						N	Y				Y			N
6248	Y			N		N		N	Y		Y	N		N		N
6263		N	Y		Y			N	Y		Y		Y		Y	
6267		N		N		N			Y							N
6310									Y							
6314	Y															
6325	Y															
6341	Y			N		N	Y		Y		Y			N		
7006	Y					N	Y			N		N		N		N
7162									Y							
7197		N		N				N	Y				Y			N
7346		N										N				N
0853A						N			Y							
0853B	Y					N			Y			N		N		N
0853C						N			Y							
1015A		N		N		N	Y			N			Y			N
1015B		N		N		N	Y			N			Y			N
1015C		N		N		N	Y			N			Y			
1023A		N		N	Y		Y			N			Y			N
1023B		N		N	Y					N			Y			N
7376A		N		N				N	Y		Y	N				N
7376B		N		N				N	Y		Y	N				N
62	**33**	**19**	**9**	**26**	**13**	**24**	**15**	**18**	**33**	**12**	**27**	**8**	**31**	**16**	**8**	**31**

Note to TABLE II ***"Effectiveness of fire protection means and fire fighting"***

Automatic Detection and/or Alarm	"Y"; Early detection and the raising of an alarm had resulted in less damage, thus mitigating the event. "N"; either no or faulty detection and/or alarm systems. No entry; lack of information or not significant.
Fire Barriers	"Y"; Physical and/or spatial barriers resented and performed correctly. "N"; Not presented, inadequate or bypassed. No entry; lack of information or not significant.
Safety Analysis	This refers to the existence of a safety analysis both prior to and/or during the event. "Y"; the analysis had identified the hazard and established adequate control measures, thus mitigating the event. "N"; the analysis was not performed or, performed incorrectly. No entry; lack of information or not significant.
Fixed Extinguishing systems	"Y"; Manual and/or automatic fixed extinguishing systems were present and worked correctly. "N"; Fixed extinguishing systems were not presented or, they worked incorrectly. No entry; lack of information or not significant.
Manual Fire Extinguishment	"Y" & "N" are the same as above mentioned.
Emergency Response Team (ERT)	"Y"; ERT was available and performed their tasks correctly. "N"; ERT was not present or, ERT performed incorrectly or inefficiently. No entry; lack of information or not significant.
Control Room Operators (CROs)	"Y"; CROs were presented and responded correctly to the event. "N"; CROs meight not have been presented or, they responded incorrectly to the event. No entry; lack of information or not significant.
Human Factors	"Y"; Positive role in the event, thus mitigated the damage by the event. "N"; Negative role in the event, thus contributed to the damage. No entry; lack of information or not significant.

TABLE III. Consequences of the Fire and Explosion Events

IRS Event No.	Degradation Coolant Boundary	Degradation Containment Boundary	Failure Reactivity Control	Failure Heat Removal	Failure Safety-Related Items	Undesired Transient Effects	Undesired Change Plant Status	Negative Environmental Impacts
5					X			
52					X			
106							X	
148					X	X	X	X
312					X			
359					X		X	
385							X	
409					X			
433					X	X		
471					X			
473					X		X	
503							X	
517		X			X			
523						X		
621					X			
651				X				
691		X			X			
702								X
734					X			
739					X			
748					X		X	
1008					X		X	
1013				X	X	X	X	
1015					X		X	X
1021					X		X	
1015					X		X	x
1021					X		X	
1025				X	X	X	X	
1183							X	
1207					X		X	
1251					X			
1427					X		X	
6095					X		X	
6164					X		X	
6227			X					X
6248			X	X	X	X	X	
6263					X			
6267								X
6301							X	
6314			X					
6325				X		X		
6341					X	X	X	
7006					X		X	X
7197						X		
7346		X						
0853A					X			
0853B					X			
0853C					X			
7376A						X		
7376B						X		
47	0	3	3	5	31	11	21	6

Note to TABLE III ***"Consequences of the fire and explosion events"***

Degradation of Reactor Coolant Boundary	X; Impact (partial or total failure) No entry; No impact or insufficient information
Degradation of Containment Boundary	X; Impact (partial or total failure) No entry; No impact or insufficient information
Failure or Degradation of Reactivity Control	X; Impact (partial or total failure) No entry; No impact or insufficient information
Failure or Degradation of Heat Removal capability	X; Impact (partial or total failure) No entry; No impact or insufficient information
Failure or Degradation of safety related items	Items such as I&C. X; Impact (partial or total failure) No entry; No impact
Undesired Transient States	X; Undesired transient was occurred at the time of the event. No entry; No transient or insufficient information.
Undesired Change of the Plant State	The needed change of the plant state AFTER the event, e.g.plant trip, shutdown, or plant power reduction. X; Undesired change of the plant state. No entry; No change of the plant state or insufficient information.
Negative impact to the environment	Radiological and/or non-radiological impacts to the environment e.g., toxic or radioactive contamination. X; Caused environmental impact. No entry; No impact or insufficient information

2.3.5. Lessons learned

The following lessons learned were derived regarding fire safety:

- Design deficiencies and human factors are large contributors to the events. Thus initiators, propagators and mitigators need to be considered;
- A fire event contains multiple causal factors. This recalls the importance of the implementation of the defence-in-depth concept in the design and operation of a NPP;
- Lack of emergency response teams makes a fire event worse;
- Improved emergency procedures including emergency communications should be required to reduce the causes relevant to human factors;
- Adequate and reliable detection and extinguishing features (both manual and automatic) should be provided. Because failure or lack of those was a significant contributor to fires;
- Failure or deterioration of fire barriers led undesired consequences to the nuclear safety. Fire barriers should be adequately provided and maintained;
- Fire and explosion events sometimes requested the plant operators to take special actions such as “change of the power level”, “reactor trip”, and “reactor shutdown”. Practical training of plant operators is needed for emergency cases together with the document preparation of emergency procedures; and
- Fire safety assessment of the plant should be re-achieved before the plant modifications are implemented so that negative impacts on the plant fire safety can be avoided.

The lessons learned on IRS database were found more in the area of fire prevention than in that of fire detection and suppression.

2.4. ANALYSIS OF THE TCM PAPERS AND RELEVANT PAPERS IN INTERNATIONAL FIRE SAFETY CONFERENCES

This sub-section describes the analysis of the papers in Annexes I–XIII and the relevant papers in Refs [14–17], for deriving the lessons learned. The analysis started from Step 5 of the methodology described in Section 2.2.

2.4.1. Extraction of the significant events

For the purpose of this TECDOC, 16 fire events and their relevant papers/reports have been selected from the subjected papers although these documents do not deal explicitly with lessons learned. These fire events in NPPs are shown in Table IV. Table IV shows also the IAEA technical meetings (TM) where such events were described and discussed.

It should be noted that the information provided for each event was very limited for a dedicated analysis of the event because very often the reports are just summaries of more comprehensive reports which are not made available.

TABLE IV. NPP FIRES REPORTED AT INTERNATIONAL MEETINGS

Year	NPP	Country	IAEA TM	Note
1975	Brown's Ferry	USA	Barcelona 1994	[14] Ppn* 23
1975	Greifswald – Unit 1	Germany	Barcelona 1994	[14] Ppn 40-41, 46
1979	Barsebeck	Sweden	Vienna 1997 Vienna 2001	[16] Ppn 214 Annex III
1982	Armenia — 1	Armenia	London 1997 Vienna 1997 Vienna 2001	[15] Ppn 221 [16] Ppn 214 Annex II
1985	Rajasthan — Unit 2	India	Barcelona 1994 Vienna 1997	[14] Ppn 40-41 [16] Ppn 196
1987	Fort St. Vrain	USA	Barcelona 1994	[14] Ppn 83
1989	Vandellos	Spain	Barcelona 1994 London 1997 Vienna 1997 Vienna 2001	[14] Ppn 81, 89 [15] Ppn 221 [16] Ppn 214 Monday lecture 9/7/2001
1991	Chernobyl – Unit 2	Ukraine	Barcelona 1994 London 1997 Vienna 1997	[14] Ppn 40-41, 81, 118 [15] Ppn 221 [16] Ppn 214
1991	Salem – Unit 2	USA	Barcelona 1994 London 1997 Vienna 1997 IRS database	[14] Ppn 77, 81 [15] Ppn 221 [16] Ppn 214 [18]
1993	Enrico Fermi	USA	Barcelona 1994 London 1997 Vienna 1997	[14] Ppn 80 [15] Ppn 221 [16] Ppn 214
1994	Biblis A	Germany	Barcelona 1994 Vienna 2001	[14] Ppn 47 Annex I
1995	DCPP	USA	London 1997	[15] Ppn 151, 159
1996	Palo Verde	USA	London 1997	[15] Ppn 241, 248
1999	Bugey	France	Vienna 2001	Annex VI
2001	Rovno	Ukraine	Vienna 2001	Annex IV

*Ppn: proceeding page number

2.4.2. Summary of lessons learned

Table V shows short summaries of the selected 16 fire events.

According to Table V, it seems that the generic problems such as lack of fire detection systems, inadequate separation of redundant cables, and use of flammable materials disappeared as causes of fire.

Lessons learned can be summarised as follows:

- Safety culture
  - As most fires started directly or indirectly by human errors, it is necessary to improve the safety culture at the plant.
- Prevention
  - In several cases a short circuit was the cause of fire. Material selection for cables and fuses should be appropriate with regard to fire safety.
  - In several cases the insulation material contributed itself to the fire propagation. Insulation materials should be non-combustible or fire retardant.
- Detection
  - Fast detection of the fire is very important. Automatic detection and alarm systems should particularly be provided in unoccupied rooms. These systems should be reliable and be regularly tested and maintained.
- Suppression
  - Communication problems between the fire brigade and operators in the control room led a delay of fire fighting. Appropriate communication means together with emergency procedures are necessary.
  - Manual fire suppression was often impossible due to smoke in the respective fire compartments (in particular in the turbine hall). Provisions for smoke removal are required.
- Mitigation
  - In the control room, smoke ventilation and fire barriers sometimes do not work as required because of cracks in walls and floors which were not well repaired.
  - A relative great number of hydrogen fires, mostly resulting in an explosion, occurred. Adequate provisions to prevent hydrogen fires should be taken.

2.4.3. Statistical analysis

The information obtained at the TM (Vienna, 2001) on the following countries has been subjected to statistical analysis:

- Finland (events occurred in 1974–1997)
- Germany (events occurred in 1975–2001)
- India (events occurred in 1988–2000)
- Sweden (events occurred in 1977–2000)

- Location of fire origin

Table VI shows the locations of the origin of the fire.

Although in the various countries different types of buildings are mentioned and different nomenclature is used, it is clear that about one third of all fires originated in the turbine building. Wherever the electric equipment is installed, e.g. in the electric building, reactor building, and switchgear building, it was also a weak point as mentioned in Table V.

TABLE V. SUMMARY OF FIRE EVENTS

Fire event	Reactor type	Reactor status	Main origin			Other risks involved	Detection	Fireman intervention	Experience learned
			Electrical (Cabling and actuators)	Mechanical	Electronics (I&C)				
Brown's Ferry 1975	BWR		Due to human factor			Flooding	No automatic detection	Successful when water was used	New regulations were introduced addressing common cause failure, cable routing, cable insulation, etc. [19]
Greifswald 1975	PWR		Human failure; short circuit			Loss of feedwater and emergency pumps	No automatic detection		Implemented selective fusing; redundant cables should be separated install smoke removal in turbine hall
Barsebeck 1979	BWR	Operating		Stress corrosion					Use a heat sensitive camera to find the fire; Install smoke removal in turbine hall
Armenia 1 1982	PWR	Operating	Human failure; short circuit			Loss of emergency cooling system	Automatic	Successful	Redundant cables should be separated
Rajasthan 1985	PHWR		Faulty plugin connection causing a overheating of the cablebox			Loss of circulation pumps	Failing detection system		Install smoke removal in steam generator room
Fort St. Vrain 1987	HTGR	Power ascension mode	Human failure; forgot to replace orifice of operative valve			Automatic detection	Within 5 min.; suppression after 30 min.	Communication problems between fire brigade and control room; coordinating training	Communication problems between fire brigade and control room; Coordinating training
Vandellos	Gas-	After		Mechanical		Loss of turbo-			Have a definite

Fire event	Reactor type	Reactor status	Main origin			Other risks involved	Detection	Fireman intervention	Experience learned
			Electrical (Cabling and actuators)	**Mechanical**	**Electronics (I&C)**				
1987	Graphite	shutdown		failure due to stress corrosion		blowers; flooding; H2 leakage			strategy for storing spent fuel
Chernobyl 2 1991	LWGR (RBMK)	Operating	Generator restart; working as a synchronius motor			Loss of third barrier; loss of five water pumps; H2 leakage			Smoke and heat removal to prevent collapsing of the roof; separation between trains
Salem 2 1991	PWR	Operating		Blade rupture		H2 explosion			Preventive maintenance of solenoid operated valves on turbine and periodic replacement
Enrico Fermi 1993	BWR			Turbine blade fatigue failure		H2 explosion; flooding; potential loss of core cooling equipment			
Narora 1993	PHWR	Cold shutdown		Fatugue failure of last stage blades		H2 leakage; complete loss of power supply		Successful	Smoke removal from control room
Biblis A 1994	PWR	Heating phase after a cold shutdown	Ground circuit die to human error				Automatic detection	Unsuccessful with CO2; successful with deluge system manually operated	Fire detected verh late by operators of site; Installation of adequate ground fault protection necessary
Diablo Canyon 1995	PWR		Short circuit due to human factor			Potential pond overflow		Deluge system manually activated	
Palo Verde 1996	PWR		Short circuit				Delay in automatic detection		Various panels involved in the event ground power system

Fire event	Reactor type	Reactor status	Main origin			Other risks involved	Detection	Fireman intervention	Experience learned
			Electrical (Cabling and actuators)	Mechanical	Electronics (I&C)				
									at the source power
Bugey 1999	PWR	operating	Short circuit due o bad operation of protection relay				Automatic detection	Too long	One single default may generate multiple fires in different fire compartments; smoke in the control room; alarms were not taken into account immediately
Rovno 2001	PWR	Unit 1: outage unit 2,3: operating	Short circuit due to crane falling onto cable entresol			Complete loss of power supply loss of water supply for fire fighting	Manual detection by security guard	Long, but successful	Standby relay not designed for this event; Deficiencies in documentation and management

TABLE VI. LOCATION OF THE ORIGIN OF THE FIRE (%)

Location	India	Germany	Sweden
Reactor building	30	12	18
Turbine building	31	32	38
Electric building	-	-	11
Auxiliary building	30	12	-
Switchgear building	-	32	-
Emergency diesel building	-	4	-
Other buildings	-	8	33
Outside building	9	-	-
Total	100	100	100

- Type of fire

Table VII shows the types of fires.

Approximately 50% of fires were caused by electrical equipment. One third of the fires were caused by leaking oil and hydrogen.

TABLE VII. TYPE OF FIRE (%)

Type of fire	India	Germany
Solid carbonaceous materials	24	-
Flammable liquids and gasses - Oil fire - Hydrogen fire	29 - -	- 24 16
Electric equipment	47	52
Combustible metals	0	-
Mechanical equipment/other fires	-	8
Total	100	100

2.5. CONCLUSIONS

The analysis of the operating experience has shown that fire and explosions represent a significant hazard to NPPs. Therefore, countermeasures have to be taken in the safety design and operation of NPPs to keep the relevant risk as low as reasonable on the basis of the international experience.
An effective preventive action to be taken is the use of appropriate feedback mechanisms in design and operation of the plants, based on the operating experience.

International event databases can be useful tools to this concern, even if a clear obstacle is represented by the confidentiality issue that prevents many events to be reported and disseminated for analysis. Although the IRS database covers nearly 7000 reactor years of operating experience and more than 2200 events, the reported fire events constitute only a fraction (66 identified fires) of all fire events that actually occurred. Moreover, the role of explosions, suspected to be significant, needs to be further examined.

However, the information provided in the public available databases is usually not detailed enough for deriving consolidated lessons learned or for a probabilistic hazard evaluation. Any adequate database for the specific need of fires and explosions should include sufficient information to allow a precise identification of the main contributing factors and to extract a safety recommendation. A more detailed database would also reduce the margin of interpretation by the analysts.

This means that additional information, such as shown on the Tables I to III in Section 2.2, on processes and equipment used to fight the fire should be provided in a dedicated database. It is also useful to capture lessons from events that have not caused any nuclear significance at the subject plant or have been near misses because similar events could lead to more severe consequences in slightly different circumstances.

Also design and human factors showed high contributions to fire and explosions: these aspects should also be reflected in the contents of a suitable database.

3. PREPARATION OF CONTENTS AND CRITERIA FOR AN INTERNATIONAL FIRE AND EXPLOSION EVENTS DATABASE

The purpose of the proposed database is to collect detailed data of a sufficient number of fire and explosion events in nuclear installations to enable detailed fire and explosion safety assessment.
At some later stage a decision could be taken if the database can also be employed for probabilistic fire and explosion safety studies.
To set up an appropriate database, the definition of overall reporting criteria and a very detailed coding list are necessary prerequisites to get all information necessary in order to extract the lessons learned.
The proposed reporting criteria for fire and explosion events will assure that the database is consistent and contains all information needed to better understand the events, their causes and their prevention. The proposal is a review of a preliminary framework suggested in [13].

3.1. EVENT REPORTING CRITERIA

The following set of overall criteria for fire and explosion event reporting are proposed:

(1) Fires and/or explosions that have the potential to (or do) affect nuclear safety, including fires and/or explosions affecting rooms containing safety (related) equipment.
(2) Fires and/or explosions that cause injury[2] or loss of life.
(3) Fires and/or explosions that result in material damage greater than $10,000[3].
(4) Fires and/or explosions that start or progress in an unexpected way or occur through an unexpected combination of circumstances.
(5) Any fire and/or explosion resulting in a reactor outage.

[2] Injury resulting in 1 man day or more of lost working time
[3] This amount excludes labour costs and loss of electricity generating revenues.

3.2. QUESTIONNAIRE FOR THE INTERNATIONAL FIRE AND EXPLOSION EVENTS DATABASE

This section contains the format of the questionnaire as they are seen to be the necessary input of an international fire and explosion events database in form of a coding legend.

I. GENERAL DATA

1. **Incident No.**: Leave blank

2. **Country:**

- ❑ 01 Armenia
- ❑ 02 Argentina
- ❑ 03 Belgium
- ❑ 04 Bulgaria
- ❑ 05 Brazil
- ❑ 06 Canada
- ❑ 07 Switzerland
- ❑ 08 China
- ❑ 09 Slovakia
- ❑ 10 Czech Republic
- ❑ 11 Germany
- ❑ 12 Spain
- ❑ 13 Finland
- ❑ 14 France
- ❑ 15 United Kingdom
- ❑ 16 Hungary
- ❑ 17 India
- ❑ 18 Italy
- ❑ 19 Japan
- ❑ 20 Republic of Korea
- ❑ 21 Lithuania
- ❑ 22 Mexico
- ❑ 23 Netherlands
- ❑ 24 Pakistan
- ❑ 25 Romania
- ❑ 26 Russian Federation
- ❑ 27 Sweden
- ❑ 28 Slovenia
- ❑ 29 Ukraine
- ❑ 30 United States of America
- ❑ 31 Yugoslavia
- ❑ 32 South Africa

3. **Company**: Enter name of the utility

4. **Plant Name/Unit:** Enter plant name and unit where fire originated

5. **Reactor Type:** Choose the type of reactor.

- 01 BWR Boiling Water Reactor
- 02 FBR Fast (Breeder) Reactor
- 03 GCR Gas Cooled Reactor (graphite or heavy water moderated; includes AGR, TGR and HWGCR)
- 04 GEN Generic report (reactor type is irrelevant)
- 05 HWLWR Heavy Water moderated, boiling Light Water cooled Reactor
- 06 LWGR Light water cooled, Graphite moderated Reactor (e.g. RBMK)
- 07 PHWR Heavy Water moderated, Pressure tube Reactor
- 08 PWR Pressurised Water Reactor (includes WWER)
- 09 SGHWR Steam Generating Heavy Water Reactor

6. **Date Of Fire:** Enter date of fire.

7. **Time Of Fire:** Enter by 24 hour clock- Examples:
   1:00 AM = 0100 1:00 PM = 1300
   12:00 Midnight = 2400 12:01 AM= 0001
8. **Plant Status:** Choose operating status of the plant at the time of the fire.
   - 01 Not applicable Go to No. 14
   - 02 On power Go to No. 9.
   - 03 Hot shutdown (reactor sub-critical) Go to No. 10.
   - 04 Cold shutdown (reactor sub-critical and coolant temperature < 93 degree C) Go to No. 11
   - 05 Pre-operational Go to No. 13
   - 06 Testing or maintenance was being performed Go to No. 14
   - 07 Decommissioning Go to No. 14

   - 802 On power: Choose the status and go to No. 14
   - 01 Full allowable power
   - 02 Reduced power (including zero power)
   - 03 Raising power or staring up
   - 04 Reducing power
   - 05 Refuelling on power

10.803 Hot shutdown: Choose the status and go to No. 14
   - 01 Hot standby (coolant at normal operating temperature)
   - 02 Hot shutdown (coolant below normal operating temperature)

11. 804 Cold shutdown: Choose the status
   - 01 Cold shutdown with closed reactor vessel Go to No. 14
   - 02 Refuelling or open vessel (for maintenance) Go to No. 12
   - 03 Mid-loop operation (PWR) Go to No. 14

12. 80402 Refuelling or open vessel: Choose the status and go to No. 14
   - 01 Refuelling or open vessel - all or some fuel inside the core
   - 02 Refuelling or open vessel - all fuel out of the core

13. 805 Pre-operational: Choose the status and go to No. 14
   - 01 Construction
   - 02 Commissioning

14. **Location or Building of Fire:** Choose building area where fire originated

01 - Containment (PWR)	18 - Oil Storage Tanks
02 - Reactor Building (BWR)	19 - Scrubber
03 - Drywell (BWR)	
04 - Radwaste Building/Area	20 - Administration Building/Area
05 - Auxiliary Building	21 - Training Building
06 - Fuel Handling Building/Area	22 - Security Building
07 - Service Building	23 - Warehouse
08 - Turbine Building	24 - Maintenance Shop
09 - Control Room/Building	25 - Cooling Tower
10 - Diesel Generator Building/Area	26- Fire Pump House
11 - Switchgear Room	27 - Intermediate Building
12 - Battery Room	28 - Other (specify)
13 - Cable Spreading Room	29 - Not Available
14 - Intake Structure	
15 - Transformer Yard	
16 - Switchyard/Substation	
17 - Boiler	

15. **Type of room:**
16. **Dimensions of the room (L-W-H in m):**

II. DESCRIPTION

17. **Brief narrative description of the fire event** (minimum half of A4 page) including:

- ❑ situation
- ❑ chronological aspects
- ❑ how detected
- ❑ how put out
- ❑ fire spread
- ❑ extent of damage
- ❑ cause of the fire
- ❑ (safety) significance of the fire
- ❑ consequences of the fire
- ❑ common mode / cause (failure) aspects

III. IGNITION PHASE

18. **Fire Origin:** Choose equipment or item where fire originated:

- ❑ 01 - Reactor Coolant Pump (PWR)
- ❑ 02 - Reactor Recirculation Pump (BWR)
- ❑ 03 - Feedwater Pump/Motor/Turbine
- ❑ 04 - Auxiliary Feedwater Pump/Motor/Turbine
- ❑ 05 - Other Safety Related Pump/Motor/Turbine (Specify)
- ❑ 06 - Main Turbine

- 07 - Main Generator
- 08 - Main Exciter
- 09 - Transformer
- 10 - Turbine Tube Oil System
- 11 - Switchgear
- 12 - Diesel Generator
- 13 - Hydrogen Seal Oil System
- 14 - Condensate Pump/Motor
- 15 - Circulating Water Pump/Motor
- 16 - Boilers
- 17 - Batteries
- 18 - Motor Generator Sets
- 19 - HVAC Equipment
- 20 - Oil Circuit Breakers
- 21 - Boiler Feed Pump/Motor/Turbine
- 22 - Scrubber
- 23 - Miscellaneous Motors (Specify)
- 24 - Compressor
- 25 - Battery chargers
- 26 - Pumps (Specify)
- 27 - Hydrogen Recombiner
- 28 - Electrical Cable/Wiring
- 29 - Electrical Cabinet
- 30 - Bus Duct/Cable Bus
- 31 - Isophase Duct
- 32 - Flammable Gas Storage Tanks
- 33 - Off Gas System (nuclear)
- 34 - Hydrogen Recombiners (nuclear)
- 35 - Transient Combustibles
- 36 - Other (Specify)
- 37 - Not Available
- 38 - None

19. Fire Origin; For pumps or other components bearing oil (go to No. 21, if not applicable)**:** Choose the power (kW).

- 01 <3.5
- 02 3.5 to 35
- 03 35 to 730
- 04 > 730 (specify)
- 05 not available

20. Fire Origin; For pumps or other components bearing oil: Choose the voltage (V/kV)

- 01 460 or 480
- 02 4160
- 03 6900
- 04 Other (specify)

21. Fire Origin; For transformers (go to No. 25, if not applicable)**:** Choose the equipment type

Yard transformer
- ❑ 01 - main transformer
- ❑ 02 - start-up transformer
- ❑ 03 - station service transformer
- ❑ 04 - auxiliary transformer
- ❑ 05 - other yard transformer (specify)

Indoor transformer
- ❑ 06 - load center transformer
- ❑ 07 - lighting transformer
- ❑ 08 - transformer inside cabinet (e.g. control power transformer)
- ❑ 09 - neutral ground transformer
- ❑ 10 - other indoor transformer (specify)

22. **Fire Origin; For transformers:** Enter the transformer type
- ❑ 01 - oil
- ❑ 02 - dry
- ❑ 03 - not available

23. **Fire Origin; For transformers:** Enter the voltage

- ❑ 01 22kv/4160v
- ❑ 02 4160v/480v
- ❑ 03 480v/120v
- ❑ 04 other (specify)
- ❑ 05 not available

24. **Fire Origin; For transformers:** Was oil involved?
- ❑ 01 - Yes
- ❑ 02 - No
- ❑ 03 - Not available

25. **Fire Origin; For electrical cabinets** (go to No. 30, if not applicable): choose the equipment type

- ❑ 01 - switchgear
- ❑ 02 - motor control center
- ❑ 03 - load center
- ❑ 04 - DC load center
- ❑ 05 - inverter
- ❑ 06- lighting panel
- ❑ 07 - control panel
- ❑ 08 - relay cabinet
- ❑ 09 - termination cabinet
- ❑ 10 - other (specify)
- ❑ 11 - not available

26. **Fire Origin; For electrical cabinets**: choose the voltage

- ❑ 01 6.9kV
- ❑ 02 4160v
- ❑ 03 480v
- ❑ 04 120v (AC)
- ❑ 05 125v (DC)
- ❑ 06 other (specify)
- ❑ 07 not available

27. **Ignition source in electrical cabinets**: choose the ignition source

- ❑ 01 - breaker
- ❑ 02 - relay
- ❑ 03 - control power transformer
- ❑ 04 - wiring
- ❑ 05 - terminal block
- ❑ 06 - resistor
- ❑ 07 - circuit card
- ❑ 08 - CRT (screen)
- ❑ 09 - computer
- ❑ 10 - personnel
- ❑ 11 - other (specify)
- ❑ 12 - not available

28. **Ignition source in electrical cabinets:** Choose cabinet fire load

- ❑ 01 - low
- ❑ 02 - ordinary
- ❑ 03 - high
- ❑ 04 - other (specify)

29. **Ignition source in electrical cabinets:** Cabinet ventilation

- ❑ 01 Yes
- ❑ 02 No

30. **Fire Origin; For electrical wiring and cable** (go to No. 33, if not applicable)**:** Choose the state

- ❑ 01 - cable type (e.g. fire rating)
- ❑ 02 - power
- ❑ 03 - control
- ❑ 04 - instrumentation

31. **Fire Origin; For diesel generators:** Choose the part of the diesel generator that was the origin of the fire

- ❑ 01 - engine
- ❑ 02 - generator

- ❑ 03 - turbocharger
- ❑ 04 - exhaust manifold
- ❑ 05 - exhaust stack (downstream of the manifold)
- ❑ 06 - shaft/bearing
- ❑ 07 - heater
- ❑ 08 - fuel pump
- ❑ 09 - other pump
- ❑ 10 - control panel
- ❑ 11 - starting battery
- ❑ 12 - other electrical (specify)
- ❑ 13 - fan
- ❑ 14 - other (specify)

32. **Fire Origin; For diesel generators:** Was oil involved?

- ❑ 01 Yes
- ❑ 02 No
- ❑ 03 Not available

32-1. Ignition Factor (Cause): Choose all ignition factor/cause of the fire:

- ❑ – Incendiary
- ❑ – Suspicious
- ❑ – Mobile/Portable Heating Devices
- ❑ – Hot Work (CuttingWelding/Grinding/etc.)
- ❑ – Personal Error
- ❑ – Mechanical Malfunction/Failure
- ❑ – Electrical Malfunction/Failure
- ❑ – Design/Construction/Installation Deficiency
- ❑ – Operational Deficiency
- ❑ – Spontaneous combustion/ignition
- ❑ – Overheated material (e.g. oil leakage on hot surface)
- ❑ – Explosion
- ❑ – Lighting
- ❑ – External Plant Fire (which can impair plant operation)
- ❑ – External Hazards (e.g. aircraft, seismic, and transportation accidents)
- ❑ – Smoking
- ❑ – Other (specify)
- ❑ – Not Available

32-2. Type of Material Ignited: Choose type of material ignited for the originating fire.

- ❑ – Transformer Oil
- ❑ – Lubrication Oil
- ❑ – Fuel Oil
- ❑ – Flammable Liquid
- ❑ – Combustible Liquid
- ❑ – Electrical Wiring
- ❑ – Wood

- ❑ – Paper/Cardboard
- ❑ 09 – Trash
- ❑ 10 – Plastic Sheets
- ❑ 11 – Hydrogen Gas
- ❑ 12 – Other Gas (specify)
- ❑ 13 – Radiation Work Clothing (nuclear)
- ❑ 14 – Charcoal
- ❑ 15 – Ventilation filters
- ❑ 16 – Other (specify)
- ❑ – Not Available

32-3. Quantity of material ignited:

- ❑ < 0.5 l (little)
- ❑ 0.5 – 1.0 l
- ❑ 1.0 – 2.0 l
- ❑ 2.0 – 4.0 l
- ❑ > 4.0 l (specify the quantity of oil)
- ❑ unknown

32-4. Was oil involved?

- ❑ - Yes
- ❑ - No Go to No. 33
- ❑ - Not Available Go to No. 33

32-5. Choose the type of oil:

- ❑ – lube oil
- ❑ – fuel oil
- ❑ – other (specify)
- ❑ – not available

32-6. Choose the type of oil source:

- ❑ – pressurised spray
- ❑ – oil soaked insulation
- ❑ – oil seepage
- ❑ – spilled oil (confined)
- ❑ – spilled oil (unconfined)
- ❑ – other (specify)
- ❑ – not available

IV. DETECTION

33. Indications of the fire: Choose all what indicated the fire

- ❑ 01 - odour
- ❑ 02 - visible smoke
- ❑ 03 - sparks
- ❑ 04 - crackling or sizzling sounds
- ❑ 05 - momentary arcing
- ❑ 06 - prolonged arcing
- ❑ 07 - flash of light
- ❑ 08 - visible flames
- ❑ 09 - explosion
- ❑ 10 - other (specify)
- ❑ 11 - none
- ❑ 12 - not available

34. **Indications of the fire:** If flames were visible, choose the flames' characteristics as one of the following (if known):

- ❑ 01 - intermittent
- ❑ 02 - continuous
- ❑ 03 - slow
- ❑ 04 - vigorous
- ❑ 05 - brief
- ❑ 06 - prolonged

35. **How Reported:** Choose the fire reported method(s), give sequence if reported by multiple ways.

- ❑ 01 - Detection System Alarm
- ❑ 02 - Suppression System Alarm
- ❑ 03 - Fire Watch (continuous)
- ❑ 04 - Fire Watch (roving)
- ❑ 05 - Security Personnel
- ❑ 06 - Maintenance/Operations Personnel
- ❑ 07 - Control Room Indication (other than detection or suppression system alarms)
- ❑ 08 - Space permanently occupied
- ❑ 09 - Other (specify)
- ❑ 10 - Not Available

36. **Fire Detection Present?**

- ❑ 01 - Yes
- ❑ 02 - No Go to No.40
- ❑ 03 - Not Available
- ❑ 04 - Not Applicable

Fire Detection System Type: Choose type(s) of fire detection system

- 01 - Smoke, ionization
- 02 - Smoke, Photoelectric
- 03 - Heat, Rate of Rise
- 04 - Heat, fixed temperature
- 05 - Flame
- 06 - Infrared
- 07 - Combination system
- 08 - Local, e.g. In Cabinet (specify)
- 09 - Other (specify)
- 10 - Not Available

38. **Fire Detection System Performance:** Choose the performance of the fire detection system

- 01 - In Room of Fire: Operated Go to No. 40
- 02- In Room of Fire: Fire too small to operate Go to No. 40
- 03 - In Room of Fire: Did not operate
- 04 - Not in Room of Fire: Operated Go to No. 40
- 05 - Not in Room of Fire: Did not operate Go to No. 40
- 06 - Not Available Go to No. 40

39. **Fire Detection System Performance:** choose the reason the detection system did not operate

- 01 - unavailable due to maintenance
- 02 - local detector failure
- 03 - detection system failure
- 04 - other (specify)
- 05 - not available

V. FIRE SPREAD

40. **Did an explosion occur after fire?:**

- \- Yes
- \- No Go to No. 42
- \- Not Available Go to No. 42

41. **Characterise the extension of the fire (flames, hot gases):**

- none
- part of a room
- 1 complete room
- more than 1 room (inside one fire cell or one fire compartment)
- between 2 (or more) fire cells
- between 2 (or more) fire compartments

42. If the fire extended, at what elevation above the base of the fire was heat damage observed (m)?:
43. If the fire extended , at what radius around the centreline of the fire was damage observed at the base (m)?:
44. If the fire extended, at what radius around the centreline of the fire was damage observed at the ceiling (m)?:
45. If the fire extended beyond its source, at what elevation above the base of the original fire was secondary ignition observed (m)?:
46. If the fire extended beyond its source, at what radius around the centreline of the original fire did secondary ignition occur at the base (m)?:
47. If the fire extended beyond its source, at what radius around the centreline of the original fire did secondary ignition occur at the ceiling (m)?:

48. If fire extended between 2 fire cells or 2 fire compartments due to failures in the fire barriers, specify the type of barrier concerned:

- ❑ 01 wall
- ❑ 02 ceiling
- ❑ 03 floor
- ❑ 04 damper
- ❑ 05 penetration closure device
- ❑ 06 door
- ❑ 07 none
- ❑ 08 other

49. Characterise the extension of smoke:

- ❑ 01 none
- ❑ 02 part of a room
- ❑ 03 complete room
- ❑ 04 more than 1 room (inside one fire cell or one fire compartment)
- ❑ 05 between 2 (or more) fire cells
- ❑ 06 between 2 (or more) fire compartments

VI. FIRE FIGHTING AND EXTINGUISHING

50. Duration of vigorous burning (hours : minutes) ___ : ___
51. Flame height during the period of vigorous burning(m):

52. How long did fire burn: choose range of time the fire burned before being declared under control.

- ❑ - 0-5 min
- ❑ - 6-15 min
- ❑ - 16-30 min
- ❑ - 31-60 min
- ❑ - more than 60 min
- ❑ - Not Available

Presence of Fixed Fire Suppression System in the area of fire origin

- ❑ - Yes
- ❑ - No Go to No. 58
- ❑ - None Go to No. 58
- ❑ - Not Available Go to No. 58

54. Choose the Fixed Fire Suppression System Type(s):

- ❑ - Wet sprinklers
- ❑ - Dry sprinklers
- ❑ - Preaction sprinklers
- ❑ - Deluge sprinklers
- ❑ - Carbon dioxide
- ❑ 06 - Halon
- ❑ 07 - Dry chemical
- ❑ 08 - Combination system
- ❑ 09 - Other (specify)
- ❑ 10 - None
- ❑ - Not Available

55. Fixed Fire Suppression System Activation:

- ❑ - Automatic
- ❑ - Manual

56. Fixed Fire Suppression System Performance:

- ❑ - In Room of Fire: Operated Go to No. 58
- ❑ - In Room of Fire: Did not operate
- ❑ - In Room of Fire: Fire too small to operate Go to No. 58
- ❑ - Not in Room of Fire: Operated Go to No. 58
- ❑ - Not in Room of Fire: Did not operate Go to No. 58

57. Fire Suppression System Performance: choose the reason(s) the suppression system did not operate:

- ❑ - unavailable due to maintenance
- ❑ - local detector failure
- ❑ - detection system failure
- ❑ - valve failed to open
- ❑ - isolation valve left closed
- ❑ - other (specify)
- ❑ - not available

58. How Long Did the Fire Burn?: Specify time from detection to start of suppressant application (hours: minutes): ___ : ___
59. How Long Did the Fire Burn?: Specify time from detection to extinguishment (hours: minutes) ___ : ___
60. Specify time from detection to control of the fire (hours: minutes) ___ : ___

61. Type of Extinguish Action: Choose by which way(s) the fire was extinguished:

- ❑ 01 - Automatic Fire Suppression System
- ❑ 02 - Manual Fire Suppression System
- ❑ 03 - Manual Hose Streams
- ❑ 04 - Portable Fire Extinguishers
- ❑ 05 - Power/Fuel Supply Removed
- ❑ 06 - Self Extinguishment
- ❑ 07 - Other (specify)
- ❑ 08 - Not Available

62. Was the application of suppressants delayed for any reason?

- ❑ - Yes
- ❑ - No
- ❑ - Not Available

63. What suppressant agent extinguished the fire? Choose the agent(s):

- ❑ - water
- ❑ - CO2
- ❑ - halon
- ❑ - dry chemical
- ❑ - foam
- ❑ - other (specify)
- ❑ - none
- ❑ 08 - not available

64. First person(s) to reach the scene of the fire: How many persons?
65. First person(s) to reach the scene of the fire: Were those persons professional firemen or staff members?
66. First person(s) to reach the scene of the fire: Specify time from detection first person(s) reached the scene:
67. First person(s) to reach the scene of the fire: Did first person(s) to reach the scene attempt to fight the fire?

- ❑ 01 Yes
- ❑ 02 Non

68. On-site fire brigade; How many persons are there?

69. On-site fire brigade; Are they professional firemen or staff members?

- ❑ 01 Professional firemen
- ❑ 02 Plant staff members

70. On-site fire brigade; Specify time from detection on -site fire brigade members reached the scene:

71. Off-site fire brigade; How many persons are there?

72. Off-site fire brigade; Are they professional firemen or volunteers?

- ❑ 01 Professional firemen
- ❑ 02 volunteers

73. Off-site fire brigade; Specify time from detection off-site fire brigade members reached the scene:

74. Who has extinguished the fire?
- ❑ - local operator/maintenance personnel
- ❑ - fire watch
- ❑ - plant fire brigade
- ❑ - external fire brigade

75. If fire fighters were delayed, or did not reach the scene of the fire, explain the reasons why it happened.

76. Did any obstacle prevent/delay personnel or fire brigade from fire fighting?:
- ❑ 01 - Yes
- ❑ 02 - No Go to No. 78
- ❑ 03 - Not Available Go to No. 78

77. Choose the obstacle(s) which prevented fire fighting.;
- ❑ 01 smoke
- ❑ 02 high temperature
- ❑ 03 insufficient personal protective equipment
- ❑ 04 others

VII. CONSEQUENCES

78. Select all events consequences:
- ❑ 01 - Unanticipated releases of radioactive material
- ❑ 02 - Exposure to radiation that exceeds prescribed dose limits for the public
- ❑ 03 - Unanticipated exposure to radiation for site personnel
- ❑ 04 - Fuel cladding failure
- ❑ 05 - Degradation of primary coolant pressure boundary, main steam or feedwater line
- ❑ 06 - Degradation of containment function or integrity
- ❑ 07 - Degradation of systems required to control reactivity
- ❑ 08 - Degradation of systems required to assure primary coolant inventory and core cooling
- ❑ 09 - Degradation of essential support systems

79. Potential Impact on Safe Shutdown Capability of the plant:
- ❑ 01 - Yes
- ❑ 02 - No Go to No. 81
- ❑ 03 - Not available Go to No. 81
- ❑ 04 - Not applicable Go to No. 81

80. Manual or automatic plant trip:
- ❑ 01 - Manual plant trip
- ❑ 02 - Automatic plant trip

81. Any injuries/fatalities resulted from the fire?
- ❑ 01 - Yes
- ❑ 02 - No Go to No. 83
- ❑ 03 - Not available Go to No. 83

82. Choose estimated dollar loss for fire damaged equipment:

- 01 Non
- 02 $ 1 - 10 000
- 03 $ 10 001 - 100 000
- 04 $ 100 001 - 1 000 000
- 05 more than $ 1 000 000
- 06 Not available

83. Other Fire Damaged Equipment: Select other equipment damaged by the fire other than the fire originating piece of equipment.

- 01 - Reactor Coolant Pump (PWR)
- 02 - Reactor Recirculation Pump (BWR)
- 03 - Feedwater Pump/Motor/Turbine
- 04 - Auxiliary Feedwater Pump/Motor/Turbine
- \- Other Safety Related Pump/Motor/Turbine (specify)
- \- Main Turbine
- \- Main Generator
- \- Main Exciter
- \- Transformer
- \- Turbine Lube Oil System
- \- Switchgear
- \- Diesel Generator
- \- Hydrogen Seal Oil System
- \- Condensate Pump/Motor
- \- Circulating Water Pump/Motor
- \- Boilers
- \- Batteries
- \- Motor Generator Sets
- \- HVAC Equipment
- \- Oil Circuit Breakers
- \- Boiler Feed Pump/Motor/Turbine
- \- Miscellaneous Motors (specify)
- \- Compressor
- \- Battery chargers
- \- Pumps (specify)
- \- Hydrogen Recombiner
- \- Electrical Cable/Wiring
- \- Electrical Cabinet
- \- Bus Duct/Cable Bus
- \- Isophase Duct
- \- Flammable Gas Storage Tanks
- \- Off Gas System (nuclear)
- \- Hydrogen Recombiners (nuclear)
- \- Transient Combustibles
- \- Other (specify)
- \- Not Available
- \- None

Did the fire result in spurious operation of equipment?

- ❑ 01 - Yes
- ❑ 02 - No
- ❑ 03 - Not Available

85. Did fire fighting cause damage to equipment? Choose damaged equipment.

- ❑ 01 - Reactor Coolant Pump (PWR)
- ❑ 02 - Reactor Recirculation Pump (BWR)
- ❑ 03 - Feedwater Pump/Motor/Turbine
- ❑ 04 - Auxiliary Feedwater Pump/Motor/Turbine
- ❑ - Other Safety Related Pump/Motor/Turbine (specify)
- ❑ - Main Turbine
- ❑ - Main Generator
- ❑ - Main Exciter
- ❑ - Transformer
- ❑ - Turbine Lube Oil System
- ❑ - Switchgear
- ❑ - Diesel Generator
- ❑ - Hydrogen Seal Oil System
- ❑ - Condensate Pump/Motor
- ❑ - Circulating Water Pump/Motor
- ❑ - Boilers
- ❑ - Batteries
- ❑ - Motor Generator Sets
- ❑ - HVAC Equipment
- ❑ - Oil Circuit Breakers
- ❑ - Boiler Feed Pump/Motor/Turbine
- ❑ - Miscellaneous Motors (specify)
- ❑ - Compressor
- ❑ - Battery chargers
- ❑ - Pumps (specify)
- ❑ Hydrogen Recombiner
- ❑ - Electrical Cable/Wiring
- ❑ - Electrical Cabinet
- ❑ - Bus Duct/Cable Bus
- ❑ - Isophase Duct
- ❑ - Flammable Gas Storage Tanks
- ❑ - Off Gas System (nuclear)
- ❑ - Hydrogen Recombiners (nuclear)
- ❑ - Transient Combustibles
- ❑ - Other (specify)
- ❑ - Not Available
- ❑ - None

VIII. REMARKS

85. In your opinion, the event was due to deficiency in:
- ❑ 01 Construction
- ❑ 02 Operation;
- ❑ 03 Design
- ❑ 04 Quality Assurance
- ❑ 05 Lack of procedures
- ❑ 06 Administration (rules and procedures)
- ❑ 07 Others

86. Describe the reason of the choice in No. 85

87. Describe corrective actions.

88. Describe lessons learned.

89. Enter any additional remarks or comments.
- ❑ 01 - short narrative description of the event (0.5 page max)
- ❑ 02 - Eventual references (e.g. detailed report, root cause analysis, etc.)

IX. ADMINISTRATIVE

90. Name of Reporter:
91. Approved by:
92. Department/Division:
93. Reporting Date:

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Nuclear Power Plants: Design, Safety Standards Series No. NS-R-1, IAEA, Vienna (2000).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Protection against Internal Fires and Explosions in the Design of Nuclear Power Plants, Safety Standards Series NS-G-1.7, IAEA, Vienna

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Nuclear Power Plants: Operation, Safety Standards Series No. NS-R-2, IAEA, Vienna (2000).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Fire Safety in the Operation of Nuclear Power Plants, Safety Standards Series No. NS-G-2.1, IAEA, Vienna (2000).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Evaluation of Fire Hazard Analyses for Nuclear Power Plants, Safety Series No. 50-P-9, IAEA, Vienna (1995).

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Fire Hazard Analysis for WWER Nuclear Power Plants, IAEA-TECDOC-778, IAEA, Vienna (1994).

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Preparation of Fire Hazard Analyses for Nuclear Power Plants, Safety Reports Series No. 8, IAEA, Vienna (1998).

[8] INTERNATIONAL ATOMIC ENERGY AGENCY, Treatment of Internal Fires In Probabilistic Analyses for Nuclear Power Plants, IAEA Safety Reports Series No. 10, IAEA, Vienna (1998).

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, Root Cause Analysis for Fire Safety Related Events at Nuclear Power Plants, IAEA-TECDOC-1112, Vienna (1999).

[10] INTERNATIONAL ATOMIC ENERGY AGENCY, Inspection of Fire Protection Measures And Fire Fighting Capability at Nuclear Power Plants, IAEA Safety Series No. 50-P-6, IAEA, Vienna (1994).

[11] INTERNATIONAL ATOMIC ENERGY AGENCY, Assessment of the Overall Fire Safety Arrangements at Nuclear Power Plants, Safety Series No. 50-P-11, IAEA, Vienna (1996).

[12] INTERNATIONAL ATOMIC ENERGY AGENCY, Organization and Conduct of IAEA Fire Safety Reviews at Nuclear Power Plants, IAEA Service Series No. 2, IAEA, Vienna (1998).

[13] INTERNATIONAL ATOMIC ENERGY AGENCY, Use of Operational Experience in Fire Safety assessment of Nuclear Power Plants, IAEA-TECDOC-1134, Vienna (2000).

[14] NUCLEAR ENGINEERING INTERNATIONAL, Fire & Safety ’94, Conference Papers, Sutton, Surrey (1994).

[15] NUCLEAR ENGINEERING INTERNATIONAL/WILMINGTON BUSINESS PUBLISHING, Fire & Safety ’97, Conference proceedings, Wilmington, Kent (1997).

[16] INTERNATIONAL ATOMIC ENERGY AGENCY, Upgrading of Fire Safety in NPPs, IAEA-TECDOC-1014, IAEA, Vienna (1998).

[17] WILMINGTON BUSINESS PUBLISHING, Fire & Safety ’01, Conference proceedings on CD-ROM, Wilmington, Kent (2001).

[18] INTERNATIONAL ATOMIC ENERGY AGENCY and OECD/NEA, AIRS manual, Version 1.2, IAEA, Vienna (1999).

[19] USNRC, Title 10, Code of Federal Regulations, Chapt. 50.48 Fire Protection, Washington (1981).

Annex I

GERMAN EXPERIENCE FROM REPORTABLE NPP FIRE EVENTS

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Abstract. The operating experience from nuclear power plants (NPP) in Germany reveals only very few reportable fire events. However, the equipment affected as well as the plant locations, where these fire events occurred are typical and representative in comparison to the fires which occurred at NPP in other countries. Up to the time being, there was no severe fire reported from any NPP in Germany, none of the fire events reported to the German authorities was reportable to INES or IRS. Nevertheless, the operating experience from reportable NPP fires events as well as from those not reported gives indications where and to what extent to improve the fire safety in German NPP.

I.1. INTRODUCTION

In Germany, there are only few data existing on fires occurring in nuclear power plants (NPPs). For commercially operating NPP in Germany with a an overall operating experience of approximately 594 reactor years, up to the end of May 2001 only 25 fire incidents out of approximately 4860 incidents obligatory reported overall to the licensing and supervisory authorities since 1971 have been identified.

The existing database on reportable fire events from NPP in Germany is relatively small. Therefore, up to now in general still generic data from US and France and to some extent also German data on fire occurrence frequencies have been applied in the frame of probabilistic fire safety assessments. These data have to be compared to the plant specific conditions. For specific plant areas the generic data can only be used as conservative assumptions because of the differences to the plant specific location and conditions.

However, all the existing data and information on reportable as well as non-reportable fire events which occurred at NPP in Germany can be used for upgrading and maintaining the high level of the German NPP fire safety. Furthermore, all these data can be applied in the frame of performance based regulations.

I.2. REPORTABLE FIRE EVENTS IN GERMAN NPP

From the operating experience of nuclear power plants in Germany covering until 1990 only the experience of NPP in Western Germany with in total approximately 594 reactor years only

25 fire events were identified by the criteria for obligatory reporting to the licensing and supervisory authorities (see figure 1). Several pilot fires or fires in non-significant plant areas which could give a good indication for the root causes of more significant ones were of course not reported. These 25 fires represent an amount of approximately 0,5 % of the overall 4860 obligatory reportable incidents from NPP in Germany.

Nevertheless, it is well known that plant internal fires may represent significant internal hazards and have to be considered also in PSA studies. The officially available German database of reported fire incidents is too small for use in probabilistic studies. The databases internationally available, such as IRS by OECD and INES by IAEA or the SANDIA fire database, are also very small and to some extent not directly applicable to the specific plant to be analysed. It is therefore necessary to use plant specific information as well as the available generic data and adapt these as far as possible to the plant specific boundary conditions. For this application of generic data engineering judgement and a detailed expert knowledge are indispensable.

The fires reported within [1] can be binned together due to the following major types of fire:

— Oil fires,
— Hydrogen fires,
— Fires concerning electric equipment, and
— Fires concerning mechanical equipment / other fires.

The following oil fires can be mentioned: In 1976 at BWR-type German NPP an oil leakage occurred during maintenance and repair work at a magnetic valve of the hydraulic-turbine control. Approximately 8m3 of lubrication oil dropped out/ flew out onto insulation materials. A few minutes later, the leaking oil partly self-ignited (auto-oxidation) at a hot pipe of a safety valve in the area of a deteriorated insulation. The fire propagated to the area of lubrication oil support.

The fire could be extinguished by the fire brigade within very few minutes. Nevertheless, the reactor had to be shutdown. The lubrication oil support was totally damaged by the fire, the turbine hall was effected by smoke and soot. Two steel constructions girds were strongly affected by the heat and showed signs of deterioration.

At a BWR plant, a fire inside the insulation material for a turbine valve occurred in 1980. The fire was detected by automatic fire detectors and could be successfully extinguished by means of portable fire extinguisher by plant personnel within minutes. The turbine hat to be taken out of operation, the reactor was shut down for repair of the lubrication oil pipe. The safety significance of the event however was low.

In 1981, again there was an oil leakage from lubrication oil for one of a twin-unit PWR plants in Germany. An amount of approximately 100 l of lubricant leaked out the support pipe work and partly went into the insulation material of the MCP. Smoke and steam became visible by the video camera supervising the MCP. The pump including the lubrication support were manually switched off. The small pilot fire self-extinguished.

Another oil leakage resulting in a turbine hall fire occurred at a German BWR-type reactor in 1985. In the insulation of the moisture separator between high pressure and medium pressure partly in turbine, signs of flames and smoke became detectable in the automatic fire detection system. Original cause for the event was an oil leakage which had occurred about 30 h earlier.

Partly leftover oil from this leakage had entered the insulation material and self-ignited inside (autoxidation). The plant internal first aid fire team and the on-site professional fire brigade were able to successfully extinguish the fire within 30 minutes. The insulation was removed and exchanged by a new one.

Another type of lubrication oil fire occurred at one of the most recent PWR-type reactor units in 1990. The bearing of a fan for the NH4-stripping system of the waste water system had been overheated. Due to the overheating of the bearing the wheel of the fan motor could not work anymore and the lubrication at the motor ignited at the hot component. The fire became visible by smoke and was detected by the automatic fire detection system and successfully extinguished by the on-site shift first aid team within a very short time period. The event was not safety significant since the NH_4-stripping system does not belong to the safety related equipment. Furthermore, this event represented a typical single event, therefore no preventive measures against a repetition had to be taken.

Last not least another lubrication oil fire at a German NPP occurred in 2000 at a PWR during restart after the annual outage. Again leaking lubrication oil perforated into insulation material of a main coolant pump and self-ignited (autoxidation) at the hot component. The on-site first aid fire team together with the professional on-site fire brigade were able to extinguish the pilot fire successfully after the detection by two automatic fire detectors by manual actuation of the stationary spraywater deluge system within 3 minutes. However, safety related I&C cables were damaged and/or deteriorated and had to be exchanged preventively although no functional failures were observed. Due to the plant state the significance of the event was low, but a potential for a more safety significant sequence under different conditions is given (see [2]).

Hydrogen fires represent another type of safety significant NPP fire events. Up to now, only four fires of this type occurred at German NPP. The first reportable hydrogen fire in an operating NPP in Germany occurred at a BWR type plant in 1983 (see [3]). During an inspection of components the water purification system a hydrogen deflagration occurred causing a short ignition of the hydrogen at the ambient air. Due to a leakage, the condensed water could not flew in the right manner. The pre-heater of the recombiner did not function as intended. The mixture from gas and steam entering the recombiner was too wet and too cold so that the recombiner could not ignite. The gas-mixture from hydrogen, oxygen and nitrogen resulted in a self-ignition of the activated charcoal at the entrance. The plant was shut down and the fire, which was detected by the automatic fire detection system, was extinguished manually by means of a portable CO2 fire extinguisher. The significance of the event was nevertheless low.

A further hydrogen fire occurred at a BWR type reactor in Germany in 1988. During the maintenance work at the hydrogen circuit of the generator, some hydrogen was released and ignited with the ambient air. The shift leader gave fire alarm and performed a turbine shut down. The hydrogen support was closed manually, the hydrogen available inside the generator was blown out by feeding CO_2 into the generator. The on-site shift fire brigade was able to extinguish the fire directly by portable fire extinguishers. The worker in charge of the maintenance works was slightly hurt by the fire, there were no effects on the nuclear safety. However, partly the generator control components were damaged and had to be repaired. In conclusion, the licensee improved the administrative procedures for maintenance and repair work at the generator.

Another reportable German hydrogen fire event occurred in 1990 at a Konvoi-type PWR unit. The event started with the observation of an increase in the hydrogen feeding the generator. The generator was therefore inspected to find the leakage. During the leakage search a fire at the electric support line at the generator entrance started. The fire was directly observed by personnel and detected by the automatic fire detectors. The fire with a lot of smoke could be extinguished manually with portable CO_2-extinguishers by the fire brigade within a period of approx. 30 min using aspiration equipment. The reactor had to be shut down. Nevertheless, the event did only cause damage to the electric support of the generator and did not have any safety related consequences.

A more significant hydrogen fire occurred in 1991 in the reactor annulus of a PWR type reactor [4]. During repair and maintenance work at a valve of the oxygen support a worker stepped on a hydrogen pipe which was installed approximately 10 cm above the floor. The pipe broke under the worker's load and the released hydrogen directly ignited at the ambient air. The worker was able to give a fire alarm by telephone to the unit control room. The shift personnel immediately closed the valve for the hydrogen support. Within 7 minutes the fire was out.

The valve itself and parts of the hydrogen pressure decrease components including their cable were effected by the fire as well as various small polymeric parts of the pipework inside the room, which had to be exchanged. Nevertheless, the event did not affect nuclear safety since the fire compartment did not contain safety related equipment and other compartments were not affected by the fire. Therefore, the significance of the event was low, although a an IRS report [5] was distributed because of the possibility that under different boundary conditions such a fire could be safety significant.

Most of the fires reported from German NPP to the authorities were fires affecting electrical or electronic equipment including cables.

Several of these fires resulted from short circuits, earth faults, hot shorts. For example, a computer for the radiation protection outside the controlled area was totally destroyed by fire caused by a short circuit (BWR, 1976). Another reportable pilot fire caused by a short circuit following a short to ground occurred in the actuation mechanism of an emergency diesel during a regular in-service inspection. The fire was signalled in the unit control room by the automatic fire detection system. The fire self-extinguished. There were no consequences on the reactor safety.

A short circuit in a 220kV/380kV high voltage system which resulting in a fire at the equipment has to be mentioned as another fire event of electric cause (PWR, 1988, see [5]) but also igniting lubrication oil. The turbine was stopped and the reactor had to be shut down, the emergency diesels were started, the residual heat had to be removed via the secondary relief valves. The fire itself was automatically detected and extinguished itself within a short time period. The significance of the fire event was very low.

Due to mechanical load by a metallic frame a cable fire in the body sound check system a 220V support cable inside the cabinet of this system occurred was damaged in so far that a hot short igniting the cable. The smouldering pilot fire self-extinguished. The fire was not safety significant. Furthermore, preventive measures against a repetition were easily possible (BWR, 1988).

A typical fire in the electronic equipment was observed when an electronic element (condensator of an electronic element for the reactor power I&C) started to smoulder (PWR, 1989). The small fire was detected by the automatic fire detection system, further electronic equipment in the close vicinity of the burning one were damaged by smoke and heat. There were no further consequences, the event was of low significance.

Another short circuit induced pilot fire caused the failure of an emergency feedwater pressuriser valve in the turbine hall. Due to an electric fault the valve motor continuously closed the valve and overheated resulting in a small fire which was detected by the automatic fire detection system. The fire could be extinguished by on-site first aid fire fighters and was limited to the motor. The significance of the event was low (PWR, 1989).

One further fire caused by short to ground occurred in the electric AC/DC equipment in the frame of re-loading the battery resulting in a pilot fire limited to the electric component itself which self-extinguished. The fire was detected by the fire detection system as well as by personnel. The event was not significant for nuclear safety (BWR, 1991).

Last not least a fire in a 10kV switchgear induced by a short to ground (PWR, 1989) has to be mentioned in this group of fires affecting electrical equipment. On the other hand this fire also belongs to the next group of electrical induced fire by arcing. When the main grid was connected, an arc at the 10kV switchgear occurred resulting in a short to ground causing a smouldering fire. After detection by the automatic fire detection system the professional plant internal fire brigade was able to extinguish the fire within 15 minutes. Since the plant was in the annual outage, the affected equipment was not needed when the event occurred. The significance of the event therefore was low.

Another type of electrical fires are fires caused by electrical arcing, as a fire of a high voltage switchgear for the emergency diesel marshalling rack (1979, PWR). The fire was detected by personnel available as well as by the fire detection system and could be successfully extinguished within a few minutes. The affected switchgear had to be repaired and cleaned.

Another fire caused by electric arcing was observed at a 380V busbar (PWR, 1986). The fire was detected by the automatic detection system and could be extinguished manually with portable CO2 gas extinguishers within 11 minutes by the on-site professional fire brigade. The busbar did not belong to safety related equipment, thus the event was not safety significant.

Typical electric fire events are fires occurring at electronic devices as computers such as event totally destroying two computers for data collection from I&C did also occur in the switchgear building of a German NPP (PWR, 1987). The fire was detected by the automatic fire detection system. Besides the computers including additional peripheral hardware several electric cabinets within the same compartment were affected by heat and smoke. Due to the reliable and effective fire protection means there fire was locally limited and had no safety related effects. The significance of the event therefore was low.

Another arcing event resulting in a fire occurred during a regular in-service inspection of a 380V switchgear (1989, PWR). The small smouldering fire was directly signalled by the automatic fire detection system and immediately extinguished by on-site first aid fire fighters. The relevance of the event was low.

Only very few single fire events resulting from other than the above mentioned causes and/or affecting different equipment can be mentioned from the experience of reportable fire events at NPP in Germany.

These fires are:

- A fire of protective clothing in the turbine hall of a German BWR type reactor in 1978. Due to hot work the protective clothing caught fire. The fire was detected by personnel. It was extinguished manually with powder extinguishers by the shift personnel immediately. The fire was not safety significant.
- A fire of polymeric material caused by a heater falling down inside the nuclear auxiliary building (PWR, 1979)

During preparative work for maintenance and repair a heater had been provisionally installed to dry the concrete. The falling heater caused the overheating of plastic material in the close vicinity, particularly of a pipeline under the building sump. A smouldering fire occurred at the pipeline which was detected manually by personnel and extinguished within minutes by first aid shift fire fighters by means of powder extinguishers. The event was not safety significant.

The experience from 25 reportable fire events clearly shows that the risk of a hazardous safety significant fire which cannot be limited to one redundancy is relatively low due to the fact that well trained and highly motivated first aid fire fighting shifts personnel as well as professional plant internal fire brigades are available at German NPP. Up to now, none of the reportable fires had the potential for a hazardous fire. The main reason is seen in the existing fire protection concepts mainly focussing on preventive measures but also taking into consideration to fight those fires which cannot be prevented as early and successful as possible to limit the fire effects as well as to limit the consequences for nuclear safety.

I.3. EXAMPLES FOR NON-REPORTABLE FIRE EVENTS IN GERMAN NPP

Several examples of fire events not available in the database of events obligatory reported to the German authorities because of being out of scope are, however, interesting due to the fact that they represent precursors or that under different boundary conditions these events could potentially develop to relevant ones.

In the following, two fire events being non-reportable due to the applicable German reporting criteria are outlined in more detail to give an indication on events not reported, but nevertheless interesting from safety point of view.

One of these incidents was a non-safety significant event titled "Potential degradation of the safety function cooling the fuel due to damage of the motor of a reactor main coolant pump (MCP)" which occurred in 1993 at a two unit pressurised water reactor (PWR) type NPP with a designed electrical power of 1200 MWe.

The unit was starting up after the annual refuelling outage and maintenance period. The reactor was still in shutdown condition with the four main coolant pumps (MCP) still running to heat up primary and secondary circuit when a short to ground was signalled. Approximately half an hour later the automatic fire detection system gave an alarm for the motor of one of the four main coolant pumps. The shift fire fighting personnel could not observe any fire signals.

3 minutes later the respective MCP tripped by a short circuit. The firemen took the lubrication oil supply system out of operation and prepared the spraywater deluge system for actuation. However, no flames were visible. 58 minutes after the first alarm flames and smoke became observable, so that the fire fighting could be started, and fire alarm had to be signalled. The spraywater deluge system was actuated manually from the unit control room. 77 minutes after the ground circuit signal the fire was successfully extinguished. The fire was limited to parts of the MCP motor. Safety related equipment was neither affected by the fire itself nor by the fire extinguishing measures.

The following direct causes could be identified for the event:

- Short to ground at the MCP motor due to a tool forgotten chisel by a worker,
- MCP failure due to short circuit because of the missing automatic ground fault protection.

However, The ground fault at the MCP motor is not of high significance, because only few equipment was affected and in case of an electrical detection of this ground short the event would have stopped without any fire occurring and without any consequences. The loss of MCP by short circuit is also not safety significant as it is considered in the plant design. The failure of one MCP during power operation and three loop operation does not cause any risk for the plant, the protection goals are achieved. During hot shutdown conditions the failure of MCPs is not safety significant. The operating experience further shows that at the end of the fuel cycle a very thin oil film without relevance for fire load and spreading can be found on parts of the motor housing which is removed at the beginning of the scheduled refuelling outage. Oil dust potentially to be found in the direct vicinity of MCP motor is not relevant. It therefore can be stated that the event sequence will not be more severe during power operation.

The following corrective actions were taken after the event:

- The acceptance criteria for contractor induction training were reviewed and the administrative procedures were revised,
- Training means were arranged to enhance the safety awareness of the shift and access control personnel to achieve an improved safety culture,
- As a technical measure, the electrical ground fault protection of the MCP was improved such that now an automatic trip of the pump on ground fault is ensured.

Another non-reportable fire events took place in 2000 at a boiling water reactor (BWR) type NPP with a designed electrical power of 930 MWe.

The unit was under start-up conditions after the annual refuelling outage and maintenance period at a power level of approximately 70%. During a plant walk-through, smoke was observed in the turbine area in the turbine hall. After alarming the unit control room two shift engineers were sent to the affected location, finding flames and open fire with heavy smoke at the turbine bearing between high pressure and low pressure part of the turbine. The first aid fire fighters started extinguishing with a manual powder extinguisher. The on site fire brigade arrived within a few minutes and was able to successfully fight the fire with an additional manual extinguisher of the same type within a very short time period. The reactor was shut down.

Direct cause of the non-reportable fire event was leaking turbine lubrication oil which penetrated into the insulation material and self-ignited due to the high component temperatures. Such autoxidation phenomena in case of leaking oil penetrating into insulation materials of hot components are well known and have several times been observed at turbines worldwide.

The event represents a smaller pilot fire which could successfully been extinguished by first aid fire fighters and the plant fire brigade within a short time period. Although a lot of smoke was released, the consequences of the fire were low, because the temperature rise was low and only few equipment was affected. Safety related equipment was not affected. The event was not safety significant.

However, the following corrective actions were taken after the event:

- The insulation was complete removed and renewed,
- An improved drain and drip device for leaking turbine oil was installed giving the possibility of a daily control of potential leakages,
- In addition, the fire detection concept was further improved by installing two types of automatic fire detectors directly above the turbine bearing.

Both examples of fire events in German NPP which were not reported due to the existing reporting criteria show that also non-reportable fires should be documented and used for improving the fire safety.

I.4. STATISTICAL EVALUATION OF THE REPORTABLE FIRE EVENTS AT NPP IN GERMANY

The statistical evaluation of the up to now only 25 reportable fire events at NPP in Germany reveals the following results (see also tables 1 and 2, figures 1–3):

- Nearly all of the fires resulted either from minor deficiencies in the fire protection means available at the time of the occurrence or represented single events which cannot totally be excluded even by a well balanced fire safety concept.
- None of the events had - under the boundary conditions of the respective plant state and measures taken - the potential to cause harm to the nuclear safety of the plant.
- All of the fires extinguished themselves or were extinguished successfully within an adequate period to be limited to the fire compartment or the ignition area itself.

Nevertheless, the statistics also show that a majority of reportable fires typically occur at electric and/or electronic equipment.

Fire incidents with the principle potential of resulting in a hazardous incident may occur from lubrication oils or hydrogen igniting at hot components. In this context, the importance of a fast reliable and effective fire detection and extinguishing has to be mentioned. Without these protection means not all of the fire events up to now reported to the German authorities would have been assessed as "not or only low significant" for nuclear safety.

I.5. CONCLUSIONS

The available data on fire events reported to the authorities from NPP in Germany give the result the amount of safety significant fire events is low. Nevertheless, several of the fire which occurred up to now at German NPP could have the potential under other boundary conditions to influence nuclear safety.

However, it should be underlined that the necessary database still has to be improved and to be expanded for several fire protection features. Moreover, the influence of human actions is to be taken carefully in consideration. In particular for German NPPs, the use of US data for the fire occurrence frequencies is insufficient due to the consequential conservative assumptions just at the starting point of the quantitative calculations; on the other hand, the presently available German data do not allow to provide verified data.

TABLE I. FIRE CONTRIBUTION IN DIFFERENT AREAS OF GERMAN NPP

Building / Area	Number of Fires	Fire Contribution
Reactor Building	3	~ 12 %
Switchgear Building	8	~ 32 %
Auxiliary Building	3	~ 12 %
Turbine Building	8	~ 32 %
Emergency Diesel Building	1	~ 4 %
Other Areas	2	~ 8 %

TABLE II. TYPES OF FIRES REPORTED FROM NPP IN GERMANY

Type of Fire	Number of Fires	Contribution
Oil fires	6	~ 24 %
Hydrogen fires	4	~ 16 %
Fires concerning electric equipment	13	~ 52 %
Fires concerning mechanical equipment / other fires	2	~ 8 %

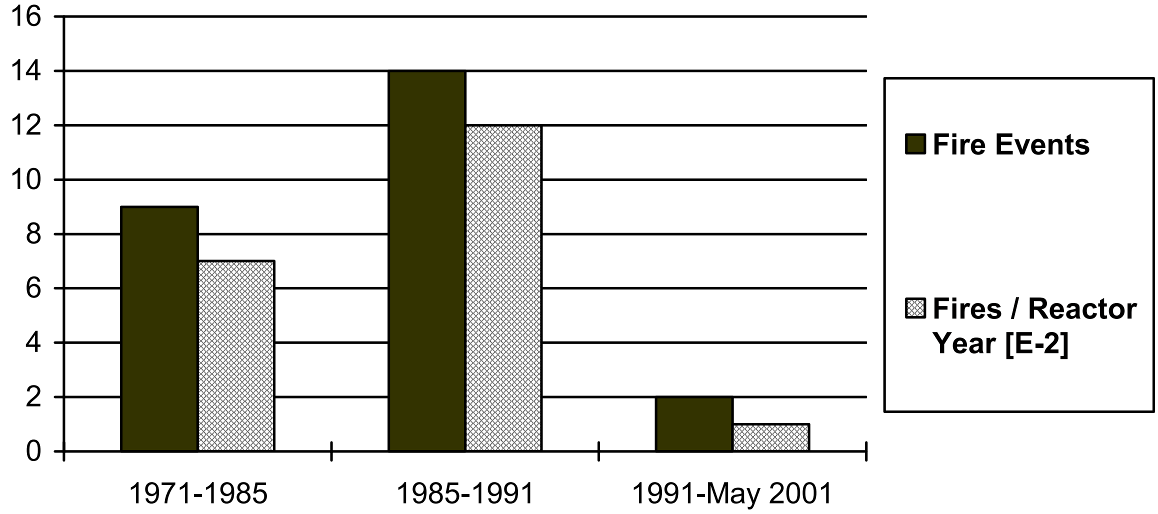

FIG. 1. Reportable fire events from NPP in Germany.

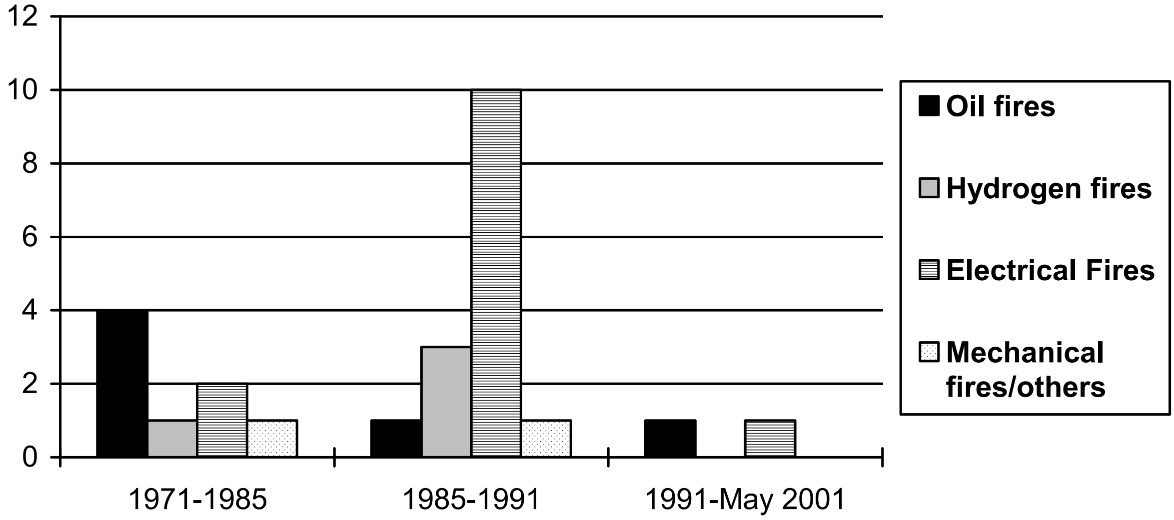

FIG. 2. Different types of reportable fire events from NPP in Germany.

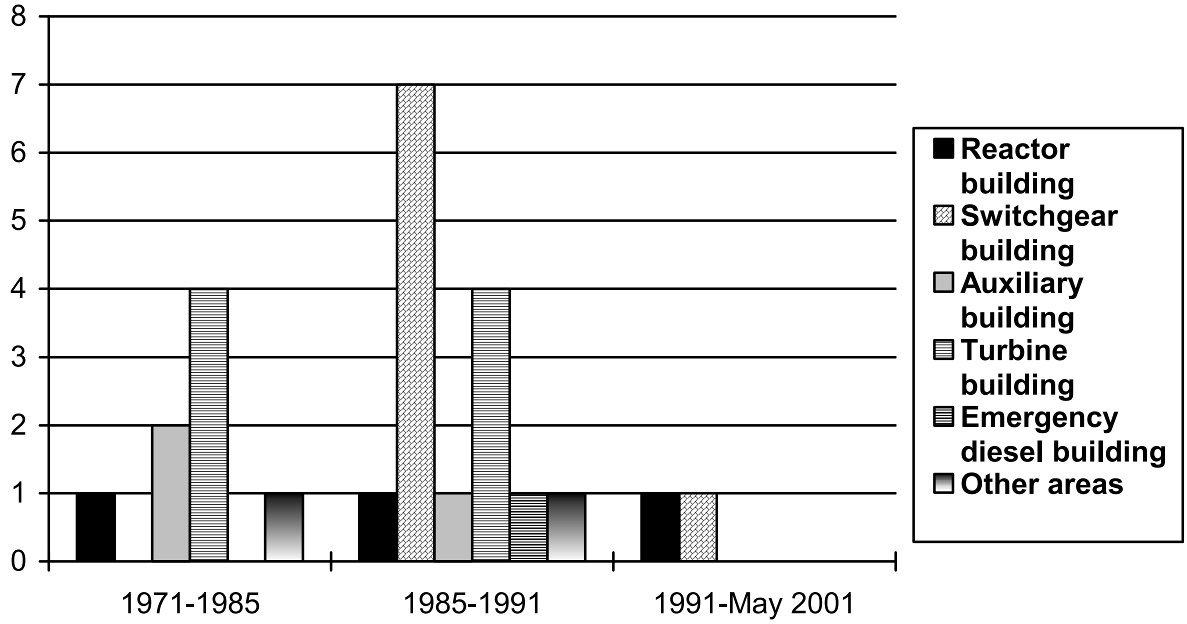

FIG. 3. Reportable fire events from NPP in Germany binned to different areas.

REFERENCES TO ANNEX I

[1] GESELLSCHAFT FÜR ANLAGEN- UND REAKTORSICHERHEIT (GRS) MBH, Datenbank für meldepflichtige Ereignisse in deutschen Kernkraftwerken "VERA", Stand: June (2001).

[2] GESELLSCHAFT FÜR ANLAGEN- UND REAKTORSICHERHEIT (GRS) MBH:, Vorabinformation zu einem meldepflichtigen Brandereignis im Kernkraftwerk Grafenrheinfeld am 05.05.2000: "Folgeschaden auf Grund Brand an der Hauptkühlmittelpumpe YD10D001", July (2000).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA), Fire in a charcoal bed of the off-gas system, IAEA Incident Reporting System (IRS), IRS-No. 359, Vienna (1983).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA), Hydrogen fire following a line rupture in the reactor building annulus, IAEA Incident Reporting System (IRS), IRS-No. 1225, Vienna (1991).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA), Damage of an instrument transformer causes loss of offsite power to both units, IAEA Incident Reporting System (IRS), IRS-No. 863, Vienna (1988).

Annex II

FIRE OCCURRED AT THE ARMENIAN NPP ON 15 OCTOBER 1982

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ANRA,
Armenia

Abstract. This paper describes the major fire event occurred at the Armenian plant Unit 1 on 15 October 1982. Many lessons have been learnt from this event, particularly on the need for improving the safety assessment techniques in relation to multiple fire sources.

II.1. INTRODUCTION

The Armenian NPP (ANPP) is located on the westbound of the Ararat Valley in a distance 28 km to the west from Yerevan and 16 km from the border with Turkey.

The ANPP represents itself a double-unit nuclear power plant with WWER-440 (V-270) reactors. The first phase of the ANPP design was developed in 1969. The ANPP belongs to the first generation V-230 NPPs. The design of the Armenian NPP was improved due to the specific features of the site.

The local feature of ANPP is the seismicity of magnitude 8 on MSK-64 scale. The ANPP Unit 1 was put into commercial operation in December 22, 1976, and Unit 2 - January 5, 1980. Each of both units has rated electrical power of 407.5 MW (e).

The main building of the ANPP includes: two reactor blocks with six steam generators and all auxiliary equipment, the turbine hall with 4 turbine generators located abreast (2 turbine generators for each unit), the cable tunnels, the switch board rooms, two main control rooms (MCR-1, MCR-2) in order to operate each unit separately and the central control room for measuring and monitoring the switchgear units (metering, signaling and alarms). The fire alarms are grouped together on the central control room, whilst in the main control room only a general fire alarm is displayed.

The redundant DG station is located in a separate building on the territory of the ANPP where six DGs are located: 3DG for each unit.

The cables are laid on the horizontal trays of the cable tunnels: low voltage, middle voltage and power cables are mixed. The cable insulation was not made from fire retardant material and was not covered with the fire retardant (intumescing) material. At that time such coatings and cables insulated with retardant materials were not used in the atomic energy in the USSR. The cable tunnels were equipped with a foam system.

II.2. THE INITIAL CONDITION OF THE ANPP BEFORE THE INCIDENT OCCURRED ON 15 OCTOBER 1982

The Unit 2 was operated in full power with loading of turbine generators TG-1, TG-2 200 MW each.

All 6 MCP (main circulation pumps) were in operation and the coolant flow rate to core was 43000 m3/hour.

- Reactor coolant heating ΔT 290C
- Coolant medium temperature 2750C
- Pressure on inlet of reactor core 1250C
- Level in pressurize 4 m

The unit 2 with all auxiliary equipment was under the repair.

NPP shift supervisor - B.Kochenev, Turbine Shop shift supervisor - A.Anokhin, engine-operator- N.Dubasov.

II.3. DESCRIPTION OF INITIATION, PROPAGATION AND LIQUIDATION OF INCIDENT 15 OCTOBER 1982

At 9:55 a.m. the engine-operator of Main Control Room -1 was ordered to start the service water pumps 2 NTV- 4 to the bus 6kW 1RB-2.

There are 7 service water pumps at the ANPP. The 2 NTV- 4 service water pump is the reserve one and is to be connected to the corresponding vital bus 6 Kw during maintenance of any service water pumps of the unit 1 or unit 2 (look at fig. 1).

2NTV-4 service water pump was started from the Main Control Room -1 by the control switch. Having switched for the first time and noticing that the pump didn't started, he made several attempts to start 2NTV-4 using the control switch.

The short circuit occurred in the terminal block of 2NTV-4 service water pump that didn't switch off by its breaker. The breaker 1RB1, 2 of the normal power supply was interrupted by the protection system. As a result the breaker of the auxiliary supply of the bus 1RB1, 2 was automatically switched on and immediately was interrupted by its protection system due to short circuit on 2NTV-4. In accordance with the requirements of instruction on operation of electric motors the repeated starting of the motors was allowed in 15 minutes according to the heating conditions.

The operating personnel noticed under the electrical light the deep and longtime decrease of voltage in the house load distribution system.

The long-term short circuit current along the cable 2NTV-4 led to its overheating and ignition on the places of rupture. This caused ignition of adjacent cables and fire in the cable compartments 59a and 60a, and also to ignition of a bunch control cables laid on metallic box and cable shaft 2 in Main Control Room -1 (look at Fig. 2, 3).

After the incident liquidation the observation of the cable of 2NTV-4 showed that it had damages on nine places with break of aluminum sheath. The cable near the electric motor terminal block burnt down. The cable isolation in the breaker cubicle completely burnt down without traces of electric ark impact, which also confirms the long-term impact of the short circuit on the cable.

In a minute, at 9:56 a.m. the central control room received a signal of fire in the cable compartment 59a. After receiving confirmation from an electrician sent there, the operation personnel called the local fire brigade and tried remotely to switch on the foam fire extinguisher. But they failed.

In 6 seconds, at 10:05 the emergency protection system-III Type of the Unit 1 activated due to switch off of the 1 MCP-3 (Main Circulation Pump). All control rods dropped down.

In several seconds on the Unit -1, at reactor power 80–85%, the emergency protection system I Type activated signaling the following first causes:

- Neutron flux exceeded 20%;
- Period of neutron flux no more than 20 sec;
- Loss of supply of control and protection system-380V;
- Loss of supply of control and protection system-220V of direct current.

Damage of a number of control and power cables resulted to numerous failures in the Unit- 1 operation system

In ten minutes, at 10:05 a.m. The operating personnel closed the stop valves of turbines, and in two minutes the generators were disconnected from the grid.

In eleven minutes, at 10:06 a.m. the service transformer N 1 was lost due to cable ignition, also all Main Circulation Pumps were lost, the light put out, the telephone link was disconnected, a number of devices and signalizing in the Main Control Room and Central Control Room were disconnected. Hence, at the ANPP Unit -1 the house load supply 6 and 0.4 kW except for vital buses 0.4 kW supplied from reversible motor-generators was lost.

Due to loss of power of vital reliable power supply buses 1 RB-2, 2RB-2 - diesel generators DG-2, DG-3 activated. But DG-3 switched off due to short circuit on outlets of generator, DG-2 switched off by the protection system and notwithstanding the repeated attempts, didn’t activate from the local control room, and DG-1 was under the repair.

The operation personnel repeatedly made attempts to restore the supply buses 6 kW of house loads from the service transformer N 2. For some time they succeeded to restore High Pressure Injection Pump 1APN-1 and the Service Water Pump.

In twenty minutes, at 10:15 a.m. the personnel initiated the fire extinguishing in the cable compartments. Further attempts to use the foam fire extinguishers from the local control panels were unsuccessful.

To the time of the fire brigade arrival the cable compartments 59a, switchgear 6/04kW, the cable compartment under the Main Control Room 1 were filled with smoke.

At about 10:25 a.m the electric shop personnel undertook actions to displace the hydrogen (dehydrogenises) from the turbine generators TG-1 and TG-2. This action was performed improperly, and as a result of that about 20% of hydrogen was left in the generators.

Due to the continued fire in the cable compartments at about 11:45 a.m. the voltage reliable power supply bus 0.4 kW 8 NA was lost and the short circuit occurred on the 3 direct current panel 1.

In 1 hour 33 minutes, to 11:28 a.m. the pressure in the main steam header increased up to 55 kgs/sm2 and resulted to activation of the safety valve of 1SG3. After opening manually the fast-acting atmospheric reduction system BRU-A and closure of the safety valve PK-PG by the operating personnel the further steam dump was performed with periodical change of opening level of the fast-acting atmospheric reduction system BRU-A.

The parameters of the reactor installation, fixed by the registering apparatus before the loss of power at 11:45 a.m. witnessed the normal transition to the regime of the coolant natural circulation on the primary side.

Till 12:00 p.m. the feed water pump 1 PEN-1 started spontaneously 3 times.

In 2 hours 15 minutes, at 12:10 p.m. TG-1 and TG-2 were spontaneously connected to the grid. TG-1 began to rotate, the short circuit occurred on the outlet of TG-2 and in the closed conductions in the area of the earth blades.

The short circuit caused the fire ignition in the area of TG-2 main oil tank. At the same time there was a short circuit on outlets 15.75 kW of station service transformer 22T. New fireplaces were quickly liquidated by the timely actions of the ANPP personnel and fire brigade. The generators breakers were switched off on the switchgear-110 and 220 kW.

The autotransformer 110-220 kW and all lines 220kW were disconnected due to the short circuit on TG-2 and switching of TG-1 to the grid. The second service transformer switched off and the plant was a total blackout. During the fires at the NPP the compartments, including the Main Control Room and the Central Control Room were in smoke. The NPP personnel worked in gas masks.

In 2 hours 35 minutes, at 12:30 p.m. The NPP personnel initiated works on installation of temporary spare cables for vital customer supply from the diesel generators 2DG-1 and the unit 2 house load switchgears.

At 12:45 p.m. the Main Control Room totally lost the control on the unit 1 reactor.

In 5 hours 18 minutes, at 15:13 p.m. High Pressure Injection Pump 1APN-4 was activated from diesel generator. The supply of the Unit 1 with boron solution with concentration 12g/kg was started.

In 6 hours 35 minutes, at 16:30 p.m. The fireplaces at the NPP were completely liquidated.
In 7 hours 5 minutes, at 17:00 p.m. Auxiliary Feedwater Injection Pump 1APEN-2 was activated.

Recovery of Feedwater Injection Pump was necessary to fill the steam generators and provide primary circuit cooling.

In 7 hours 15 minutes, at 17:10 p.m. the control on SG water level was restored. The control on neutron flux was restored at 20:40 p.m.

Till 20:00 p.m. the average temperature of the primary circuit was kept on level 260°C at average temperature change in hot and cold legs for about 15°C. The pressure on the primary circuit did not drop below 100 kg/sm2. At operating of High Pressure Injection Pump 1APN-4 the pressure of the primary circuit reached 130 kg/sm2.
The water from the deaerator supplied the steam generators.

The analysis of the emergency shutdown and cooling of the reactor showed that the failure of the reactor core cooling did not occur. The radiochemical analysis of the primary circuit coolant activity also showed the damage of fuel elements did not occur.

The direct cause of the incident was the short circuit in the terminal block of electric motor 6kw of the service water pump 2NTV-4.

The root causes of the incident were error of the control room engine-operator who several times in short period of time remotely switched on the pump 2NTV-4 on the short circuit and the electric shop personnel who did not ensure sealing of the terminal block and fixing of cables 6kW. In both cases the violation of the instruction on operation of electric motors was observed.

The causes of the incident progression were:

The breaker did not switched off during short circuit.

Long term short circuit current flow through the cables 6 Kw of the pump electric motor 2NTV-4, that resulted to the unallowable heating of the cable, its damage and ignition.

Delay connected with the foam fire extinguisher of the cable compartments due to unclear requirements reflected in the operational and positional instructions that led to impossibility to start the working system of fire extinguishments.

Fire propagation from the fireplaces in the cable compartments (direction 59a) to the cable compartment (directions 58a and 57a) and to the vertical shaft ¹2. The fire brigades, arrived timely at the ANPP, couldn't start the fire extinguishments in the cable compartments as far as the acting "Instruction on fire extinguishments at the electric facilities of electric stations and substations" prohibited to extinguish the fire in heavily smoked compartments without turned off power, and it was impossible to fulfil this requirement in relation to the systems of reactor control and cooling.

Due to existence of hydrogen in the turbine generator TG-2 there occurred the hydrogen explosion with internal damage to the generator that resulted to damage of station service transformer.

The connection of the stopped turbine generators TG-1 and TG-2 to the grid and long term over current led to the TGs damage. Spontaneous connection of the TG to the grid could take place due to bridge control wires due to burnt cables. The bridging of the conductors could be resulted by the mechanical impact on the cables with burnt isolation of strong water flows during fire extinguishing.

The investigation results showed:

- In the cable entresols the cables were placed in the closed blocks, that didn't allow organizing their effective extinguishments.

- Between the parallel cable sections there were cross-linkages the metallic boxes enabling the fire propagation.
- The smoke removal devices were absent in the Central Control Room and reactor shop stairwell.
- The automatic device of fire extinguishments in cable tunnels was brought in remote control.
- The entry doors in the cable compartment on the level 3.6 m. from the side of the control room were not fire resistant.
- The cable lines installed on the metallic box that connected the cable tunnels directions 57-60 through the walls were not sufficiently sealed.
- The automatic start of the fire extinguisher device was not supplied from the NPP vital buses. It was supplied from the normal supply buses.
- The instruction on fire extinguisher operation did not contain requirements about the persons who should activate this device and their actions during failure to activate.
- The cable 2NTV-4, selected in accordance with the electric device rules, did not ensure the thermal resistance in case of failure to switch off the short circuit by its breaker and further automatic activation of reserve switcher, then automatic switch off of the reserve switcher by the protection system.
- The fire destroyed relatively not big cable area, the path length- 20m incurred fire.

II.4. CONCLUSION

On the basis of the operation deficiencies discovered during investigation there were developed the ANPP safety improvements measures, which covered all spheres of operation. There was developed the ANPP reconstruction project, in particular, there was developed and introduced the additional emergency cooling system that ensured the independent supply, physical separation of cables of vital consumers that participate in the NPP emergency cooling.

After this fire event there were revised the rules for design of emergency electric supply that should include the principle of channels independence, i.e. physical and functional separation. The unit 1 was restarted in September 1983.

Before the ANPP restart in 1995 there was conducted significant reconstruction connected with the fire protection with respect to the new requirements to designing of emergency electric supply.

In 1998 the TACIS specialists with participation of the ANPP specialists conducted the deterministic fire risk analysis. This analysis investigated and quantified the prevailing risks for internal fires in areas most relevant to nuclear safety. As a result there was proposed a list of measures that will mend the most aggravating deficiencies.

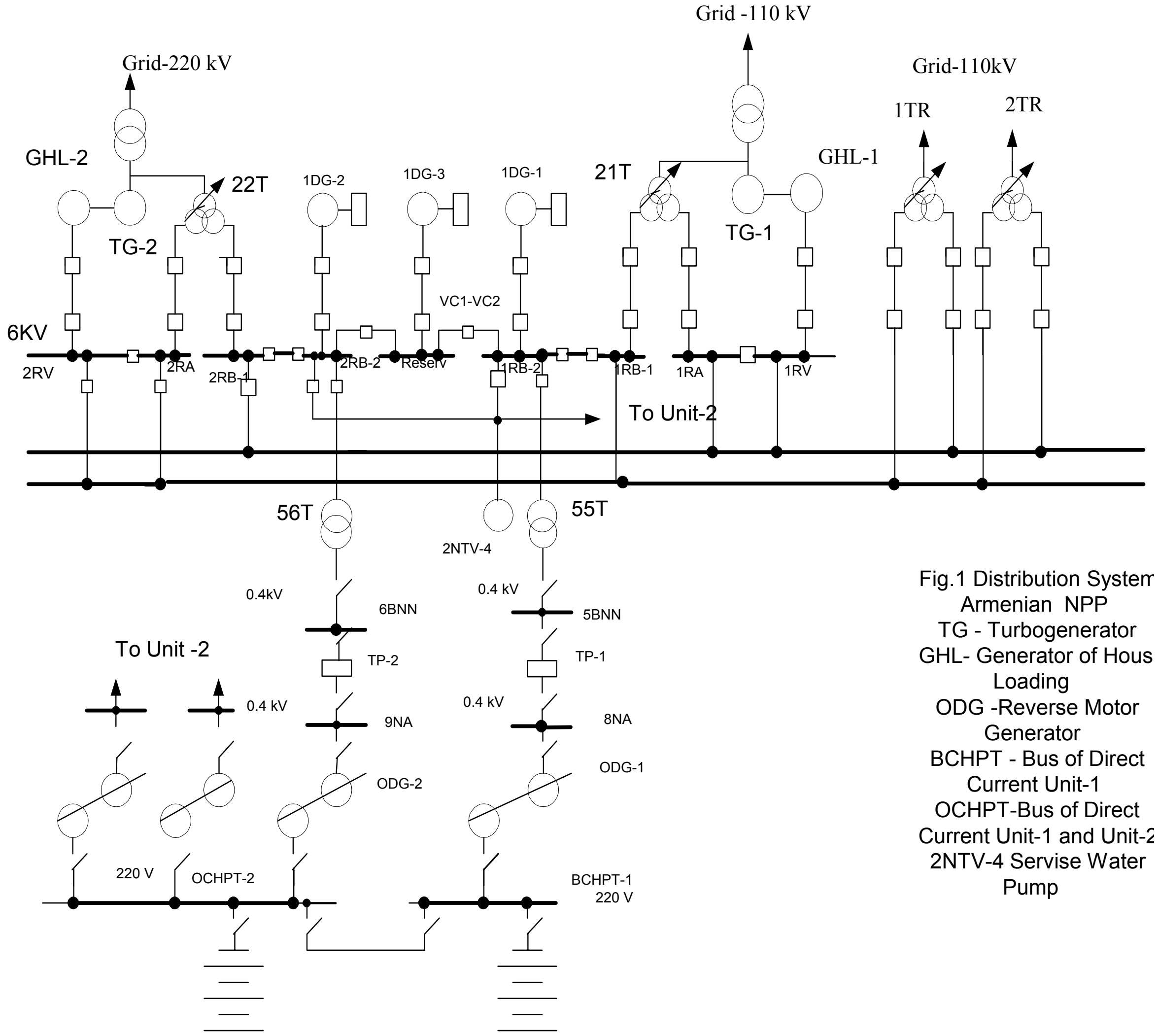

Fig.1 Distribution System Armenian NPP
TG - Turbogenerator
GHL- Generator of House Loading
ODG -Reverse Motor Generator
BCHPT - Bus of Direct Current Unit-1
OCHPT-Bus of Direct Current Unit-1 and Unit-2
2NTV-4 Servise Water Pump

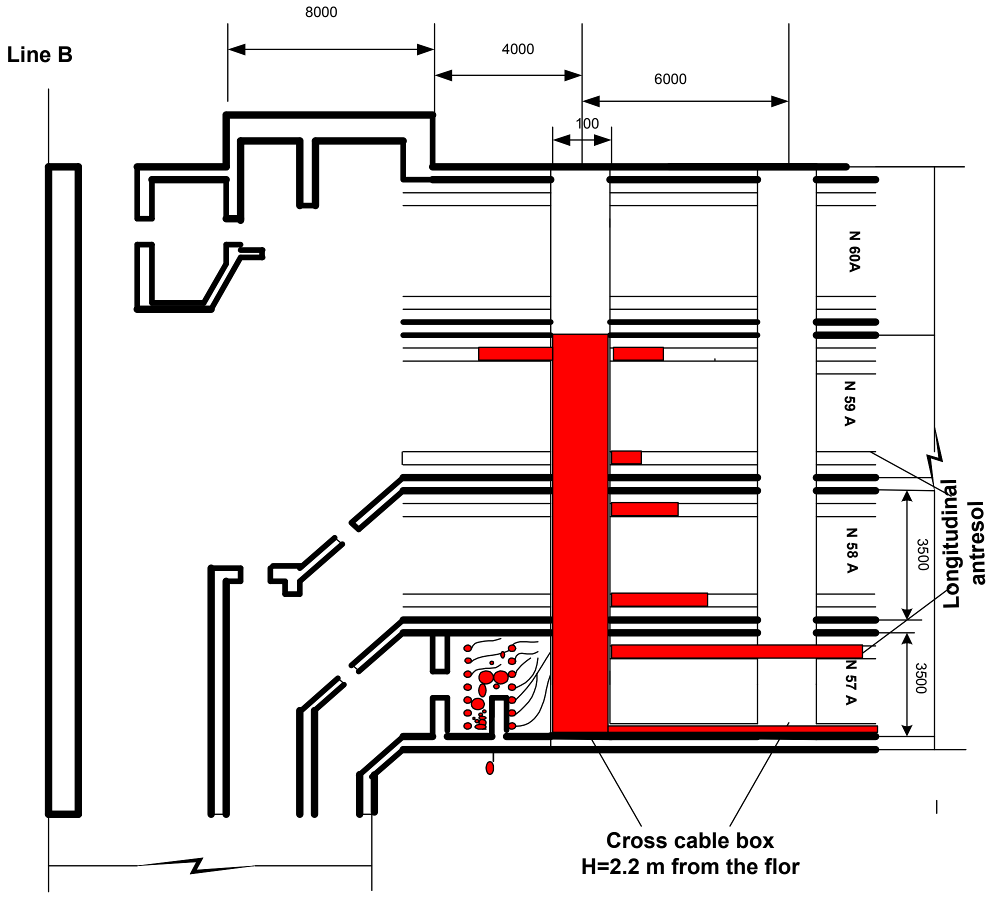

FIG.2.
Armenian NPP Layout
Level - 3.6 m
The red color indicated
fire propagation

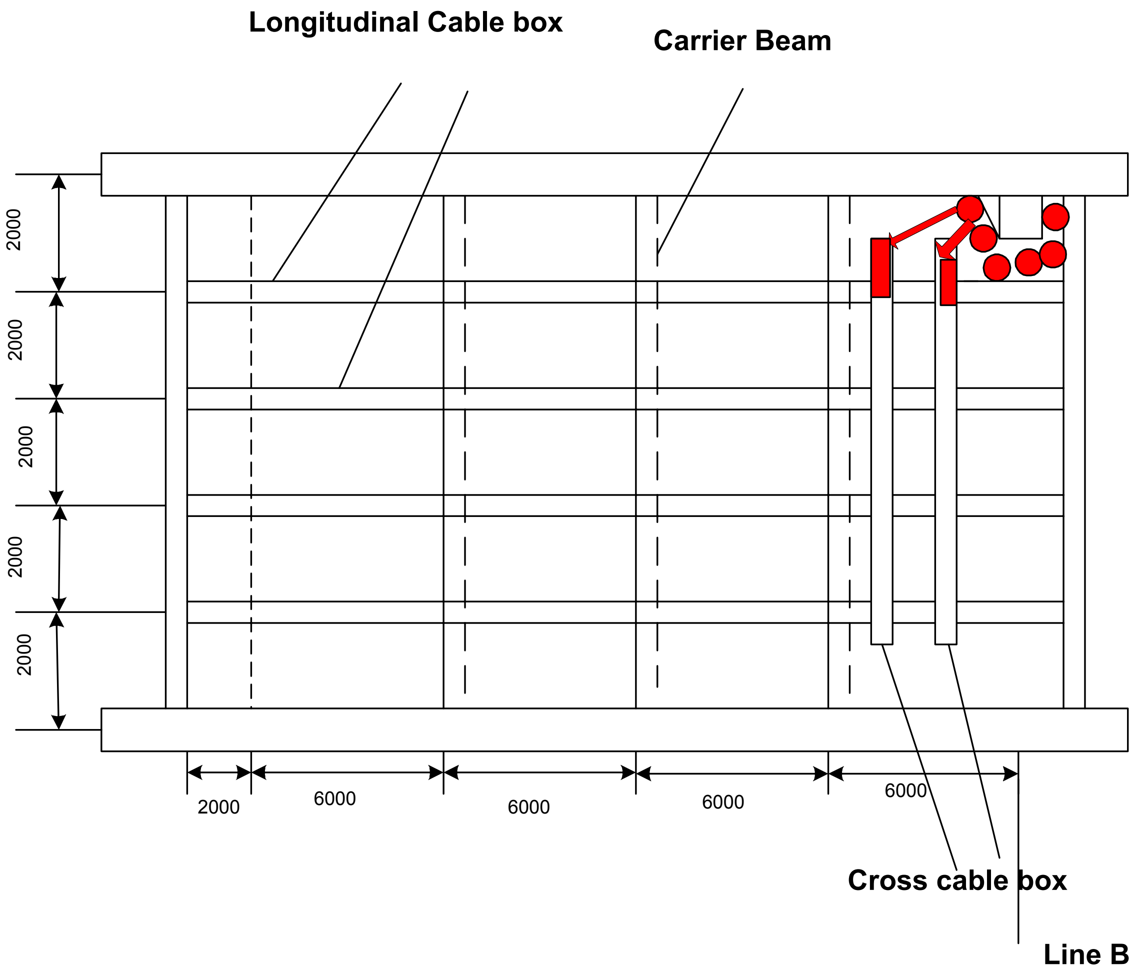

Fig.3. Armenian NPP
Layout
Level 5.4 m
The red color indicated
fire propagation

Annex III

FIRE INCIDENTS IN SWEDEN, A SELECTION

J. Svensson, Sweden

Abstract. The paper describes the major fire events occurred in Sweden in recent years. The fire database and the lessons learnt are carefully described for future use.

Fire Incidents in Sweden, a selection

1. Introduction

This paper is written for the IAEA technical committee meeting 9–13 of July 2001 in Vienna. It describes statistical data and fire events in Sweden. It does not give out to cover all experiences in Sweden, only some details from events considered interesting.

2. Method

At first a brief conclusion of reporting fire events in Sweden is made from the stastical dara gathered in a common database. The database also includes statistics concerning two Finnish NPP's. Also Anger's and Pörn's[1] presentation of quantitative and qualitative results from searchers and analaysis of the Swedish NPP fire database is refferd to. A few fire events are described and how experiences in general are taken care of and used.

3. Nuclear power in Sweden

In Sweden there are 11 commercial NPP's, since Barsbäck 1 was decommissioned a few years ago. The 11 NPP's are allocated at four different sites. Three sites have their own local fire brigade, and one has an extended agreement with the municipal fire brigade about co-operation in the case of fire.

The oldest of the now existing plants was commissioned in 1972. The regulations then prescribed a one hour rated fire barrier between different fire compartsments. Both the nuclear industry as well as SKI, the Swedish nuclear inspectorate is presently conducting work on moderniazation of the regulations, including fire regulations.

4. Statistical dara from Sweden (and Finland)

4.1 The database

The data concerns registered events from 1977–2000.

4.2 Definitions

In the database fire events are separated into different categories.

Near fire – self extinguished, if the fire dies before causing any damage.

[1] Angner and Pörn.

Near fire – early extinction, no damage

Smoke – if smoke is produced without an open flame

Heavy smoke – the whole room is filled with smoke

Interesting events – such as leakage of flammable materials, identified failure in barriers can also be registered in the database.

4.3 Overall Picture

The overall fire frequency per year (Swedish and Finnish NPP's) is calculated to:

	5%	50%	95%	Average
Effect	0.07	0.13	0.22	0.14
Shutdown	0.00	0.47	3.84	1.05

The percentiles are one way to measure uncertainty. There is a 5% possibilitiy that the fire frequency for a certain year is 0.07 or lower, during effect operation.

4.4 Fires

Among the 211 registered events there are 555 cfires in the database. The database contains information about one third is equally divided in electric and reactor buildings and about one third is allocated in other buildings. Looking at the type of room that are involved more then one third is located in process rooms. The major part of the fires in process rooms is caused during shut down. None are located in cable or battery rooms. The registered fires seldom caused the reactor to trip.

Hot work and human error cased 14 fires, at leasr thirteen of them was put out manually (one has no extinction cause registered).

5. Fire experinces

5.1 Fire in turbine building, Barsebäck 1979

5.1.1 Description

A blade in tge turbine broke and caused the generatir changing position. Oil leaked out and ignited. Missiles damaged the sprinkler system, which severely effected the function oth the sprinkler. After that the sprinker helped the fire spread since burning oil floated on the water. The damages were extensive.

5.1.2 Failing barriers

As mentioned above, the mitigating system worsened the consequences since it was damaged and the fire could have affected other systems.

5.1.3 Lessons learned from this fire

One thing one can learn from this fire is he need for mitigating the area where the fluid can spread, After the fire a smoke evacuation system was installed. Though the volumes in the turbine halls a large, visibility is rapidly reduced when considerable amounts of oil are burning. This makes it more diffucult for manually attacking the fire. Therefore, e.g. Barsebäck has obtained a heat sensitive camera, since there are examples of successful fire fighting with such equipement. Even though there are no Swedish examples of cable fires, a heat sensitive camera can be presumed to be useful in the case of a relatively small fire in a large volume.

5.2 Fire in turbine building, Ringhals 1981

5.2.1 Description

A leaking steam isolation under a metal sheet. A flammable liquid ignited. The fire was put out manually.

5.2.2 Failing barriers

No instruction or experience on how to attack this type of fire.

5.2.3 Lessons learned from this fire

A technique was developed which focused the importance of uncovering the insulation.

5.3 Bin bag fire, outside building, Ringhlas 1979

5.3.1 Description

Someone had placed bin bags outside the building and for some reason they ignited. The local fire brigade put out the fire. It caused no serious damage.

5.3.2 Failing barriers

Keeping control of transient fire load is essential. Though this incident took place outside, it stresses the need for administrative control to limit storage of unnescessary fire load within the facility.

5.3.3 Changes due to this fire

In the development of new fire protection programs the need to reduce and control transient fire load is stressed.

5.4 Fire in Diesel building, Ringhals 1992

5.4.1 Description

Sparks from sawing metal ignited oil in insulation. The fire was put out manually, and did not cause any sersious damage.

5.4.2 Failing barriers

The safety covering before starting work was not extend enough.

5.4.3 Changes due to this fire

No information available.

5.5 Fire spread from small compartment, Gothenburg 1998

A devastating, well-known fire with lethal outcome, occurred in Gothenburg in 1999. The fire has no direct linking to nuclear industry, but since large fires rarely occur we can learn at least one thing from this terrible event. The fire started in adjacent stairs, where considerable amounts of flammable products ignited. The fire spread to the large room within a very short time causing a fully developed fire.

5.5.1 Lessons lerned

From now on the risk with fire spread from a small adjacent room is considered when Swedish sites are analysed. One site has conducted an analysis referring to risk of fire spread from adjacent rooms, where no rated firewalls exist.

6 How do we learn?

The Swedish nuclear industry has a system for exchanging information that might be generic. This includes all events and failures of safety equipment. There is an open attitude between the sites, and informations about occurred problems are generally generous. Each site has a local organization for transferring reports about incidents to the functions it might concern. Far from all reports result in any administrative or technical changes. But when the people involved has knowledge about incidents, this apparently reduces the risk of making the same mistake at another site.

REFERENCE

A. Anger & Kurt Pörn *Nordiska kraftreaktorers branddatabas, version 2*2001-01-08, ES-konsult

Annex IV

FIRE EXPERIENCE AT THE UKRAINE'S NPPs AND LESSON LEARNED

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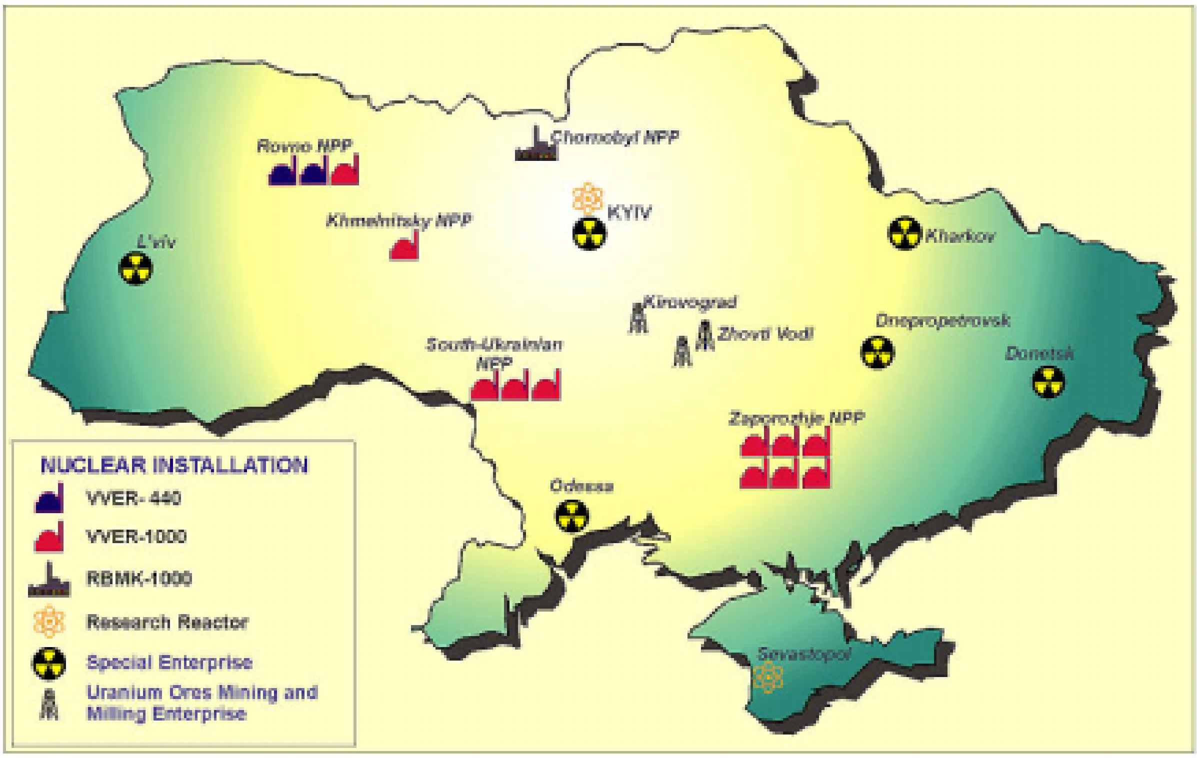
Abstract. The paper describes the major fire events occurred in Ukraine in recent years. The fire data base and the lessons learnt are carefully described for future use.

IV.1. INTRODUCTION

In 2000 there were 14 power units at the 5 nuclear power plants under operation in Ukraine (see map):

- 11 power units with WWER-1000 reactor (6 at Zaporizhia NPP, 3 at South Ukraine NPP, 1 at Rivne NPP and 1 at Khmelnytskyi NPP)
- 2 power units with WWER-440 reactor (at Rivne NPP)
- 3 power unit with RBMK-1000 reactor (at Chornobyl NPP) – in accordance with the Decrees of the Cabinet of Ministers were shut down for good. They are in the state of the preparation to decommissioning
- 4 power units are under construction (Rivne-4 and Khmelnytskyi-2, 3 and 4). 2 of them (Rivne-4 and Khmelnytskyi-2) are almost completed



In 2000 Ukrainian Nuclear Power Plants generated 77,355 billion kWh of electricity that is 45,3% of the whole part of power generated in the country.

In 2000 the established plant-use factor in the Ukrainian NPPs was 68,9%.

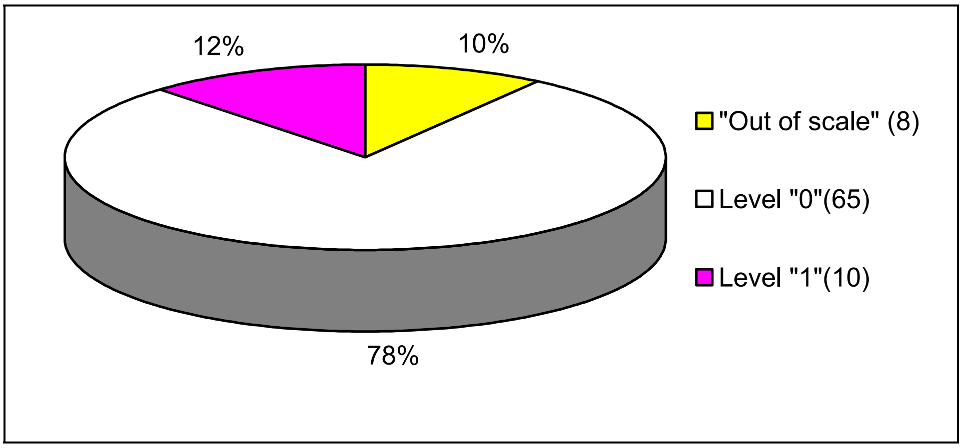
The main reasons of losses in production is shortage of funds for purchasing fuel, spare parts, equipment, repair service, maintenance, scientific support that caused substantial exceed of power units outage time.

In 2000 Ukrainian power plants keep on operating in the conditions of organic fuel deficiency and plural defaults of payments for produced electric power. It had essential influence on operational reliability and safety of the whole electric power system of Ukraine including nuclear power engineering.

Nevertheless in 2000 there were no accidents at Ukrainian nuclear power plants.
There were 83 events at Ukrainian NPPs.

73 events in NPP operation are classified as zero level (do not impact safety).

10 events are referred to level 1 of INES scale.



Distribution of events in INES scale

In 2000 the biggest part of events in nuclear power plants operation related to such that connected with inefficient serviceability of equipment.

A number of events are caused by poor quality of repair and maintenance.

In spite of some increase of total number of events there were no safety-significant fires at Ukrainian NPPs during 5 past years, excluding this year, when there were 2 fires at our NPPs.

One of them came to pass at the Unit No.1 Zaporizhia NPP at 07.01.01 and the second one – at Rovno NPP at 11.04.01.

Further I'll represent more detailed information about Rovno NPP'event as more complex event.

IV.2. THE ANALYSES OF THE ROVNO EVENT

Event title: Potential degradation of safety function “Cooling of fuel” and “Control of reactivity” due to full loss of station power as a result of crane’s fall on the cable trays, which entailed a long short circuit, loss the electrical power 6kV, control and instrumentation cables, a damage of the some Emergency Auxiliary transformers’ equipment and a major fire in some power supply system rooms.

IV.2.1. The state of the Rovno NPP units before event

Unit No.1 was in the state of Scheduled Preventive Maintenance Outage. Unit No.2 was in operation. Unit No.3 was operating at the reduced level (80% of nominal level) because of operation schedule. The Unit No.4 was under construction.

This event was happened on unit No.4 in April 11 at 12.38 when work on dismounting of the lifting crane was fulfilled. The scheme of the event site is shown on the Fig.1.

The crane was located near 330/6kV Emergency Auxiliary transformers TP4 and TP5.

The Emergency Auxiliary transformers Tp4&Tp5 are designed for transformation 330kV voltage to 6kV for power supply of 6kV AC House Distribution System of the Units No. 4 and emergency power supply system 6kV for Unit No.3. They are located on the open area at a distance 50 m from the Turbine hall of the unit No.4. There are 2 Metal Clad Switchgear Rooms at the distance 4 meters from Tp4&Tp5. There are 26 cabinets and 8 switchers in them. From those Power Centre Rooms to Supply Subdistribution Buses Building a trestle with the cable trays are placed. There are power, control and instrumentation cables for the Units No.3,4 in those trays. All trays were provided with the cut-off fire barriers. The Transformers’ Rooms were supplied by the Automatic Fire Extinguishing System, which actuated when the gas and differential protection actuated.

IV.2.2. Brief description of the event

At 12.39 p.m. the jib of the crane fell on the trestle with the cables passed from 330/6kV transformer TP4&TP5 to Unit 4 and broke them. The cables fell on the ground.

Damages of all cable trays lead to loss of instrumentation cables for relay protection of the transformers TR4&TR5 and Trunk line 6kV.

As a result the Earth fault of the cables 6kV could not be disconnected rapidly. The emergency relay protection of the transformers TR4&TR5 during Earth fault 6kV from the side 330kV with the executive current from the storage buttery for open-type distribution substation 330kV (ORU-330kV) was not designed.

To remove this Earth fault all plant was cut off from outside High-voltage transmission lines 330kV by electrical protection actuation.

In that voltage on the power supply bus was decreased. There was a loss of Normal and Emergency Auxiliary power supply. As result of this fact the frequency of power supply buses of the Main Coolant pumps was decreased. The Emergency protection was actuated and the Reactors of Units 2&3 were scrammed.

The personnel introduced boron into primary circuit, cut off the nearest to short circuit breakers and then restored the House distribution power supply.

Because of overload the Central Alarm Indication system on the central electric control pane was disabled that caused any difficulties in the event management by personnel. There was loss of emergency processes control by the operators.

Long-term exposure (1 min.36sec.) of this Earth fault caused high earth fault currents, burning of the cables and the following fire spread to the 6kV supply distribution buses and 6kV Metal Clad Switchgear Rooms and inside them with high temperature and release of the toxic substance. The equipment of the transformers 4TP&5TP was damaged too, especially for TR4. Earth fault in TR4 must be disconnected with differential protection of the line 330kV. But it was actuated unsuccessfully in that differential protection actuated with the output relays of the TP4&TP5 which was damaged.

The fire was detected by the security guard. At 12.39 the information about fire was given to Shift Supervisor of NPP, which informed to Fire brigade, including the outside agency. The first fire brigade arrived at the fire spot at 12.44 p.m. The automatic fire extinguishing system was activated but stopped working right away because of fire pump's power supply loss. There was no water in the fire mains. Then the fire brigade laid fire-fighting hoses and provided water with mobile pump unit. Then they were waiting the permission from the personnel of the Unit.

In compliance with a Procedures after elimination of the short circuit and restoration of House distribution power supply the personnel of Unit gave to the fire brigades permission to start fighting fire. It was at 13.07 p.m. The fire brigade fought fire manually. After renewal of fire pumps operation the water seals of the water lines were open with the hand drive. And fire-extinguishing system of transformers 4TP&5TP was operated successfully.

At 13.45 the fire was localised. At 14.10 the fire was successfully extinguished.
Water was used as the main extinguishing agent.

IV.2.3. The state after the event

The plant was kept under hot shutdown condition to be restarted again. After permission the reactor and turbine-generator were actuated, normal operation of the units was restored.

Actual consequences of the event/Impact on Plant structures:

- As a result of the fire some buildings and cable trays were damaged.
- As a result of rupture and burning of cables there was a complete loss of electric power supply and control power supply to the plant and unplanned scram of the reactors of the Units 2 and 3.
- There was no breach of operational limits and conditions, no fire consequences.
- There was no off site impact.
- There has been no release of radiation outside.

- There was no impact on personnel. Nobody was died and injured.

The positive features during fighting fire are the following:

- Good interaction between the plant personnel and fire brigade.
- The headquarter of fighting fire was established and successfully operated.
- Expansion of the fire was not allowed.
- Using of fire equipment was as much as possible successful.
- Water power supply was restored very fast.

At first this event was classified as level "0" on INES (International Nuclear Event Scale). It did not affect the safety of the plant. The full loss of power supply of the Units is the Design Basis Event. Because of Work planning deficiencies and design quality control deficiencies, violation of the Ukrainian safety requirements [N2][N3]the level on INES was increased to "1".

IV.2.4. Direct causes

Crane's failure and the following prolonged short circuit in the circuit 6kV and 330kV.

The Root causes were determined as follows:
Crane dismounting management deficiencies (the work of contractor's group was insufficiently controlled and co-ordinated by shift management staff, the crane during operation was defective, pre service qualification tests had not been carried out, the crane was not tested before operation).

Lack of design:

- The insufficient Earth Fault Protection of the Emergency Auxiliary transformers Tp4&Tp5 (Wrong arrangement of routine control circuit and wrong design of relay protection of the transformers TP4&TP5, an insufficient rated capacity of the emergency power supply 6kV for Units No.1, 2);
- Deficiencies of power supply circuit of the Fire protection water system (lack of the independent power supply source);
- Deficiencies of power supply circuit of the central alarm indication system (low protection settings),
- Lack of up-to-date indicators of emergency processes.

IV.2.5. Corrective actions and Lessons learned

Various rehabilitation works have been carried out in the plant after fire: restoring of the damage after the event, cable rerouting.

Further actions:

- Plant management concerning planning of the contractor's work and its control should be improved.

- The administrative procedures for barrier control of the used equipment, check of preparedness to work should to be reviewed.
- The fire brigade should be provided with modern communicative means.
- The personnel should be provided with modern failure logging equipment.

The following technical measures should be carried out:
- to arrange the independent power supply for water pumps;
- to improve design of power supply system protection.
- to improve power supply circuit for central signaling system on the main electric control pane.

Other utility operators have been provided with the lesson learned from this event and should make similar improvements.

IV.3. FIRE PROTECTION PRACTICE IN THE UKRAINIAN NPP: GENERIC LESSONS

The analysis has highlighted the need to improve safety culture. This calls an urgent need for training of personnel at various levels for maintaining better standards of safety culture.

A systematic fire hazard analysis has not been performed so far for any of the Ukrainian NPPs. But the review of the safety features (including fire protection features) of WWER reactors shows that the main safety concept of these reactors is similar to the PWR units designed at the same time in other countries. However, there are any deviations from current safety standards and practices in design and operation.

The identification of such safety issues for Soviet Type Reactor Plants, including Fire Safety Problems and Deficiencies, was developed under the IAEA's Extra-budgetary Program on the WWER NPP Safety Improvement in 1994-1998. It is based on safety studies conducted by the operators of these units and by organisations dealing with these reactors, on findings of IAEA safety missions to NPPs and on experience practice of other countries.

Currently, to improve safety, reliability and effectiveness of NPPs' performance, a number of programs are being implemented, agreed with the regulatory authority. These programs provide for technical and organizational activities to be implemented within the next few years are aimed at upgrading the safety and reliability level of the operating nuclear power units. After the activities related to the operational units safety assessment are completed the areas of the further modernization will be defined.

The main purposes of modernisation are as follows:
- To maintain the units' current safety level;
- To extend equipment's lifetime;
- To improve reliability and operational preparedness of power units;
- To increase capacity factor;
- To eliminate inconsistencies with effective national safety rules and standards, first of all, on the safety significant items, and/or to reduce these inconsistencies' impact on the safety by implementing compensatory measures.
- To implement the IAEA's recommendations developed under the IAEA's Extra-budgetary Program on the WWER NPP Safety Improvement, as well as to consider

foreign experience in cases when it is justified and suitable for the VVER type reactors, based on the specific character of technology and technical developments.

Over 1994-2000 a number of the following measures were implemented on WWER NPPs with the purpose of improving the Fire Safety and Reliability:

- Replacement of the circuit breaker for upgrading of selectivity in fusing.
- Development of the detection and control system of hydrogen leakage for the turbine generator.
- Replacement of qualified fire doors, penetration seals,
- Covering of cables with fire resistance overlays.
- Arrangement of the fire resistant dampers in ventilation ducts.

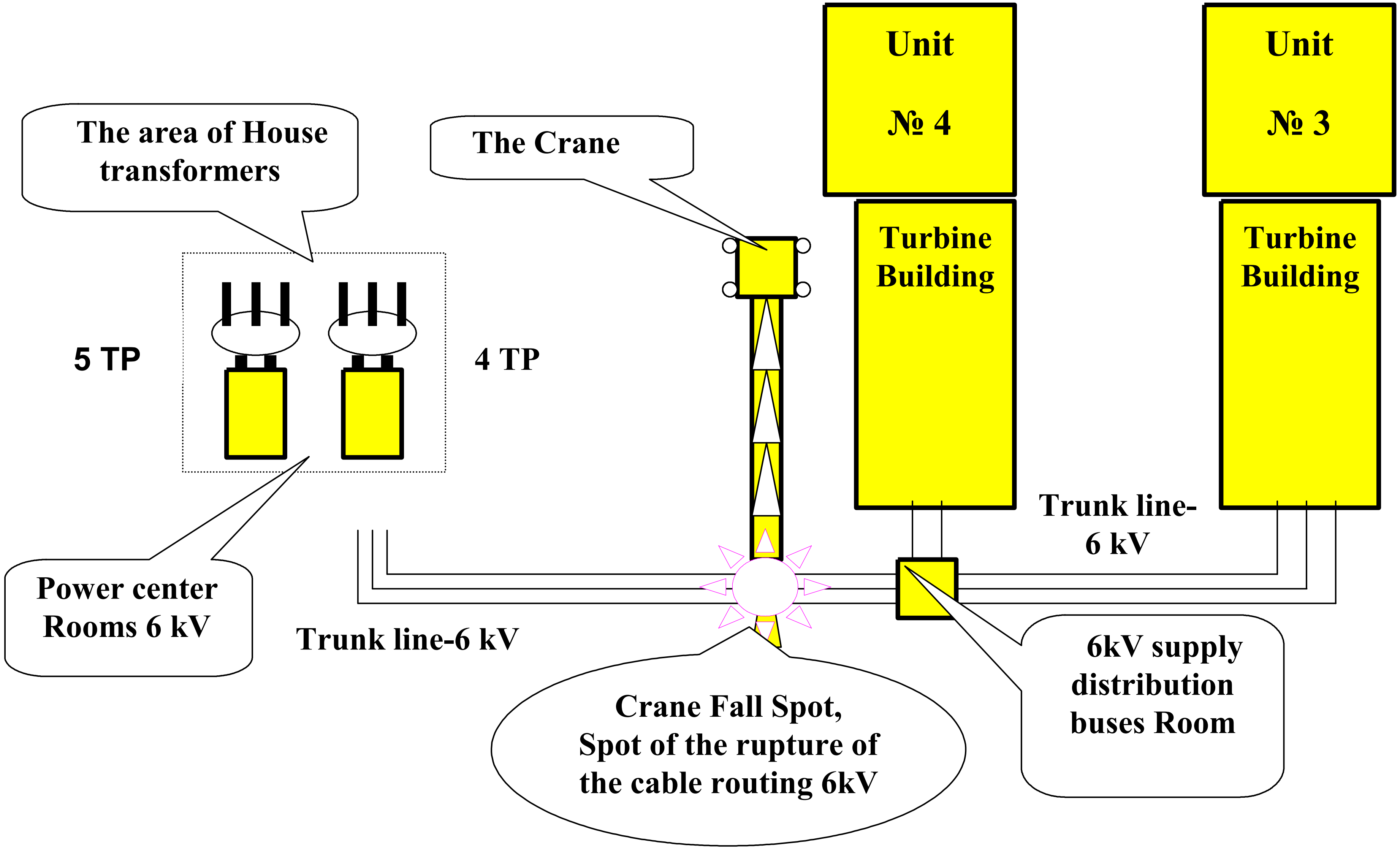
The following measures are planned to realization at the nearest time:

- Implementation of the fire detection system equipment capable under abnormal condition
- Development and arrangement of automatic gas system for fire extinguishing in the MCR, ECR and I&C rooms.
- Performing of systematic fire hazards analyses.

A specific concern in this respect is related to the cable spreading rooms. In the cable spreading room under the main control room (MCR) a separation of the redundancies is not possible. This is a serious weakness, since a fire in one of these channels could potentially affect other channels. A systematic fire hazard for this room was carried out by GRS in the framework of bilateral cooperation between our regulatory authorities. This analysis shows that the safety in this room during the fire meets the requirements.

Fire protection is considered to be an especially important topic during operation of NPPs. Ukrainian utilities and Regulatory authority have paid a big attention to this question.

FIG.1 The scheme of the event.



Annex V

MANAGEMENT OF FIRE INCIDENTS AT NPCIL UNITS

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Abstract. The paper describes the major fire events occurred in India in recent years. The fire data base and the lessons learnt are carefully described for future use.

V.1. INTRODUCTION

Fires in Nuclear Power Plants (NPP) can cause common cause failures and can affect plant safety. NPCIL was the victim of a 'large' fire incident, which occurred at one of its Plant (Narora unit #1) in March 1993 due to failure of turbine generator. Though the reactor could be kept in 'safe shutdown' state, it took considerable time and resources to rehabilitate the affected unit. It also raised many regulatory concerns to NPP's of NPCIL. Increased vigilance and fire prevention activities have reduced fire incidents at NPCIL units over the last decade. Most units of NPCIL recorded zero fire incidents in 1999 and 2000. The Atomic Energy Regulatory Board (AERB) has also stepped up fire safety reviews of NPP's and has pinpointed areas for improvement. In addition to this, AERB has brought out safety guides and 'Standards for a Fire Protection Systems of NPPs'. Efforts in fire protection activities are also recognized by AERB through the `Annual Fire Safety Awards'.

V. 2. FIRE SAFETY SCENARIO IN INDIAN NPP'S

In order to understand the fire safety issues of NPCIL an analysis of fire incidents for the period of 1988–2000 for 3 NPCIL sites was conducted and is described in this paper. These three sites are Tarapur Atomic Power Station (TAPS) in the state of Maharashtra, Madras Atomic Power Station (MAPS) in the state of Tamil Nadu and Kakrapar Atomic Power Station (KAPS) in the state of Gujarat. Of this TAPS is a Boiling Water Reactor (BWR) of capacity 2 X 160MWe operating since 1969 and MAPS and KAPS are Pressurized Heavy Water Reactors (PHWR) of capacity 2 X170MWe and 2 X 220MWe respectively. These two stations have been operating since 1983 and 1993 respectively. A total of 90 fire incidents (most of them insignificant) were reported from these units in the above reporting period. An analysis of these incidents to understand their general characteristics and specific fire prevention methods adopted to prevent such incidents are given in this analysis.

V. 3. FIRE INCIDENTS 1988-2000

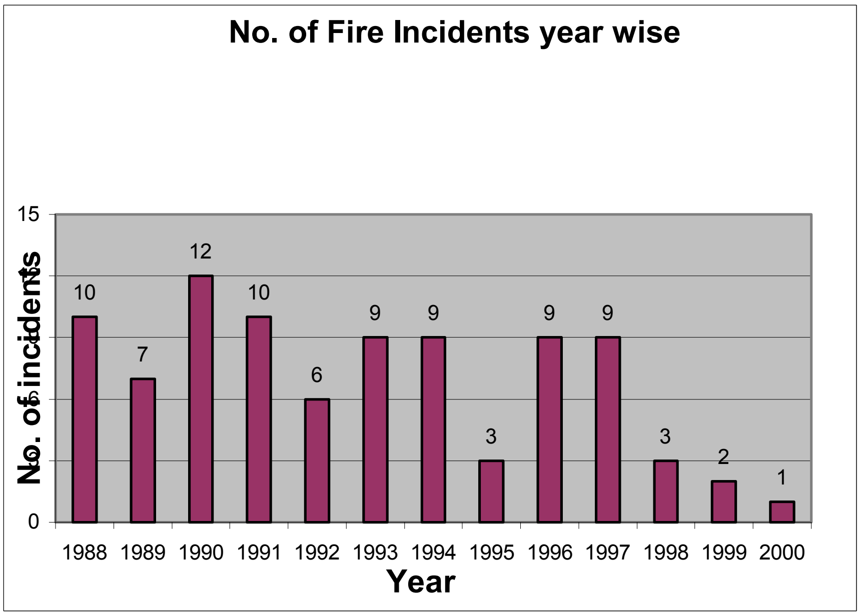
An average of 8.4 fire incidents per year was reported cumulatively from these three sites during the years 1988–1997. However a number of engineering and administrative controls were initiated to reduce such incidents during these years. By 1988 fire prevention measures initiated by the management started yielding results. During 1998 TAPS recorded no fire incidents and in 1999 KAPS recorded no fire incidents. In the year 2000 both TAPS and KAPS reported nil fire incidents. The total number of fires reported from these 3 sites from

1998–2000 were 6 i.e., 3,2 and 1 respectively. This is a remarkable improvement from an average of 8.4 incidents/year during the previous 10 years. This data is illustrated in Table I and Figure I.

Table -1

Year	No. of Incidents
1988	10
1989	7
1990	12
1991	10
1992	6
1993	9
1994	9
1995	3
1996	9
1997	9
1998	3
1999	2
2000	1

Figure-1



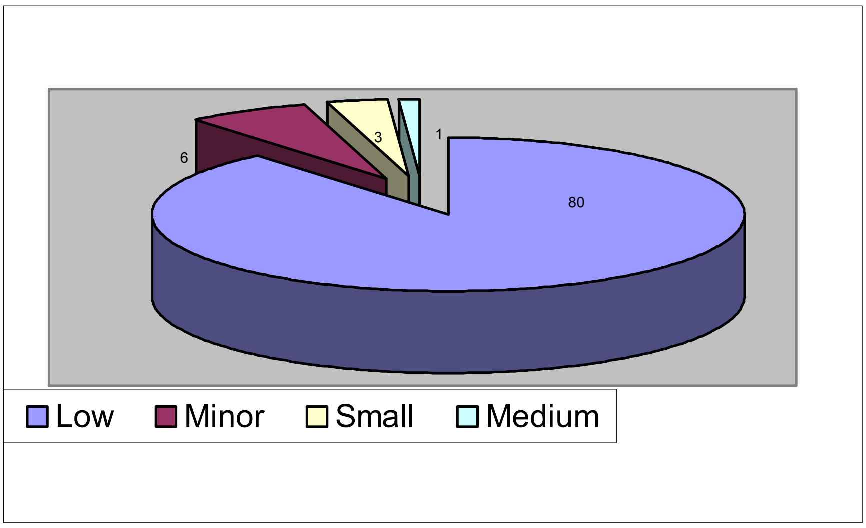
V.4. FIRE INCIDENTS AND PROPERTY LOSS

Atomic Energy Regulatory Board (AERB) has classified fire incidents into 5 categories based on financial loss and/or injuries resulting from the incident. These are 'low', 'minor', 'small', 'medium' and 'large' as given in Annexure I. Out of 90 fire incidents reported during the above period, 80 of them were classified as 'low' i.e., loss ≤ Rs.10, 000/-. A majority of these incidents caused negligible or no loss. Of the remaining 10 incidents 6 were 'minor' (loss Rs.0.1–2 lakh), 3 were 'small' (loss Rs.2-20 lakh). Only one `medium' fire (loss Rs.20-400 lakh) took place during this period. This data is given in Table 2 and illustrated in Figure 2.

Figure-2

Table -2

Classification	No. of Incidents
Low	80
Minor	6
Small	3
Medium	1
Large	0



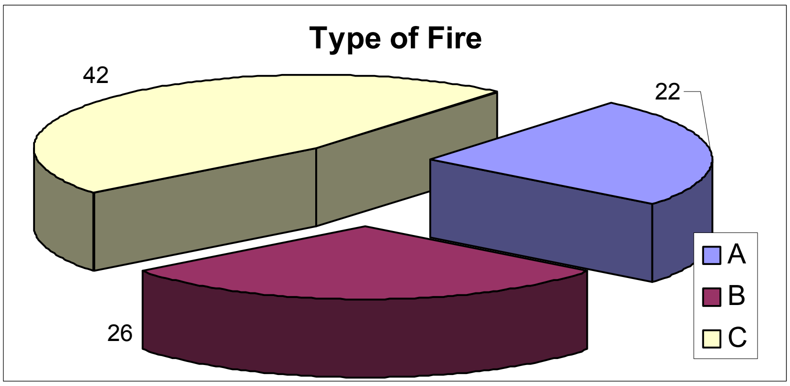
V.5. TYPE OF FIRE

AERB has classified fires into classes A, B, C and D based on the nature of material under fire as per AERB/S/IRSD-1 as given in Annexure II. Solid carbonaceous materials under fire are classified as Class-A, while flammable liquids and gases on fire are classified as Class B. Fires due to live electrical equipment are classified as Class C and combustible metals are classified as Class D. Of the 90 fire incidents under study 42 (47%) were Class C and 26 (29%) were class B, while the remaining 22 (24%) fires were class A. There were no Class D fires. This is illustrated in Table 3 and Figure 3.

Table -3

Type	Incidents	%
A	22	24.4
B	26	28.9
C	42	46.7
D	0	0.0
Total	90	100

Figure-3



As described above 80 of these fire incidents were of `low' category, most of them reported as emanating smoke but no flames or damage to property. Among the 10 `minor', `small' and `medium' fires reported 6 were due to live electrical equipment, one due to oil soaked insulation, one as a result of gas cutting of a paint drum and the other two incidents carbonaceous in nature. Fire due to live electrical equipment is seen as the major cause of fire incidents under all `loss' categories. Approximately 50% of all fire incidents both low and higher loss categories are due to failure of electrical equipment.

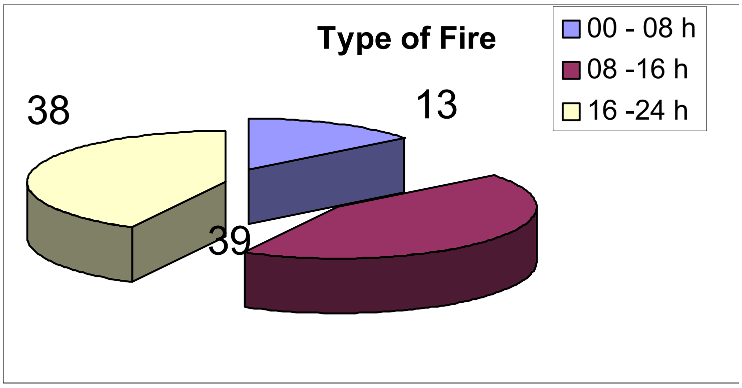
V.6. TIME OF FIRE INCIDENTS

It is observed that fires take place when equipment are left unattended and in operating condition. As a result fire incidents are generally found to be more during night hours. However this is not the case in the NPP's under this study. In this analysis it was observed that about 43% each of the fire incidents occurred during day and evening time i.e., 0800-1600 hrs and 1600–2400 hrs. During 0000-0800 only 14% of the incidents took place. This indicate that most of the fire incidents took place during regular working hours or evening time as a result of activities, such a operation or maintenance work. This data is illustrated in Table 4 and Figure 4.

Table -4

Shift	Incidents	%
00 - 08 h	13	14.4
08 -16 h	39	43.3
16 -24 h	38	42.2
Total	90	100.0

Figure-4



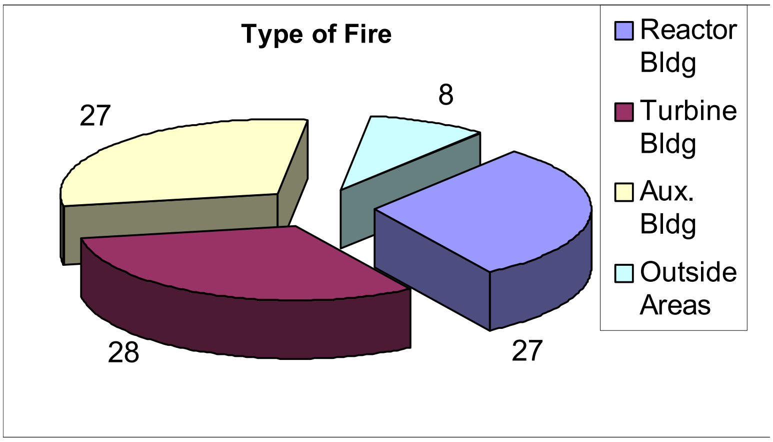
V.7. LOCATION OF FIRE INCIDENTS

The above 90 fire incidents were categorized into four as per the area of incidence. i.e., reactor building, turbine building, auxiliary buildings and outside areas as given in Table 5 and Figure 5. It was observed that about 30% each of the incidents took place in reactor buildings, turbine building or auxiliary plants. Only 9% of the incidents took place in outside areas such as switchyard, store yard, open areas etc. The fire incidents in open areas were mostly grass fires.

Table -5

Location	Incid-ents	%
Reactor Bldg	27	30.0
Turbine Bldg	28	31.1
Aux. Bldg	27	30.0
Outside Areas	8	8.9
Total	90	100

Figure-5



A number of initiatives were made both by the Corporate Headquarters as well as individual sites to prevent fires and improve emergency response in case of a fire. Some of these are described below:

V.8. FIRE PREVENTION MEASURES INITIATED BY HQ.

(1) The post of Fire Protection Engineer (FPE) was created at each NPP to look after fire prevention activities and conduct Fire Hazard A nalysis of critical areas. These FPE's were provided detailed training on fire protection aspects of NPP's.

(2) A number of Head Quarters Instructions (HQI) was issued by the corporate management to be followed uniformly by each unit. These HQI's are:

– Guidelines for control of combustibles and ignition sources
– Guidelines on duties of FPE and fire safety organisation at stations and projects
– Guidelines for surveillance program on Fire Protection System
– Guidelines on `Fire Emergency drill'
– Guidelines on `Fire Safety Training policy'

(1) Fire Safety audits of all sites were conducted annually. Such audits were conducted by AERB also.
(2) Standardization of fire station equipment in all NPP fire stations.
(3) Fire hazard analysis of critical areas of NPPs was carried out and corrective actions were initiated.
(4) Staff strength of all Fire stations attached to NPP's has been standardized and recruitment made to fill up vacancies.

V.9. FIRE PREVENTION MEASURES INITIATED BY NPP'S

(1) Storage of combustible materials has been limited to bare minimum in operating areas and where such materials can be eliminated it has been done. This has been ensured through `work permits' and regular field surveys.
(2) Preventive maintenance and energy conservation measures have been initiated to prevent electrical accidents.
(3) Regular measurements of bearing temperature of motors are done to avoid fire due to overheating. Condition monitoring of equipment is also done to minimize fire risk due to overheating, friction and jamming of internal parts.
(4) Smoking inside operating island is strictly prohibited at all sites.
(5) A number of training and awareness programs are initiated on fire safety aspects.
(6) Mineral wool insulation, which used to catch fire due to oil leakage, has been replaced by calcium silicate as an insulation material on steam pipelines and below turbine. Similarly in hot, active and inaccessible places the insulation material has been changed to 'reflective metallic mirror insulation'.
(7) Hydrogen leak detectors have been provided near generator hydrogen addition station, generator bearing and near hydrogen dryer areas.
(8) Systematic training of fire staff to familiarize them of all critical areas of the plant.
(9) Periodic fire emergency drills and review of the results under a standard format.
(10) All operation and maintenance staff was trained on fire fighting operations and on the use of Self-Contained Breathing Apparatus.
(11) Fire squads have been formed at all stations to cover all three shifts and all areas of the plant to attack any fire at its initial stage itself before arrival of Fire Station Personnel. These fire squad personnel have been given detailed fire safety training.
(12) Installation and testing of fire detectors and installation of additional fire detectors in sensitive areas like cable vaults and cable galleries.
(13) Fire watch during `hot work' in sensitive areas and special work permits for carrying out such jobs.
(14) Investigation and analysis of fire incidents.
(15) Segregation of power and control cables and application of fire retardant coating on cables and per guidelines.

V.10. CONCLUSION

The above analysis indicates that NPPs have probability for fire incidents and these can have a role in the safe operation of the plants. The organisation should be aware of this fact and make employees aware of these dangers through regular safety training programs. They should also know what to do in case such an emergency occurs. This can be assured though regular fire drills, periodic fire safety inspections and detailed training of plant personnel including Fire Station staff.

Attachment 1

TABLE: CLASSIFICATION OF FIRE – LOSS

Type of fire	Loss in Rupees	Loss in Man-days
Low	<0.1 lakh	Nil
Minor	0.1-2 lakh	Injury treated but no hospitalized
Small	2.0-20 lakh	Hospitalized but no fatalities
Medium	20-400 lakh	1-5 fatalities
Large	>400 lakh	>5 fatalities

Note: The higher of the two criteria will be considered for classification of the type of fire.

Attachment 2

FIRE CLASSIFICATION (REF: AERB/S/IRSD-1)

1. Class A- Fire: -Fires in ordinary combustible materials such as wood, cloth, paper, rubber and plastics.
2. Class B- Fire: - Fire in flammable liquids, oils, greases, tars, oil-based paints, lacquers and flammable gases.
3. Class C- Fire: - Fires that involve energised electrical equipment.
4. Class D-Fire: Fires in combustible metals such as magnesium, titanium, zirconium, sodium etc.

Annex VI

FIRE AT BUGEY NPP: INCIDENT SURVENU SUR LA TRANCHE 3 DU CNPE DE BUGEY LE 31 JUILLET 1999

P. Dupuy, France

Abstract. The paper describes the major fire event occurred in France at Bugey in 1999. The root causes and the lesson learnt are carefully described for future use.

VI.1. DÉROULEMENT DE L'INCIDENT

VI.1.1. Chronologie des défauts électriques

Au moment de l'incident, le samedi 31 juillet 1999 à 4 h 38 minutes, la tranche est stable à pleine puissance et aucune intervention n'est en cours.

Un premier défaut apparaît au niveau du tableau LLE de distribution 380 V secouru par la voie A, situé à la station de pompage.

Ce défaut entraîne une surintensité qui génère un défaut d'isolement dans une armoire du tableau LGA renfermant le disjoncteur 6,6 kV (3LGA01JA), et amorce un court-circuit au niveau des bornes d'alimentation du tableau LGA situés dans le local L 461 du bâtiment électrique.

Le délai entre ces deux défauts est d'environ une seconde.

VI.1.2. Chronologie de l'intervention

La détection d'incendie se déclenche dans un premier temps à 4h 39 minutes et 23 secondes dans le local L461, inclus dans le secteur de feu de sûreté SFS L0402 du bâtiment électrique, dans lequel le court-circuit sous 6,6 kV a occasionné un dégagement important de fumée et de chaleur.

Trois secondes plus tard, un sprinkler du système d'aspersion JPL, assurant la protection contre l'incendie dans un autre SFS du niveau inférieur (local L 361, SFS L0301), est activé par destruction de son ampoule fusible tarée à environ 75°C (la surtension du court-circuit a provoqué la pyrolyse d'un câble électrique passant dans le local de l'étage inférieur).

Dans les quarante cinq secondes qui suivent, trois autres détecteurs d'incendie, implantés dans deux Volumes de Feu de Sûreté (VFS) limitrophes du local contenant l'armoire en défaut, se déclenchent du fait de la propagation des fumées.

A 4 h 40 minutes et 11 secondes, une alarme provenant du détecteur d'incendie situé dans le local P141 de la station de pompage abritant le tableau LLE de voie A, apparaît en salle de commande.

A environ 4 h 55 minutes, un rondier est envoyé en reconnaissance dans le local L 461 et le gréement de l'équipe de deuxième intervention est demandé. Celle-ci se rend sur les lieux à 5 h 00.

Pendant que le rondier applique la fiche d'action incendie correspondant au SFS L0402, les agents de l'équipe de deuxième intervention maîtrisent le feu en utilisant plusieurs extincteurs portables (5 à gaz carbonique et 1 à poudre) à 5 h 15. Un rondier est alors envoyé en reconnaissance à la station de pompage et confirme une odeur de brûlé sans incendie visible.

Les secours extérieurs sont appelés à 5 h 20 soit quarante minutes après la première alarme d'incendie.

A 5 h 45 l'intervention dans le local de la station de pompage est engagée. L'équipe dépêchée sur les lieux confirme l'absence de feu dans ce local.

VI.2. PREMIERS ENSEIGNEMENTS TIRÉS

VI.2.1. Hypothèses sur le comportement des matériels électriques

Parmi les hypothèses faites par Électricité de France dans le cadre de sa réflexion sur les enseignements à tirer de l'incident de Bugey, l'IRSN a noté en particulier deux affirmations:

"La propagation des défauts électriques empruntant systématiquement un circuit préférentiel, le phénomène peut générer deux défauts au maximum, se traduisant au pire par la défaillance d'un tableau 380 V et d'un tableau 6,6 kV ou de deux tableaux 6,6 kV."

"Compte tenu de son mode de propagation et du fait qu'il est propre à un seul enroulement de transformateur, ce type de phénomène ne peut pas affecter à la fois un tableau voie A et un tableau voie B."

De plus, il est mentionné dans la synthèse des aspects de l'incident réalisée par le site de Bugey que quatre jours après la remise sous tension du LGA, un amorçage s'est produit sur un câble d'alimentation du LGA en salle des machines, à mi-chemin entre le tableau et le transformateur. Électricité de France avance l'explication d'une faiblesse préexistante du câble qui se serait accentuée sans s'affranchir lors du défaut initial.

Concernant la première affirmation, le régime de neutre du réseau 6,6 kV est un régime dit à "neutre isolé", qui n'entraîne pas un déclenchement des protections au premier défaut. Le premier défaut est détecté automatiquement par le contrôle d'isolement et signalé par une alarme. Si le défaut n'est pas recherché et éliminé, à l'apparition d'un deuxième défaut, le courant de défaut biphasé se reboucle par les masses via la terre en passant à l'endroit des 2 défauts et fait déclencher par surintensité la protection concernée la plus en aval car la moins temporisée (sélectivité chronométrique).

Cependant, si plusieurs défauts d'isolement sont générés par le défaut initial (succession dans le temps de défauts d'isolement provoquée par la secousse des câbles due au courant de court-circuit) ou par la montée de potentiel des autres phases (cas classique d'une phase à la terre), alors le courant de défaut, qui emprunte toujours un circuit préférentiel, alimente au plus 3 défauts (1 par phase) si les 3 phases sont concernées. Ce courant de défaut fait déclencher par surintensité les 2 protections les plus en aval dans la boucle de défaut car les moins temporisées de telle sorte de ne laisser qu'une seule phase en défaut (cas du 1er défaut en régime de neutre isolé).

Pour obtenir la mise hors tension de plus de 2 tableaux sur un défaut de court-circuit triphasé dû à 3 défauts d'isolement, il faut supposer la défaillance de plus d'une protection. Cette hypothèse va au-delà de l'application du critère de défaillance unique.

Concernant la deuxième affirmation, les transformateurs auxiliaires (TA) ou de soutirage (TS) possèdent chacun 2 enroulements secondaires qui assurent donc un isolement galvanique entre les 2 réseaux associés respectivement à ces 2 enroulements. Un enroulement alimente notamment le tableau 6,6 kV secouru LHA associé à la voie A par l'intermédiaire du tableau LGA, l'autre alimente notamment le tableau 6,6kV secouru LHB associé à la voie B par l'intermédiaire du tableau LGB.

Compte tenu de son mode de propagation, le phénomène observé lors de l'incident, ne peut affecter des tableaux associés qu'à un seul enroulement donc à une seule voie.

Concernant l'explication avancée par Électricité de France selon laquelle le câble avait une faiblesse existante qui s'est accentuée lors de l'incident, l'IRSN considère qu'il est en effet probable qu'il existe un lien de causalité entre ce nouveau défaut découvert quelques jours après l'incident et le défaut triphasé sur LGA qui est resté alimenté pendant 10s par l'alternateur lors de l'incident.

Si ce défaut d'isolement s'était révélé pendant les 10 secondes où le défaut triphasé en amont des cellules LGA était alimenté, le courant de défaut se rebouclant préférentiellement par le défaut triphasé, il n'aurait pas provoqué un nouveau départ de feu au niveau du câble en salle des machines.

VI.2.2. Conséquences sur le référentiel de sûreté incendie

Électricité de France indique que le postulat figurant dans le RCC-I et les Directives Incendie selon lequel "La simultanéité de deux ou plusieurs incendies ayant des causes indépendantes et affectant des locaux d'une même tranche ou de tranches différentes n'est pas prise en compte" n'est pas remis en cause.

EDF justifie cette affirmation en précisant que les deux événements qui se sont produits sur les tableaux LLE et LGA et qui ont donné lieu à deux départs de feu quasi simultanés ne sont pas indépendants car liés électriquement.

En ce qui concerne ce point, l'IRSN convient que ces deux défauts résultent d'une même cause et qu'à ce titre le postulat figurant dans le RCC-I et les Directives Incendie n'est pas remis en cause.

Néanmoins, il convient de souligner que l'occurrence de deux incendies dans des VFS distincts et résultant d'une même cause, non exclue par le postulat mentionné ci-dessus, n'est pas considérée dans la conception de la protection contre l'incendie des tranches.

VI.2.3. Maintenance des disjoncteurs 6,6 kV

Les disjoncteurs à huile, présents notamment dans les tableaux 6,6 kV du système LGA, sont des matériels qui équipent l'ensemble des tranches des sites 900 MW du parc nucléaire d'Électricité de France. Ce matériel de conception ancienne présente des risques importants d'incendie voire d'explosion.

L'explosion d'un disjoncteur à huile, du même type que ceux utilisés sur les tranches REP 900 MW françaises, s'est produite le 31 octobre 1996 sur la tranche 1 du site de Tihange en Belgique.

Cette explosion d'une grande violence a, d'une part causé la mort d'un agent ainsi que des dégâts matériels importants (écroulement d'un mur, arrachement de portes …), d'autre part entraîné un incendie.

Plus récemment, une explosion d'un disjoncteur de ce type a eu lieu le 18 septembre 2001 sur la tranche 4 de Gravelines, lors du démarrage d'une pompe primaire. Le réacteur était alors en cours de redémarrage suite à un arrêt de tranche. Dans ce cas, une partie de l'huile présente au niveau des contacts (10 litres sur 33) a participé à l'incendie qui a suivi. Ce disjoncteur avait fait l'objet d'un contrôle de bon fonctionnement au cours de l'arrêt de tranche.

Le vieillissement de ces matériels peut entraîner une augmentation de ces dysfonctionnements et doit être pris en compte dans la perspective d'un éventuel allongement de la durée de vie des centrales. Compte tenu du risque potentiel important qu'ils représentent du fait de leur implantation en nombre significatif dans les bâtiments électriques des tranches nucléaires 900 MW (plusieurs dizaines par tranche), il convient d'y prêter une attention particulière.

Il faut noter que des avaries de matériels pouvant conduire à des départs de feux importants sont parfois la conséquence de défauts pouvant sembler mineurs. Ainsi, un court-circuit sur un contacteur 6,6 kV dans un tableau LHB de la tranche 4 de Cruas a entraîné un début d'incendie le 30 octobre 1990. L'origine de ce défaut est la dégradation, due à leur vieillissement par échauffement, de rondelles jouant le rôle d'amortisseurs sur les liaisons mobiles du contacteur.

Électricité de France ne retient pas l'hypothèse selon laquelle l'explosion du condensateur du mesureur d'isolement serait l'initiateur de l'incident dans le tableau LGA. Cependant, son analyse d'une part constate que ce composant était en place depuis 23 ans, d'autre part indique qu'il est prévu de modifier les PBMP pour remplacer ces composants au bout de 20 ans, soit la durée de vie annoncée par le constructeur.

A ce jour, la majorité des tranches REP du palier 900 MW sont en exploitation depuis plus de vingt ans.

Électricité de France indique qu'en ce qui concerne les disjoncteurs à huile, l'expertise qu'il a réalisée ne lui permet pas de considérer que cet incident est lié au vieillissement de ce matériel ou à une trop longue période entre les contrôles. Électricité de France précise que pour éviter que cet incident ne se reproduise, des dispositions de mesures de résistances et de contrôles de propreté ont été prises. En outre Électricité de France demande le remplacement des condensateurs de chaque platine tous les vingt ans en indiquant qu'une mise à jour du Programme de Base de Maintenance Préventive correspondant est en cours.

VI.2.4. Conduite de la tranche en cas d'incendie

Électricité de France indique que le retour d'expérience de cet incident met en évidence la possibilité qu'un défaut, apparaissant sur un tableau de la voie A, conduise à la dégradation d'équipements électriques situés dans un VFS de voie A distinct.

Sur la base d'un scénario identique, mais en considérant le défaut initial sur un tableau de la voie B, il s'avère qu'il est possible de perdre un tableau de la voie B (LLE par exemple) et un tableau dit "hors voie" implanté par conception dans un VFS de la voie A. Dans le cas où ce VFS est redevable de la procédure de conduite I.4.D, qui n'était pas encore d'application sur la tranche le jour de l'incident, les opérateurs pourraient demander la coupure de l'ensemble de la voie A alors que n'était plus garantie la disponibilité des Moyens Minimaux de Conduite (MMC) nécessaires au repli de la tranche vers un état sûr et non protégés contre l'incendie dans les VFS de voie B.

Cette analyse a conduit Électricité de France à reconsidérer les conditions d'entrée dans la procédure I.4.D afin d'éviter qu'une application trop rapide de celle-ci, et sans vérification préalable de la disponibilité des MMC, ne conduise à une situation hors dimensionnement de type H1 ou H3.

Ceci s'est traduit par une montée d'indice du Document d'Orientation Incendie (DOI) qui définit les prescriptions à mettre en œuvre par les équipes de conduite lors d'un incendie et la conduite à tenir pour maintenir ou ramener l'installation dans un état sûr.

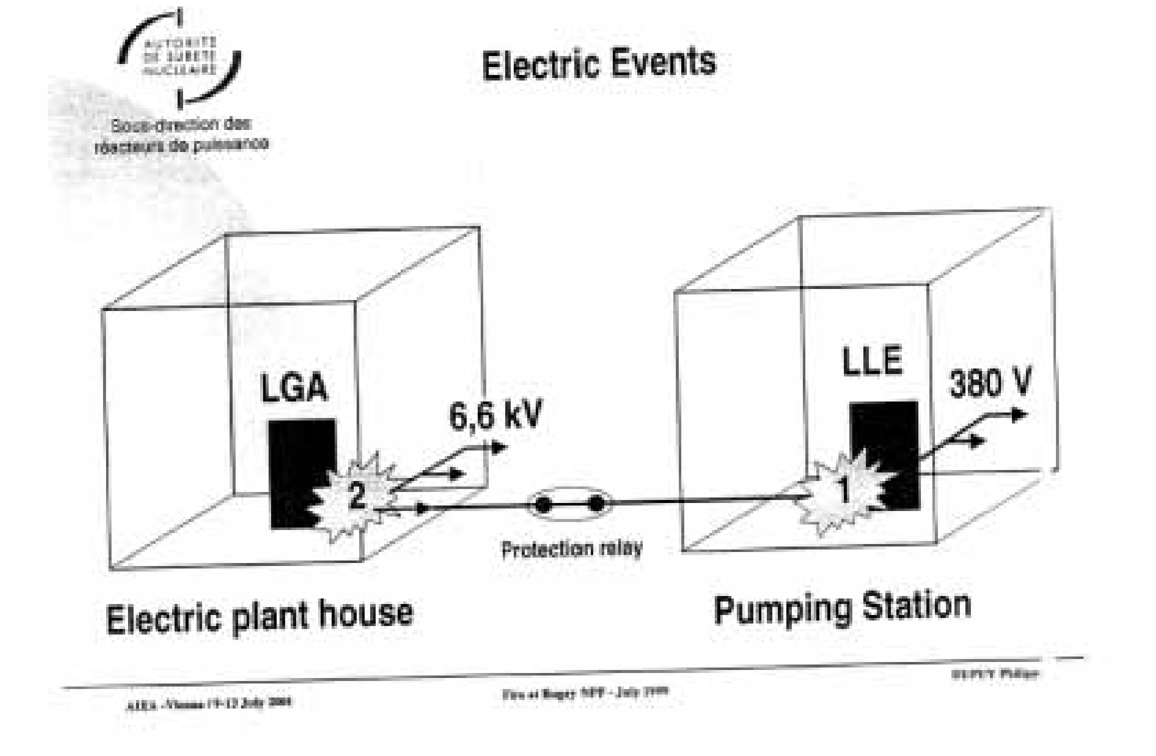
VI.2.5. Prise en compte de plusieurs alarmes d'incendie

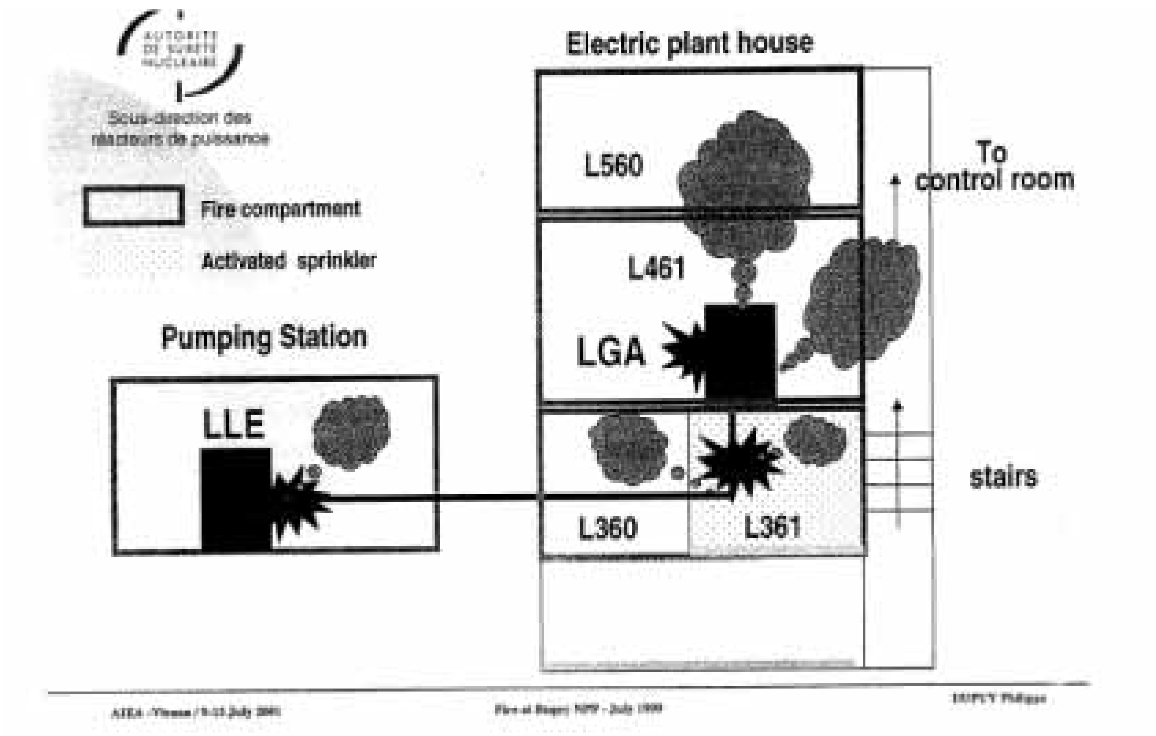
Il apparaît, à la lecture du scénario de l'incident, qu'il y a eu un retard en ce qui concerne la prise en compte des alarmes d'incendie en salle de commande. En effet, plusieurs alarmes d'incendie (niveaux 4 et 7 m du BL et station de pompage) ainsi qu'une alarme aspersion (entreponts de câblage au niveau 4 m) se sont déclenchées entre 4 h 38 et 4 h 39. L'appel de l'équipe de deuxième intervention et l'envoi d'un agent en reconnaissance dans le BL n'ont eu lieu qu'à 4 h 55 soit 16 minutes après.

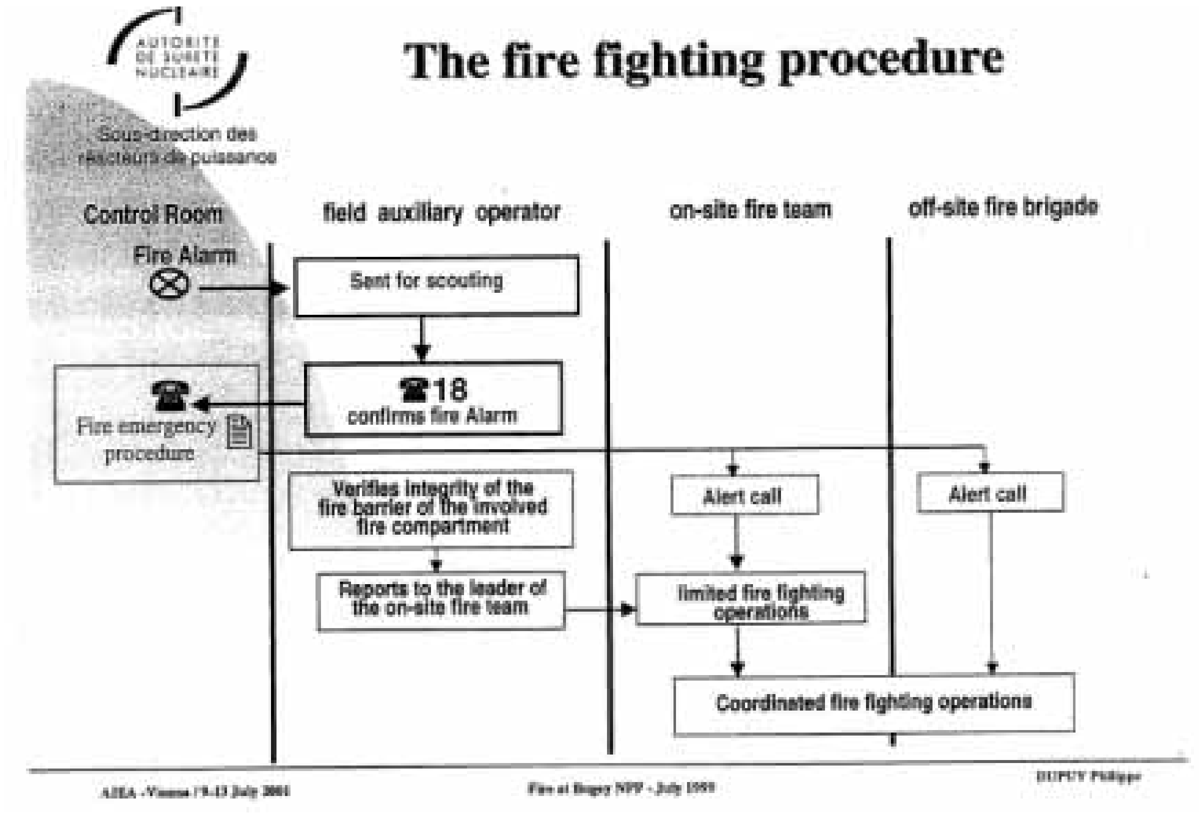
Par ailleurs, l'envoi d'un agent en reconnaissance vers la station de pompage, située à plusieurs dizaines de mètres du BL, n'a été décidé qu'à 5 h 15, soit plus de 35 minutes après l'alarme.

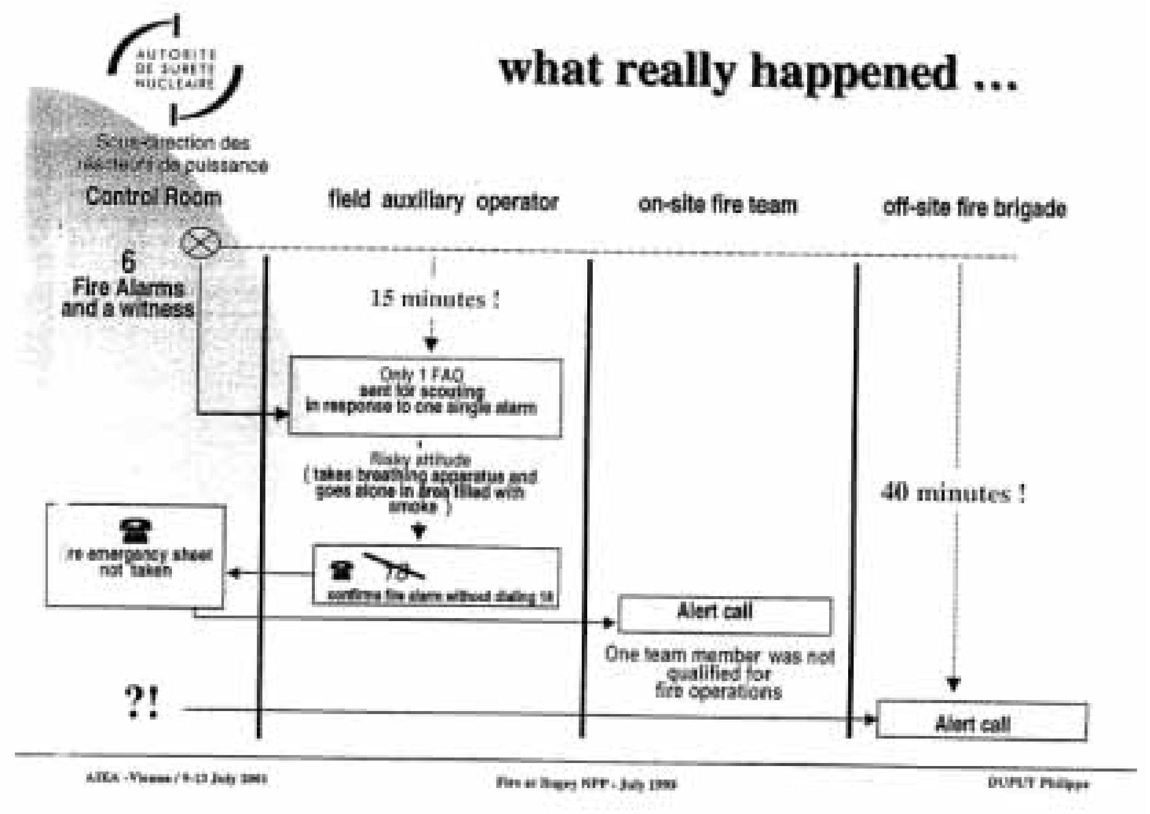
Ces retards s'expliquent par le fait que les opérateurs en salle de commande au moment de l'incident ont privilégié l'arrêt d'urgence lié à la perte de source électrique au détriment de l'incendie.

La prise en compte de plusieurs alarmes d'incendie successives par les opérateurs n'est pas prévue de manière explicite dans les consignes actuellement en place dans les salles de commande des tranches REP.


AUTORITE DE SURETE NUCLEAIRE
Sous-direction des réacteurs de puissance
Electric Events
LGA
6,6 kV
2
Protection relay
LLE
380 V
1
Electric plant house
Pumping Station


AUTORITE DE SURETE NUCLEAIRE
Sous-direction des réacteurs de puissance
Fire compartment
Activated sprinkler
Pumping Station
LLE
Electric plant house
L560
L461
LGA
L360
L361
To control room
stairs


AUTORITE DE SURETE NUCLEAIRE
Sous-direction des réacteurs de puissance
The fire fighting procedure
Control Room
field auxiliary operator
on-site fire team
off-site fire brigade
Fire Alarm
Sent for scouting
18
confirms fire Alarm
Fire emergency procedure
Verifies integrity of the fire barrier of the involved fire compartment
Alert call
Alert call
Reports to the leader of the on-site fire team
limited fire fighting operations
Coordinated fire fighting operations
AIEA -Vienne / 9-13 July 2001
Fire at Bugey NPP - July 1999
DUPUY Philippe


AUTORITE DE SURETE NUCLEAIRE
Sous-direction des réacteurs de puissance
what really happened ...
Control Room
field auxiliary operator
on-site fire team
off-site fire brigade
6
Fire Alarms
and a witness
15 minutes !
Only 1 FAO
sent for scouting
in response to one single alarm
Risky attitude
(takes breathing apparatus and goes alone in area filled with smoke)
40 minutes !
not taken
18
confirms fire alarm without dialing 18
Alert call
One team member was not qualified for fire operations
?!
Alert call
AIEA -Vienne / 9-13 July 2001
Fire at Bugey NPP - July 1999
DUPUY Philippe

AUTORITE DE SURETE NUCLEAIRE
Sous-direction des réacteurs de puissance

Lessons learned

> **one single electrical default can generate multiple fires in different fire compartments**
(situation not expected by the present fire emergency organisation)

> control room operators did not take fire alarms into account immediately (too busy with incidental procedures)

> sending one FAO to confirm fire before calling any fire team can be a hazardous action in regards of rapid extinguishing operations

> one small break in the fire barrier can have important consequences (more fire detections to cope with, fire fighting operations hardened, smoke in the control room...)

Annex VII

GERMAN PRACTICE ON ACTIVE FIRE PROTECTION FEATURES

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Abstract. In the course of a longer lasting operating period, the safety related range of information is broadened; the methods and instruments for safety analyses are being further developed. This should lead to a continuous progress in a nuclear power plant's (NPP) safety status and its operational safety. Thus, it has been recommended to perform periodic safety reviews (PSR). In order to stipulate a federal uniform procedure within the Federal Republic of Germany, regulatory guides have been developed outlining deterministic as well as probabilistic methods. In order to perform probabilistic fire safety analyses, a comprehensive database is needed, including physical characteristics of fire compartments and their inventory, fire occurrence frequencies, technical reliability data for all fire-related equipment, human actions and human error probabilities, etc. For German NPP, the operational behaviour of different fire protection features has been analysed in order to provide updated reliability data, mainly regarding the technical reliability of active fire protection features. These analyses are based on the examination of reported results of the regular inspection and maintenance programs for NPP as well as on further observations during the plant operation. Last not least, the raw data have to be assessed and statistically treated to be processed for application in a database. The recommended approach for a quantitative fire risk assessment to be applied within PSR for NPP in Germany starts with a screening process providing critical fire zones and is followed by a quantitative analysis using a standard event tree with elements for fire initiation, ventilation of the room, fire detection, fire suppression, and fire propagation. In a final step, the fire induced frequencies of initiating events, the main contributors and the calculated hazard state frequency for the fire event are determined. For that purpose, a comprehensive database is needed which has been developed, in particular for active fire protection measures such as fire detectors, fire dampers, fire doors and fire extinguishing systems. The operating experience of fire dampers is discussed in more detail.

VII.1. INTRODUCTION

Operating German nuclear power plants (NPP) have been designed and constructed in different plant generations leading to differences in the fire protection layout.

However, as a result of permanent supervision and specific fire safety reviews, comprehensive backfitting and upgrading measures have been realised including structural measures (e.g. fire barriers) as well as the active fire detection, alarm and extinguishing features and operational fire protection measures (for manual fire fighting) resulting in significant improvements in fire safety, in particular of NPP built to earlier standards.

In the past, most of the engineering work in designing fire protection features for German NPP has been performed on a deterministic basis. However, the use of probabilistic fire risk analysis is current practice in Germany to review the fire protection state of operating NPP. Moreover, the probabilistic approach provides different insights into design and availability of systems and components and can be seen as a supplementary tool to the deterministic analyses. Thus, probabilistic considerations have been considered for decision making on a case-by-case basis. A more comprehensive fire risk assessment is recommended in the frame of periodic safety reviews (PSR) in Germany which have to be performed in time intervals of approximately 10 years.

In order to stipulate a federal uniform procedure within the Federal Republic of Germany and to define a clear frame with regard to objective and scope of the PSR, regulatory guides [1] have been developed supplemented by more detailed technical reports.

These documents also describe the fire specific aspects which have to be assessed within a PSR.
The approach applied in the PSR allows to make use of the operating experience in fire safety assessment for German NPP. Depending on the data available, plant-specific or generic German data are recommended to be used. In this context, important tasks art to find out whether or not the existing data are exhaustive and sufficient to perform the review, to estimate the level of confidence of the data provided and to verify the particularly plant specific data, e.g. by NPP walk-downs.

VII.2. REGULATORY GUIDANCE FOR FIRE RISK ASSESSMENT

The existing German PSA Guide contains reference listings of initiating events for NPP with light water reactors (PWR and BWR) which have to be checked plant specifically with respect to completeness and applicability. Plant internal fires are included in these listings of initial events.

Detailed instructions are provided in the technical documents on PSA methods [2] and PSA data [3] which are briefly reported. These technical documents have been developed within a working group of technical experts chaired by BfS (Bundesamt für Strahlenschutz - Federal Office for Radiation Protection). The German regulatory guidance, as it is meanwhile available, has been restricted in scope to comprise only those applications for which sufficient practical experience is available and a reasonable consensus between the parties involved has been achieved. However, the PSA working group is continuing its activities to further develop and amend the technical documents, in particular regarding fire specific aspects.

The probabilistic assessment is carried out within two steps: after a so-called screening process to identify critical fire zones as an important first step within a fire risk assessment, a detailed quantitative analysis including simulations is carried out for selected representative fire scenarios.

The screening analysis should not be too conservative resulting in an extremely high number of fire scenarios remaining for the detailed quantitative analysis. However, it has to be ensured that all significant plant areas are covered by the quantitative analysis.

For German NPP, there is a general screening approach as outlined in [2]. This methodology was further improved by GRS within actual activities of developing methods for fire PSA in the frame of a recent research project [4]. In this approach, the critical fire zones are identified in a qualitative selection process (qualitative screening) followed by a quantitative one (screening by frequency). Due to the application of appropriate deterministic selection criteria the qualitative screening gives a possibility for roughly determining critical fire zones with a limited effort. Applying the quantitative screening method on those zones left after the qualitative step, the significant critical fire zones can be identified by means of a simplified event tree analysis.

For the detailed quantitative fire risk analysis, a standard event tree has been developed with nodes for fire initiation, ventilation of the room, fire detection and suppression, both as well for the pilot fire phase as for fully developed fires, and a node for fire propagation.

The standard event tree has to be adapted to every critical fire zone, revealing the following results

- frequency and nature of fire initiating events,
- list of equipment damaged, binned corresponding to different damage states, and
- damage frequencies.

If a complete plant specific PSA is available, the fire induced frequencies will be summarised for all initiating events and specified as input to the corresponding event tree of the PSA, Level 1+. Furthermore, the equipment damage states have to be introduced into the fault trees. The plant hazard state frequencies are estimated for each transient as the sum of the single event core damage frequencies. The total plant hazard state frequency is obtained by summarising the contributions of all transients.

In this context, it has to be stated that the requirement to use only qualified PSA codes has also to be met for fire PSA. Moreover, validated fire simulation models and codes have to be used in case of deterministic fire hazard analysis and probabilistic fire risk assessment.

VII.3. DATABASE

A state-of-the-art analysis of fire effects has to consider all sources of combustibles and their quantity being present, the potential for ignition and the provided active and passive fire protection features to determine frequency and extent of a fire.

In order to perform probabilistic fire safety assessments, different types of data are necessary to quantify the fire event tree, such as fire occurrence frequencies, fire propagation parameters, unavailabilities of active and passive fire protection features, and failure rates for human (mainly NPP personnel) actions in case of fire extinguishing.

For quantification of the potential hazard and damage states identified for the respective plant, data with regard to fire enclosure, fire detection and extinguishing including damages not caused directly by the fire but resulting from the fire fighting (e.g. the extinguishing media) have to be provided.

Data on failure rates for personnel actions in case of fighting fires can be taken generically from all types of fires occurring in NPP over the world. They only have to be adapted to the plant specific conditions inside the plant under investigation.

The operational behaviour of active fire protection features may vary depending on the type and the manufacturer of the equipment. Therefore, generic data concerning the technical reliability of such features can be considered to some extent only. Plant specific data are needed partly. In particular, data from nuclear installations are different to those from non-nuclear facilities gained e.g. from the insurance companies because of the more frequent and detailed inspection and maintenance.

For German NPP under operation, up to the end of 2000 only 25 reportable fire incidents were identified of approximately 4834 incidents obligatory reported overall to the licensing and supervisory authorities. Hence, the fire event data based on the German reporting system are not appropriate for fire PSA use.

In principle, the more comprehensive US database is applicable to German NPP. However, there are lots of, in some cases significant, design differences between German and US NPP. Therefore, certain adjustments by engineering judgement are recommended.

In the past, the unavailabilities for the fire protection features were taken from statistics of German investigations prepared by the so-called ”Association of Property Insurers” and important fire protection system manufacturers. In addition, data from the American Nuclear Insurers, the Nuclear Power Experience and the Industrial Risk Insurers are used in those cases for which German data are not available and if the data are transferable to German NPP conditions.

This insufficient situation was the reason to collect updated technical reliability data by analysing the operational behaviour of different fire protection features in different German reference NPP and to draw general conclusions from these investigations. These reliability data represent updated values of those provided in [2, 3] by processing additional information from further reference plants. The respective scattering factor k given in these tables is correlated to the failure rates.

With regard to fire ignition frequencies, the latest published database for US nuclear power plants [5] is usually taken, including 753 fire incidents caused by fixed and transient ignition sources due to normal plant operation and maintenance states from 114 BWR and PWR units representing a total sample size of 1264 reactor years.

Only very few data are internationally available regarding the reliability of active fire protection features. Since the methodological approaches for the data processing are not uniform and to some extent not known in all detail, the uncertainty concerning these data is high.

VII.4. GERMAN APPROACH FOR ESTIMATING TECHNICAL RELIABILITY DATA FOR NPP FIRE PROTECTION FEATURES

As a contribution to fire PSA, input data on the reliability of active fire protection features are required for application in the event tree analysis. Two types of data can be distinguished: unavailabilities per demand or failure rates per hours of plant operation. In this context, it has to be clearly stated that the reliability of specific features does not only cover the technical reliability but also the fire specific human influence.

For determining the technical reliability of active fire protection features, the plant specific documentation of regular in-service inspections and, in addition, as far as available and applicable, the inspection and maintenance records were analysed for the following fire protection features, including fire barrier components with active protection functions (e.g. fire doors and dampers):

- Fire detection systems including alarm boards and panels as well as fire detectors including their power supplies,
- Fire and smoke dampers in the ventilation systems,
- Fire doors, mainly with devices to keep them in open position,
- Stationary fire extinguishing systems including their respective extinguishing media supplies.

For assessing the raw data, suitable criteria are necessary to receive realistic failure rates and unavailabilities to be applied within a fire PSA. Considering the significance of the affected feature for application in the fire PSA event tree, a careful assessment by engineering judgement based on expert knowledge, whether the documented findings can be estimated as potential failures or only as deficiencies, is necessary. It has to be mentioned in this context that a detailed knowledge of the plant specific conditions is important for this assessment. That means, a walk-through for all plant locations where the fire protection features being analysed are installed and a close co-operation with the plant personnel responsible for fire protection are essential for a meaningful assessment.

The raw data on technical findings from inspections, tests and maintenance activities are collected in a flexible database with the possibility of a computer based statistical evaluation of the respective data for the technical reliability of the protection features considered. For the statistical estimation of the reliability data, their distribution ranges and the respective scattering factors k of the estimated values, a computer based PSA specific statistical evaluation procedure is applied, which is outlined in more detail in [6–8].

VII.4.1. Plant specific data

The analyses of fire protection equipment failures and unavailabilities as outlined in Refs [6] and [9] verify the general impression that most of them are single disturbances without significance to the plant safety. However, some failures with safety significance occurred. Even after having performed analyses for four NPP in Germany, the database is still too small for some of these features, particularly for applying plant specific data in the frame of fire PSA, and has to be expanded.

A comparison of the recent plant specific data on the technical reliability of various fire protection features with former plant specific data for the same fire protection features gave only less important deviations (see [9] and Figs 1 and 2).

Most of the estimated values for the technical reliability of active fire protection features represent realistic data for these systems and components installed in German NPP. They can be applied in the frame of PSA studies instead of conservative data from past nuclear specific reliability studies as well as instead of generic values available from data of the insurance companies for the reliability of equivalent fire protection means in non-nuclear industry, both being available up to the time being.

For most of the fire protection features recently analysed (NPP 1 and 2 in figures 1 and 2), the failures rates per operating hours as well as the unavailabilities per demand are in the same order of magnitude or a little lower than those gained from former analyses (NPP 3 and 4 in figures 1 and 2). Only for some specific features the unavailabilities are higher. These deviations should result from more realistic assumptions for the actual investigations on the one hand and from backfitting actions taken as a result of the feedback from former analyses.

On the other hand, a partly higher scattering of the statistical values can be observed for the more recent data from reference plant NPP 1 (see figure 1), while the expected value is reasonably lower. This higher statistical uncertainty can be explained from so-called zero-event statistics (no failure during the reference observation period).

As another result of the overall analyses, differences can be found concerning the reliability of fire protection features between the nuclear and the non-nuclear field. In general, the technical reliability is higher for NPP fire protection equipment. These deviations may result from more frequent and detailed in-service inspections for the equipment in nuclear installations with a highly sophisticated quality assurance and maintenance program as well as from the strongly regulated qualification programmes for the NPP personnel.

VII.4.2. Generic data

Table 1 gives an overview of the generic failure rates for active fire protection equipment from four German nuclear power plants as estimated in [9]. Figure 3 outlines a uniform behaviour for a majority of active fire protection features with failure rates in the range of 10–6/h. The reliability of the fire detection features is slightly higher. The highest value estimated for CO2 gas extinguishing systems can only be seen as a first rough estimate not applicable as verified input data in a fire PSA because of the still much too small database from only few operating hours in two reference NPP.

As one important result, most of the technical reliability data revealed in the frame of the recent analyses for active fire protection features are representative for different reactor types and NPP generations in Germany. Furthermore, these data are as far as possible no longer conservative, but realistic because of uniform and reproducible criteria for the assessment on the one hand and more representative reference periods on the other taking potential ageing effects also roughly into account. Thus, the estimated statistical values discussed above can be better used as input data for assessing the effects of fire detection and fire extinguishing during the different phases of a fire event in the framework of the fire specific event tree analysis.

The actual failure rates estimated are time independent with regard to the inspection periods for in-service inspections. Therefore, the values determined nearly for all active fire protection features mentioned above are applicable to those in any other German nuclear power plant with an equivalent design of the active function.

The failure rates might also be applied to active fire protection features implemented in other European NPP, if the design of this equipment and their respective inspection and maintenance procedures are equivalent.

VII.5. OPERATING EXPERIENCE OF FIRE DAMPERS

The operating experience of NPP in Germany has revealed several findings with respect to deterioration and potential unavailabilities of fire dampers during the last years. These findings mainly resulted from observations in the frame of the regular in-service inspections and maintenance. They indicated different problems and difficulties in manufacturing and quality assurance, in particular, mechanical problems for large type fire dampers.

Furthermore, between 1994 and 1998 different failures of the thermal actuation of fire dampers by fusible links occurred. These failures were found by random thermal actuation tests that did not belong to the normal inspection and testing procedure of fire dampers in Germany before. The various findings resulted in different, so-called “Information Notices” being relevant for the German licensing and supervisory procedure corresponding to deterioration of fire dampers of NPP in Germany.

Until 1992-94, the regular in-service inspections of fire dampers in NPP were limited to specific buildings (e. g. belonging to the controlled area), a visual inspection of the dampers, and a functional inspection of the remote controlled actuation, depending on the plant specific conditions of each plant. Up to this time, only very few findings could be observed, e. g. at pneumatically remote controlled actuation mechanisms after an exchange of valves. In this context, it has to be noted that up to this time the regular in-service inspections were performed with special authorised experts present, in particular for NPP built to earlier standards, and that in general the inspections were carried out directly after maintenance.

Since 1994, the regular in-service inspections of fire dampers in NPP also include inner inspections and tests of the thermal actuation by fusible link for a specific percentage of the fire dampers, varying from plant to plant. These additional tests in the frame of the regular in-service inspections and maintenance revealed several findings at the fire dampers in German NPP. They indicated different problems and difficulties in manufacturing and quality assurance, in particular, mechanical problems for large type fire dampers.

The first malfunction of the thermal actuation mechanism was detected during the annual in-service inspection of fire dampers located in the ventilation system for controlled areas of one NPP in 1993. During this inspection, the function of the electrical remote controlled actuation as well as the manual actuation were checked, and a visual inspection of the inner and outer parts of the dampers was performed.

In the frame of subsequent tests of the thermal actuation mechanism at 652 fire dampers in this NPP 109 dampers showed the same deficiencies with identical causes. It should be mentioned that all fire dampers affected closed properly at the previous check of the electrical and manual actuation.

Following this incident, GRS recommended inspections of the thermal actuation mechanism of fire dampers at all nuclear facilities in Germany. During these inspections, further malfunctions were detected, including different types of fire dampers from several manufacturers. In total, up to now deficiencies were found at more than half of the German NPP as well as in one nuclear reprocessing plant. Differing damper designs from different manufacturers were affected. Most of the deficiencies identified were systematic failures. However, some of the malfunctions could be regarded as single failures.

In November 1995, the first finding on a fire damper affecting both the electrical and the thermal actuation mechanism was observed.

The event can be briefly described as follows (cf. [11]): During the acceptance test which took place following the installation of a new fire damper in the ventilation system of the conditioning building, the respective damper was found to be impossible to close electrically by remote control from the fire alarm centre. An inspection of the damper revealed that the thermal actuation mechanism was also affected by the malfunction. The same failure was found in one further damper in the ventilation system of the conditioning building.

Figure 4 shows schematically the typical function of the fire damper actuation mechanism: On electrical actuation, the latch is released. It moves downward and releases the manual lever, thus enabling the damper to fall into “closed” position. On thermal actuation, the pin moves out of the casing of the damper on actuation. It thereby removes the knob of the manual lever from the latch, thus also releasing the manual lever and closing the damper.

The direct cause of the finding was an erroneous operator action when the dampers were reset following an actuation before the acceptance test. Due to this mal-operation the latch was not set back into the correct position. This led to the condition that the electrical actuation could not become effective even though the damper was locked in open position. In addition, there existed unfavourable manufacturing tolerances, therefore it was possible for the pin of the thermal actuation mechanism to slide past the knob of the manual lever, thus rendering this actuating mechanism ineffective as well. The manual actuating mechanism on the system itself remained available. One specific reason for the malfunction however is a lack of indications on the damper itself showing that the damper has been reset correctly.

Findings with a non-closing of fire dampers due to other causes were observed in 1997. Meanwhile, detailed investigations have shown with a high certainty that the bending of the lever arm does not result from deficiencies in the construction (as preliminary assumed) but from an erroneous adjustment of the opening mechanism.

As far as the observed malfunctions of fire dampers were resulting from deficiencies in the design, manufacturing, or quality assurance it can be assumed that the problems and deficiencies have been recognised in the meantime by additional tests and/or inspections and that correctives measures have been taken at all NPP in Germany to ensure a high level of reliability for these components. From the operating experience during the past 2-3 years, it can be expected that that this assumption is valid.

VII.6. CONCLUSIONS

Periodic safety reviews are to be performed for all German NPP to demonstrate plant nuclear safety. The review of the actual state of the fire protection features and their reliability is also part of these PSR, which have already been performed for more than half of the operating NPP in Germany. Although these reviews were mainly focusing on deterministic investigations in the past, the existing German regulatory guidance for performing PSR recommends a fire PSA as an additional tool to the deterministic analyses, requiring appropriate methods, models and data. In the frame of these reviews, particularly those NPP have to be assessed carefully which have been designed and built to earlier standards taking into consideration the already implemented fire protection improvements.

The first fire PSA which have been performed for German NPP show that the contribution of plant internal fires to the total plant hazard state frequency is low for the investigated plants and that these events do not represent significant contributors. However, the results of the fire PSA can be used to analyse and assess in detail potential findings of the deterministic part of the periodic safety review, to determine the necessity and urgency of safety improvements and to set priorities for fire protection backfitting and upgrading measures.

With respect to the statistical data to be applied in the frame of a realistic fire PSA, it has to be pointed out that the existing national database for several fire protection features still has to be improved and to be expanded. Moreover, the human influence has to be considered carefully. The use of internationally available generic data, mainly from US and France, in particular fire occurrence frequency data, is not always appropriate for application within fire PSA for German NPP due to design, inspection and maintenance differences. On the other hand, the presently available German data do not always allow to provide a verified database.

In the particular case of fire dampers implemented in nuclear installations, the analysis of the operating experience revealed mainly from the regular testing, inspection, and maintenance practice shall be continued and the information distributed between all experts from nuclear industry, authorities and expert organisations involved to gain further insights on the reliability of fire dampers in NPP and to improve their reliability further.

REFERENCES

[1] BUNDESMINISTERIUM FÜR UMWELT, NATURSCHUTZ UND REAKTORSICHERHEIT: Bekanntmachung der Leitfäden zur Durchführung von Periodischen Sicherheitsüberprüfungen für Kernkraftwerke in der Bundesrepublik Deutschland — Leitfaden Probabilistische Sicherheitsanalyse vom 18. August 1997. undesanzeiger Nr. 232a vom 11. Dezember 1997.

[2] FACHARBEITSKREIS (FAK), Probabilistische Sicherheitsanalyse für Kernkraftwerke, Methoden zur probabilistischen Sicherheitsanalyse für Kernkraftwerke. Dezember 1996, BfS-KT-16/97, Salzgitter 1997.

[3] FACHARBEITSKREIS (FAK) Probabilistische Sicherheitsanalyse für Kernkraftwerke: Daten zur Quantifizierung von Ereignisablaufdiagrammen und Fehlerbäumen. April 1997, BfS-KT-18/97, Salzgitter 1997.

[4] FASEL, H.-J., TÜRSCHMANN, M., RÖWEKAMP, M.: Die Auswahl kritischer Brandbereiche bei probabilistischen Brandanalysen, GRS-A-2835, November 2000 (in press).

[5] WHEELIS, W. T.: Users Guide for a Personal-Computer-Based Nuclear Power Plant Fire Data Base. SAND86-0300, NUREG/CR-4638, Sandia National Laboratories, Albuquerque, NM, 1986.

[6] RÖWEKAMP, M., BERG, H. P.: Reliability Data Collection for Fire Protection Features, Kerntechnik, 65, No. 2–3, 102-107, 2000

[7] Hofer, E., Peschke, J.: Bayesian modeling of failure rates and initiating event frequencies‘, Proceedings of ESREL 1999 - The 10. European Conference on Safety and Reliability, Munich (Germany), 13–17 Sept. 1999.

[8] Peschke, J.: Methoden zur Gewinnung von Verteilungen für Zuverlässigkeitskenngrößen aus Vorinformationen und anlagenspezifischer Betriebserfahrung. Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH, GRS-A-2220, 1995.

[9] Röwekamp, M., Oltmanns, S.: Ermittlung kernkraftwerksspezifischer Zuverlässigkeitskenngrößen für Brandschutzeinrichtungen in einem älteren Kernkraftwerk und in einer Konvoi-Anlage , GRS-A-2826, Dezember 2000.

[11] Röwekamp, M., Liemersdorf, H.: Operating Experience of Fire Dampers in Nuclear Power Plants in Germany, Proceedings of 3rd International Conference Fire & Safety ´99, Nuclear Engineering International/Wilmington Business Publishing, Dartford 1999.

TABLE 1. GENERIC FAILURE RATES FOR ACTIVE FIRE PROTECTION FEATURES FROM FOUR GERMAN NUCLEAR POWER PLANTS

Fire Protection Feature	Data Source	Scattering Factor k	Failure Rate (expected value)
Fire alarm boards:			
- Fire detection lines	NPP 1-4	8.81	7.8E-08
Automatic fire detectors	NPP 1-4	7.61	1.0E-07
Manual fire detectors (press buttons)	NPP 1-4	19.42	7.0E-07
Fire dampers:			
- with remote control	NPP 1-4	10.95	2.2E-06
- without remote control	NPP 2-4	6.65	5.3E-07
Fire doors	NPP 1-2	9.13	5.9E-06
	NPP 3-4	1.71	5.7E-07
Heat & smoke removal dampers	NPP 1-4	5.06	2.5E-06
Gas extinguishing systems:			
CO_2 gas extinguishing systems	NPP 2-3	11.43	1.8E-05
Inergen gas extinguishing systems	NPP 1	26.75	1.2E-04
Spray water deluge systems:			
Dry sprinklers:			
- total failure	NPP 1-4	8.14	7.3E-07
- remote control failure	NPP 1-4	6.73	7.9E-06
Fire pumps	NPP 1-4	6.45	7.5E-06
Wall hydrants	NPP 1-4	7.61	2.1E-07
Field hydrants	NPP 1-4	6.20	1.1E-06

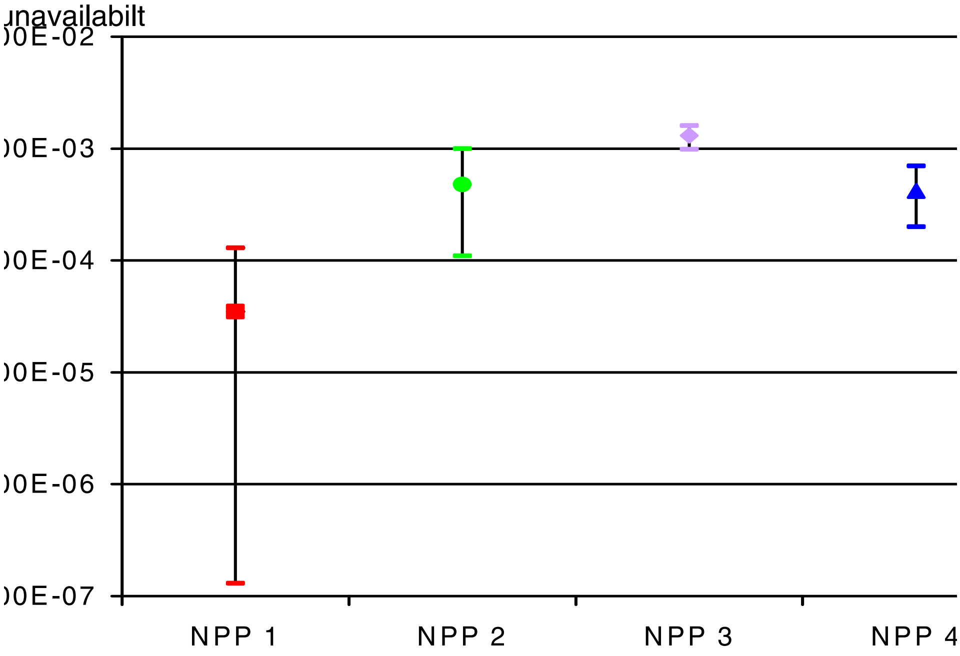

FIG. 1. Plant Specific Unavailabilities per Demand for Automatically Actuated Fire Detectors from Four German Nuclear Power Plants [9].

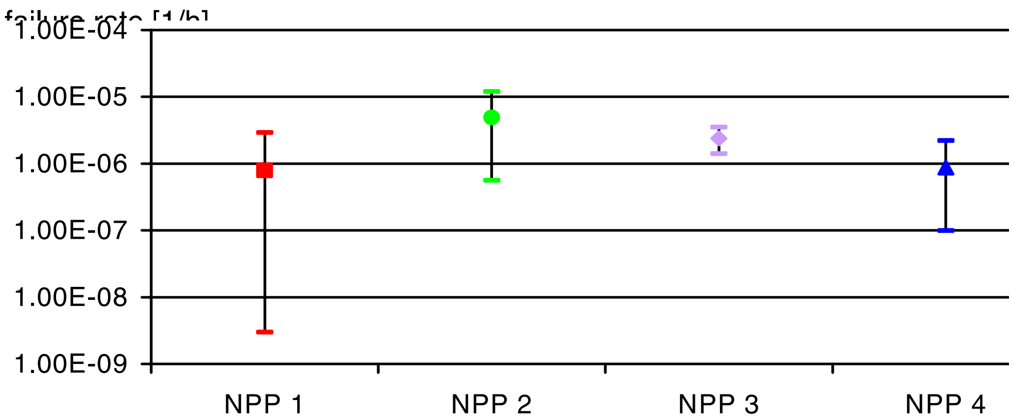

FIG. 2. Plant Specific Failure Rates λ [1/h] for Smoke & Heat Removal Dampers from Four German Nuclear Power Plants [9].

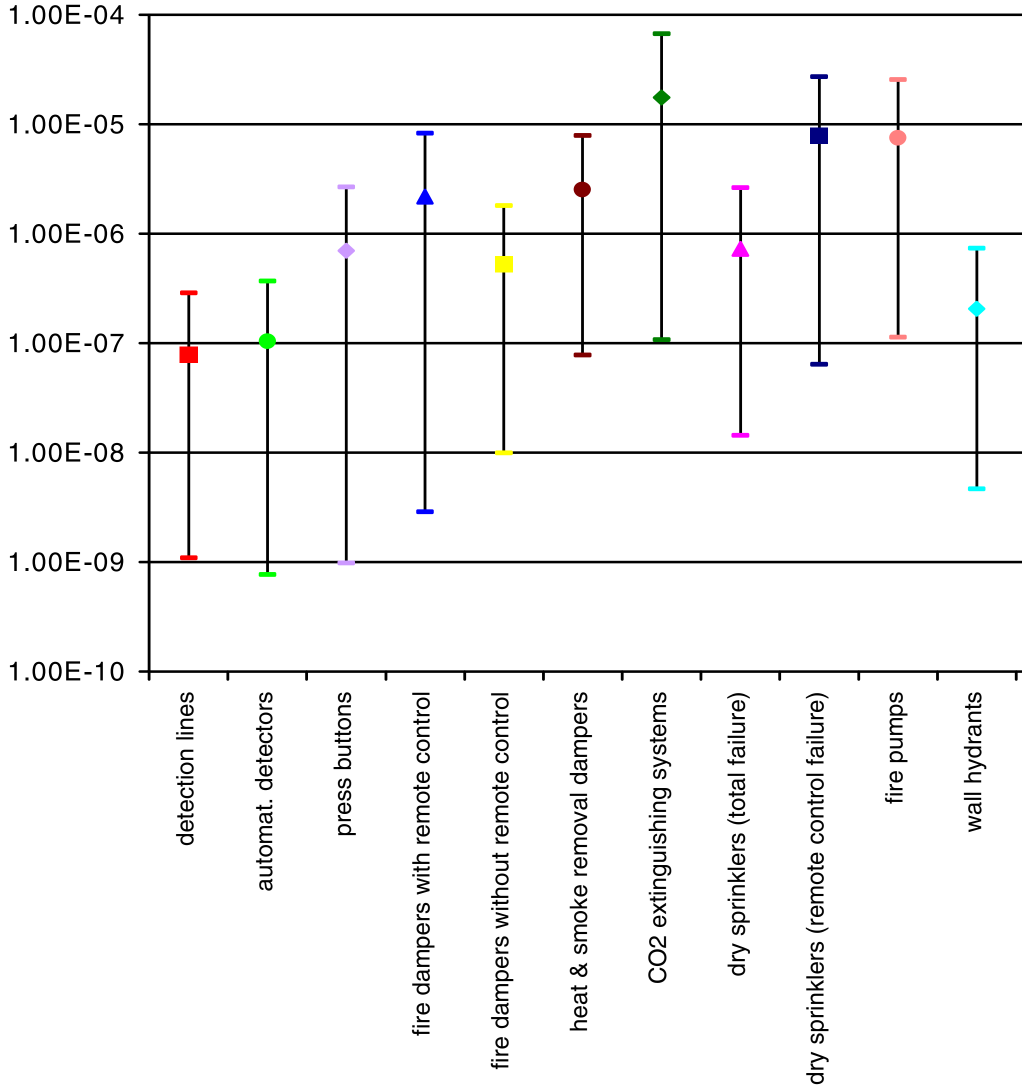

FIG. 3. Generic Failure Rates λ [1/h] for Active fire Protection Features from Four German Nuclear Power Plants [9].

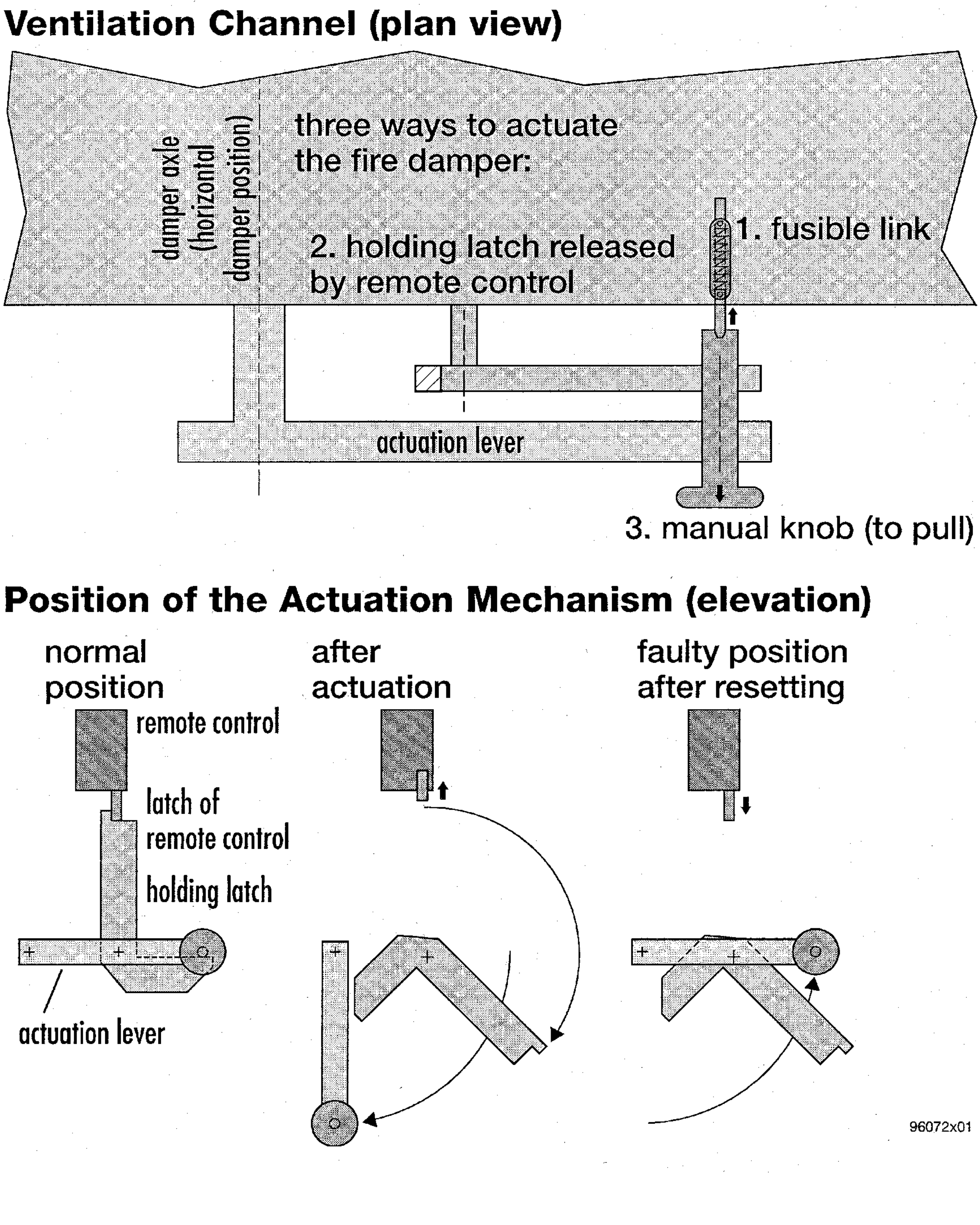

FIG. 4. Schematic drawing of the actuation mechanism positions of fire dampers with findings.

Annex VIII

ADMINISTRATIVE CONTROL OF TRANSIENT WORKS

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Cernavoda NPP, Romania

Abstract. The paper describes the administrative measures adopted at Cernavoda NPP in relation to fire protection.

VIII.1. INTRODUCTION

The Fire Protection in Cernavoda Nuclear Power Plant was developed based on the concept of protection in depth as well stated by AIEA:

- Preventing fires from starting;
- Detecting and extinguishing quickly those fires which do start, thus limiting the damage;
- Preventing the spread of those fires which have not been extinguished, thus minimizing the effect on essential plant functions.

The first objective requires that the design and operation of the plant are such that the probability of a fire starting is minimised. The role of design is worldwide recognized as the first step in building up fire safety of the plant. Later on during the operation attention should be paid to the administrative control of the fire hazards induced by the operating equipments and human activities. This approach shall be defined and documented as an operational Fire Protection Program. The program is aimed to provide the administrative means which clearly shall define the interfaces between human resources and activities, including responsabilities and lines of communications.

All the activities we have identified as contributors to fire safety have been included in the Fire Protection Program as showen in the appendix.

Basically the two direction by which the fire safety shall be achieved are fire prevention and fire control.

Fire prevention is always desirable as the main line of defence. Preventing fires from starting is an achievable objective as long as the potential sources of fires are identified and then controlled.

This is a fairly statement but the following question appears: how to effectively control the fire hazards?

Operation of the plant involves a diversity of works performed by numerous employees. As long as the control of fire hazards is not one man show the involvement of all employees acting on different levels is mandatory.

The experience showed that the commitment in achieving the desired level of preventive behaviour is not always satisfactory.

VIII.2. TRANSIENT WORKS

For the purpose of this presentation, two subjects of concern have been focused. In fact both aspects refers to those activities which might be defined as transient works including hot works and bringing combustible materials into the plant. The first one provides readly open sources of ignition and the second one provides accesible material to be ignited.

These transient works are so common that can be encountered in any plant no matter the design is. Transient works represent a real threat to safe operation of the plant just because they are so common, have been done many times before and nothing happened.

More over the workers are used to focus on the completion of their work without thinking to the effects that their work might have to the safety of workplace or the operating systems. The workers do not always realize that through their negligence a fire may not only cause them physical harm but may mean loss of income until repairs are completed and production resumed.

Operation of the plant requires both planned maintenance and occasionally repairs.

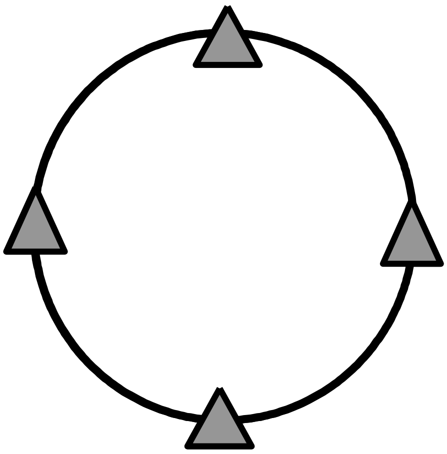
Activities such as welding, cutting, grinding, lube oil replenishment, greasing, cleaning or painting are the main contributors to the increase of the fire hazards by bringing into the operation areas of the ignition sources and temporary combustibles. The presence of these temporary fire hazards in the vecinity of the operating systems poses a real threat to safe operation. In some circumstances they may represent the initial start of a fire which propagates to the systems nearby. On the other hand, a fire starting on the operating system may extend more hazardous due to additional fire loads represented by temporary combustible materials.

During the commissioning and early stage of the plant's operation field inspections showed that the tendency to solve maintenance needs was to choose the most comfortable and convenient way for the maintainers. The following aspects have been noticed:

- Insufficient protective measures during the welding or grinding works;
- Insufficient surveillance after the completion of works;
- Lack of additional and independent evaluation of fire hazards;
- Lack of appropriate safety rules to be followed by workers;
- Quantities of combustibles exceeding the necessity for one day work or single work;
- Use of defective equipment for hot works;
- Insufficient control when bringing into the plant of combustible in respect of the start of works.

All the inappropriate practices noticed during the walk down inspections showed that the aim to create an effective attitude of fire safety can be accomplished only through a systematic approach including:

- Set of fire safety rules which shall state the prevention standard;
- Appropriate training aimed to ensure that the preventive rules are acknowledged;
- Regular field inspections to monitor the adherence of workers to the fire safety expectations;
- Corrective action process to investigate, evaluate and correct bad practices or violations of the fire safety rules.



Based on above directions Cernavoda NPP developed a functional framework which clearly defines the way how the transient works has to be controlled.

VIII.3. CONTROL OF TRANSIENT WORKS

VIII.3.1. Fire prevention rules

As a first step in implementing the control of transient works a standard has been defined including the good practices to be followed whenever a work which might affect the fire safety is to be performed. The standard covers both the potential ignition sources and the modification of the thermal loads introduced by the temporary works.

Fire prevention rules have been developed as a section of the Industrial Safety Manual. In order to better control the works the standard contains:

- Fire Permit which states the steps to be followed in order to ensure the safety conditions during the hot work;
- Combustible Permit which states the conditions to be followed whenever combustibles are to be brought inside the plant. These conditions refers to allowable amount of combustibles, destination, duration of work, removal and appropriate safety precautions if necessary.

VIII.3.2. Training

In addition to the plant training program a safety meeting process has been implemented. The safety meetings process is aimed to provide a better adherence of employees to the safety rules.

For the employees involved in the operation of the plant the frequency of safety meeting is monthly. Based on the topics established annually a set of training materials are provided to each work group. Each topic provides highlights of applicable fire rules and advice to help the employees recognize potential safety problems.

Annually an individual verification is performed as an additional tool in assessing the understanding and subsequently the adherence of the employees to the safety rules.

VIII.3.3. Monitoring

The adherence of workers to the good practices has to be demonstrated by their day by day activity. For this purpose a field inspection system has been implemented. The responsibility for these inspections has been assigned to the Fire brigade. This independent inspection process does not minimize or replace the other ways of supervision.

By routine walkdown surveillance through the plant the professional firefighters are assigned to check the status of housekeeping and the compliance of the works with the fire prevention rules. The nonconformities or violations are recorded and reported through hierarchy. Whenever an imminent fire hazard has been identified the Shift Supervisor has to be notified for immediate corrective actions.

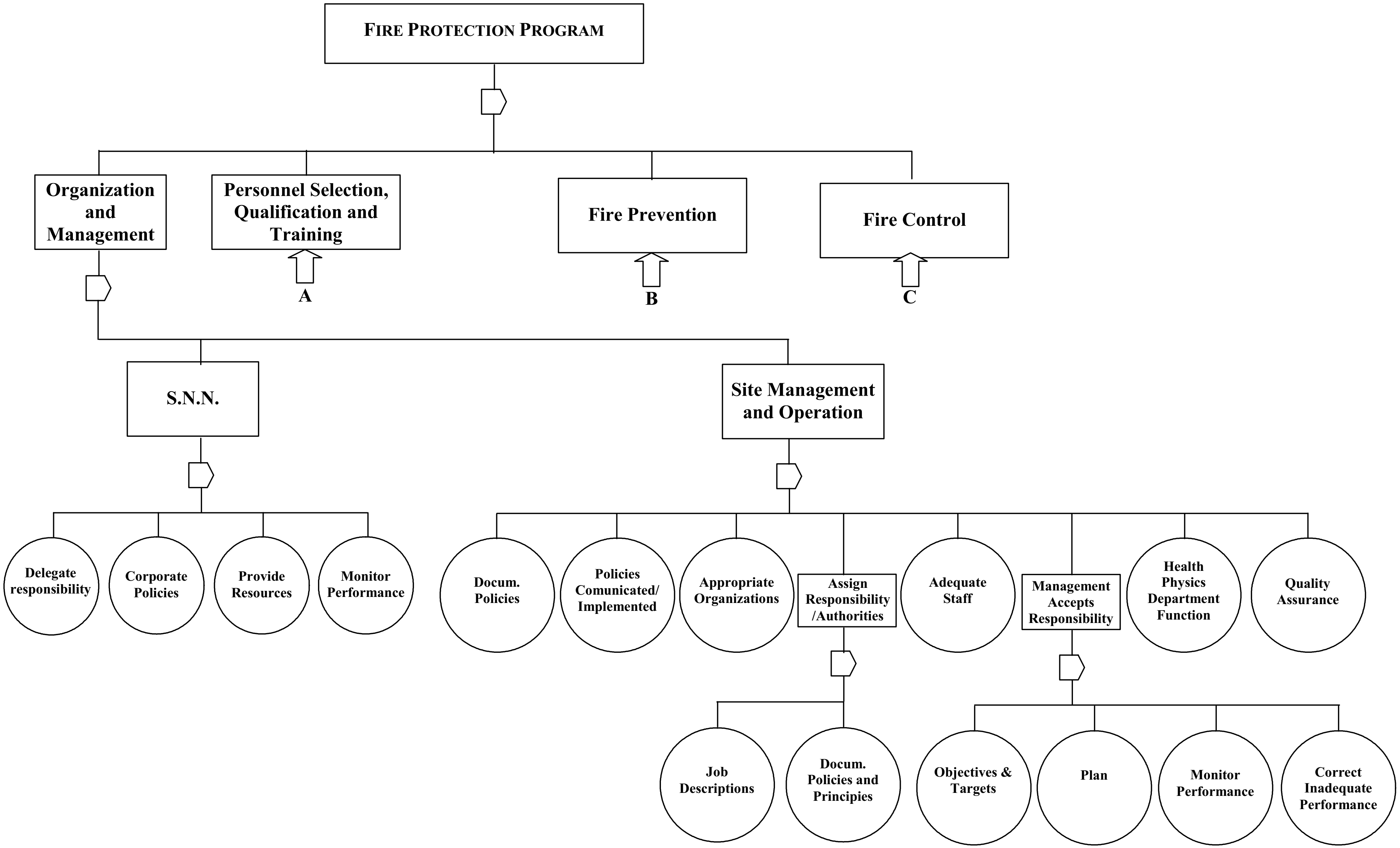
VIII.3.4. Correcting

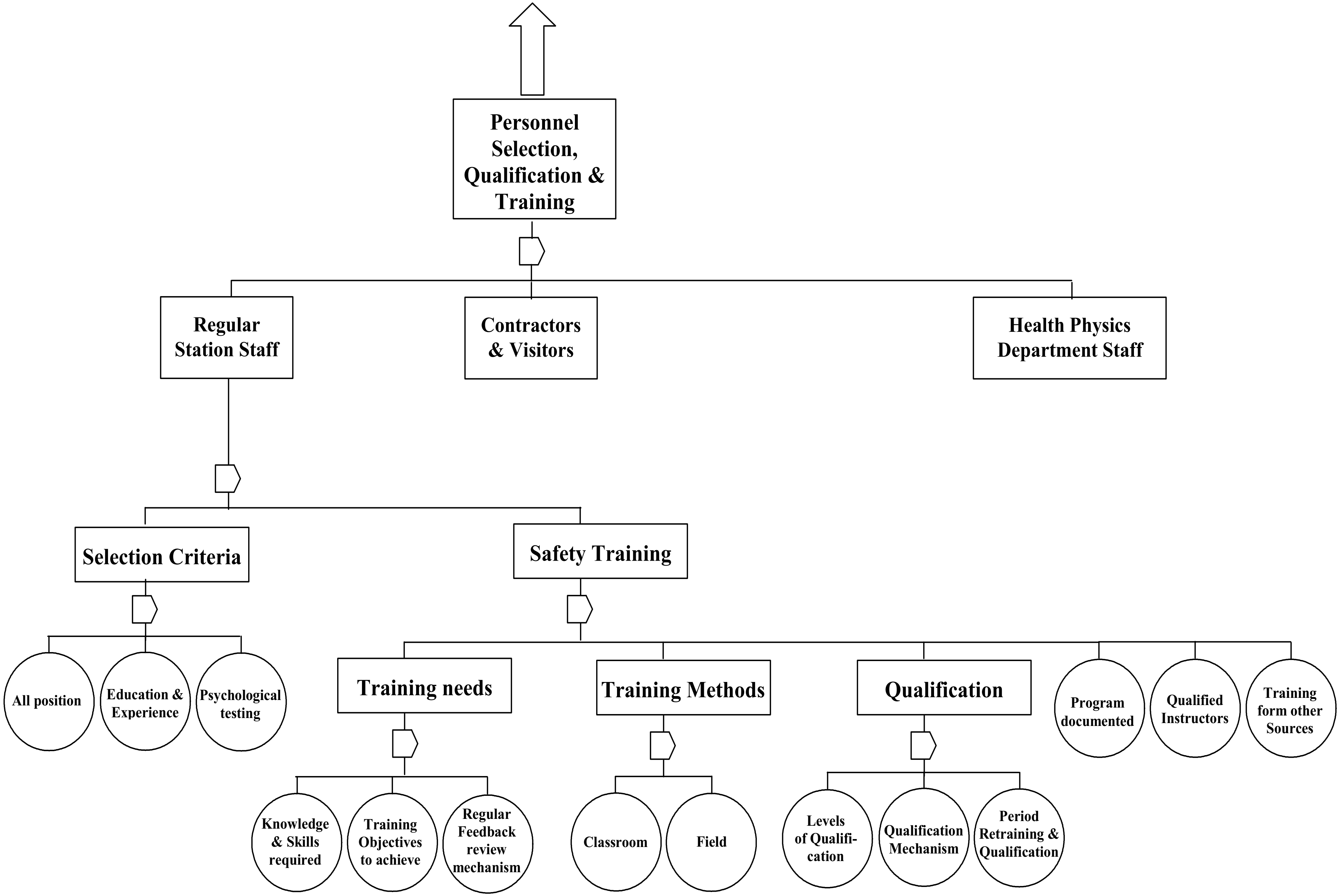
Whenever a violation of the safety rules has been identified it is processed through Abnormal Condition Report system. This system provides the opportunity to adress either low level events which can induce adverse conditions to safe operation of the plant.

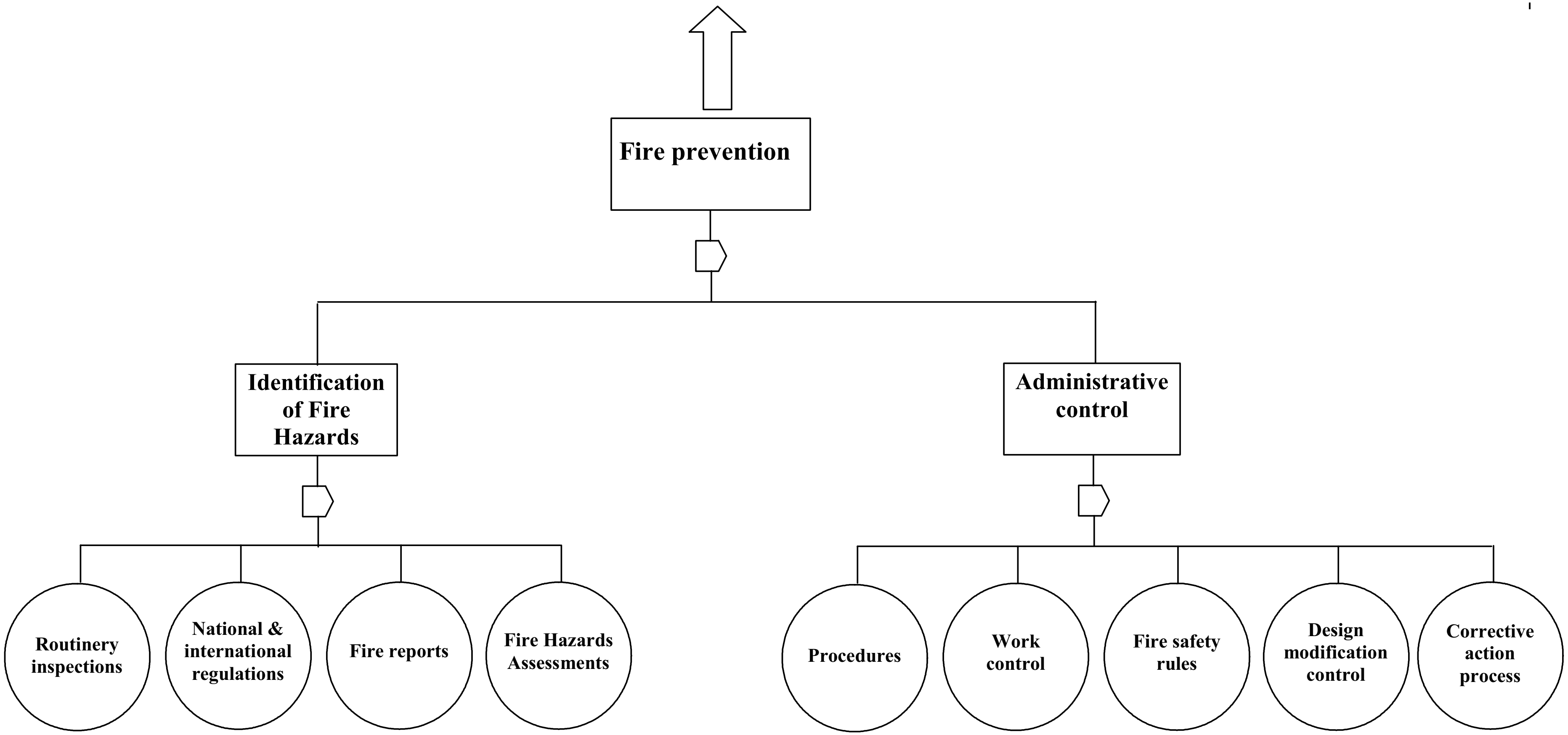
VIII.4. CONCLUSIONS

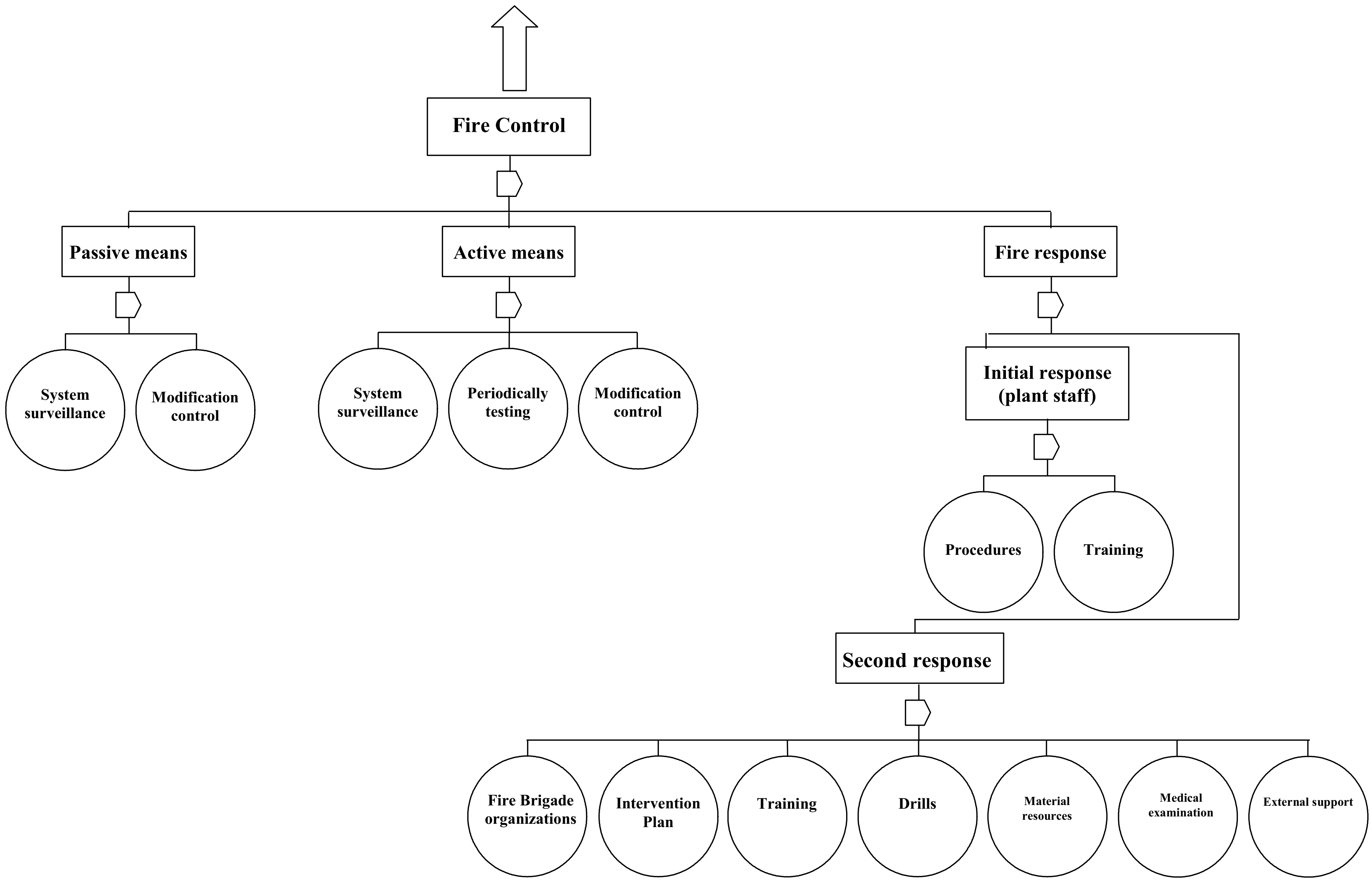
Addressed to those common activities defined as transient works the administrative control system described above has nothing spectacular but provides a logical and consistent approach.

The system ensures its own self-assessment function. Whenever a weakness within the circuit occurs the next steps shall reveal it. Based on the appropriate evaluation further actions for improvement and reinforcement can be developed and applied.


FIRE PROTECTION PROGRAM
Organization and Management
Personnel Selection, Qualification and Training
Fire Prevention
Fire Control
A
B
C
S.N.N.
Site Management and Operation
Delegate responsibility
Corporate Policies
Provide Resources
Monitor Performance
Docum. Policies
Policies Comunicated/ Implemented
Appropriate Organizations
Assign Responsibility /Authorities
Adequate Staff
Management Accepts Responsibility
Health Physics Department Function
Quality Assurance
Job Descriptions
Docum. Policies and Principies
Objectives & Targets
Plan
Monitor Performance
Correct Inadequate Performance


Personnel Selection, Qualification & Training
Regular Station Staff
Contractors & Visitors
Health Physics Department Staff
Selection Criteria
Safety Training
All position
Education & Experience
Psychological testing
Training needs
Training Methods
Qualification
Program documented
Qualified Instructors
Training form other Sources
Knowledge & Skills required
Training Objectives to achieve
Regular Feedback review mechanism
Classroom
Field
Levels of Qualifi-cation
Qualification Mechanism
Period Retraining & Qualification


Fire prevention
Identification of Fire Hazards
Administrative control
Routinery inspections
National & international regulations
Fire reports
Fire Hazards Assessments
Procedures
Work control
Fire safety rules
Design modification control
Corrective action process


Fire Control
Passive means
Active means
Fire response
System surveillance
Modification control
System surveillance
Periodically testing
Modification control
Initial response (plant staff)
Procedures
Training
Second response
Fire Brigade organizations
Intervention Plan
Training
Drills
Material resources
Medical examination
External support

Annex IX

MODERNISATION OF FIRE DETECTION SYSTEMS ON OLKILUTO 1 AND 2

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Teollisuuden Voima OY, Olkiluoto,
Finland

Abstract. Olkiluoto units have been erected in the 1970s. OL1 has been in commercial use from 1979 and OL2 from1982. The modernization of fire detection systems has been started at the end of the 1990s by pre-planning, which was followed by the procurement and planning. The implementation will be ready by the end of the year 2001. In the text, there is described the modernization project from the pre-planning stage to the implementation. The new system is an addressable system and it is equipped with graphic interface (PC). Detectors are mainly of optical type, but multi-criteria and line-detectors have also been used. The old cables have been used in implementation, whenever it has been possible. The modernization project was realized mainly during the normal run of the plant units, working during the outage was minimized. The fire detection systems have been in use during the whole project. Old and new systems have been used in parallel, so that after a new area has been installed and checked, it has been taken into use.

IX.1. INTRODUCTION

Teollisuuden Voima Oy (TVO) owns and operates two identical 840 MW ABB Atom type BWR units, OL 1 and OL 2, in Olkiluoto (Finland). The units have been in commercial use since 1979 and 1982, respectively. The fire alarm systems of TVO nuclear power plants were over 20 years old and their replacement became necessary. The modernization of fire detection systems has been started at the 1990s by pre-planning, which was followed by the procurement and planning. The implementation will be ready by the end of the year 2001.

IX.2. PROJECT DESCRIPTION

IX.2.1. Groundings for modernization

The technical structure of the old fire alarm systems were old-fashioned, and in comparison with new addressable fire alarm systems on the market, the detection sensitivity of the systems was not sufficient, the accurate localisation of the burning place was impossible and maintenance was laborious. The supply of spare parts was getting worse too.

IX.2.2. Aim

The aim of the project was to plan, to buy, to install and to implement of the new fire alarm system, which was able:

- To carry out the demands of the fire rescue organization
- To comply the rules by the authorities
- To fulfil demands of plant safety

- To find out the real fire as quickly as possible and
- To improve remarkably other information, which system was able to product
- To integrate into the developing process of the main control room.

IX.2.3. Content

The most important stages of the project were basic design, equipment procurement, detail planning, installations and implementation.

X.2.3.1. Basic design

During several years in the 1980s and 1990s there were several reports how new fire alarm systems on the market would be suited to the plant units.

The essential part of the report work was to familiarize with other modernization projects of fire alarm system, especially with projects in Loviisa NPP and in Swedish nuclear power plants.

The regulations and guidelines of authorities must be taken into consideration, especially YVL-guide by Finnish Centre for Radiation and Nuclear Safety.

The aim of this stage was to declare basic information, so that it was possible to prepare technical specifications for equipments to make invitations for tender of equipment supplies.

IX.2.3.2. Equipment supplies

Technical specifications for systems and for equipments were made in 1998. Invitations to tender to five suppliers were sent in the beginning of 1999; (back at the end of February). After technical and financial comparison the decision of the equipment supplier was made in August 1999, contract with Esmi Oy was signed on December 22, 1999. Scope of supplier included follows: Fire alarm units and operator terminals, detectors, push buttons, PLC-units, local operating and monitoring systems, programs and programming devices and licences, spare parts, training of owners staff, documentation. Owner's scope was erection of equipment and detectors, cables and erection of cables, graphic layouts, id-codes, texts etc. for programming and power supplies 230 VAC.

IX.2.3.3. Detailed planning

After the selection of equipment supplier the detailed planning was begun, which consisted checking of detector locations, loop- and cable modifications, connections and programming information for central units. Esmi Oy and TVO made work specifications together.

IX.2.3.4. Installations

Installations were contracted out to an installation company. After the selection of the contractor in the beginning of the year 2000, the detailed schedule consisting installations of central units, detector- and cable installations and loop modifications was made. The present cable network was used as much as possible. The new cables were needed mainly between central units or when the locations of detectors were modified or there were new detector locations or several old loops were connected to one new loop.

IX.2.3.5. Commissioning

- Central units

Fire detection equipment supplier Esmi Oy was responsible for the commissioning of the complete systems. The supplier commissioned local control units (ESA), central alarm/control equipment (MESA) and their cable network before the changing detectors.

Configuration programs (detector addresses, fire alarm groups etc.) were run into central units and checking the addresses was carried out with the help of "testing panel". Also graphics was checked at the same time.

- Graphic PC

In the room next to the main control room, there was graphic PC workstation, which was in "job use", because the incomplete system would have disturbed the other control room working. The PC will be moved to the main control room, when the whole system is ready.

- Transferring loops to new system

Old detectors were changed to new ones loop by loop.

Before commissioning the new loop, the control measuring was made. When a new loop was implemented, the system automatically checked the addresses of detectors in the loop and other that kind of things. Also control of fans and dampers were taken into use. Detectors were tested with testing magnet. Transferring a loop to new system was tried to carry out in a day.

IX.2.2.6. Organization

TVO grounded a project group. The project leader was electrical engineering and other members were fire protection engineering, fire chief of the plant, electrical planner, electrical work leader, the head of the OL1/OL2 control room personal and instrument engineer.

The responsible of detailed planning was the design office of TVO.

IX.2.2.7. Method of implementation

TVO bought equipment from the manufacturer of fire detection and alarm system and installation work from installation contractor.

The manufacturer of fire detection system was responsible for the whole commissioning.

IX.2.2.8. Timetable

Preliminary OL1 would have been commissioned on June 15, 2001 and OL2 on June 15, 2002. OL1 has been ready according to the schedule, some development and rest work is left. OL2 is probably ready in September 2001. This has been possible, because in outages 1999, 2000 and 2001 there was detailed planned working schedule, which was strictly followed.

IX.2.2.9. Expenses

The total expenses for OL1 and OL2 are about 2 M€.

IX.2.2.10. Training

The planning staff was trained in the beginning of the detailed planning. Control room personnel, fire brigade, security guard and maintenance people have been trained before the system implementation. A test loop has been installed to the units, which has been used for training purposes. The training simulator has been planned to be installed to the plant, too.

IX.3. GENERAL SYSTEM DESIGN

IX.3.1. Functions of the system

The function of the system is to provide automatically a fire alarm, should fire occur within the plant. Further functions of the system are to make it possible to identify the point in the plant at which fire has broken out from central control room and also provide other information dealing with fire alarm point. System provides also information functioning of fire extinguishing systems and is able manually to control functioning of some fire extinguishing systems. Further, the system is able to provide automatically a signal to the ventilation systems so that for example overpressure in staircases is achieved.

IX.3.2. General description of the system

IX.3.2.1. General

The system has been decentralised so that it complies aerial subdivision (A, B, C and D). In each sub, alarm centre units have been decentralised so that lengths of cables and amounts of detectors provide possibilities to increase detectors later on, if needed. Control alarm units inside the sub have been connected to each other via communication interfaces and to the central unit in the main control room in the same way.

The fire alarm system is fully addressable, so that every detector, push button, control unit etc. has its own individual address.

In the main control room there is a working station with monitor and system consoles with printers. All information from fire alarm and detection system is in full view in the workstation and all needed actions are possible to make with help of the graphic system.

IX.3.2.2. Functions in working station

System consoles will perform the following functions:

- The same messages and operations as those in the operating terminals of the central units
- Handling of alarm messages etc
- Action instructions for fire brigade for every alarm address.
- Status supervision of detectors, detector groups and other objects (fans, dampers)
- Control of fans, dampers etc
- Printing of reports and layouts

IX.3.2.3. Systems linked to working station

Some other system will be connected to the monitoring and operating system:

- Fire alarms from outside buildings
- CCTV (closed circuit TV)
- PPC (Plant Process Computer)
- Nextinfo (announcing to fire brigade, rescue staff etc. by radio communication)
- Graphic work stations for fire brigade, for security guard and for OL2 are also connected to the same network as OL1. In principle in these stations there are the same function properties as in OL1

IX.3.2.4. Fire plans and alarm functions

The plans of the buildings in the unit, which are linked to each other with hierarchy like tree, make the background to the view of the workstation.

The control elements of the fire alarm and system, which are detectors, push buttons, address units, control units, fire alarm group definitions etc. have been put into plans as symbols. The changes of control elements you can see as modifications of the symbols or as changing of symbol colour.

In the alarm situations an alarm list comes to the screen. From the list the user can choose the information, which he wants. After the selection, it comes the plan, where the element, which has given the alarm, is situated. The symbol is blinking and around is, it is fluctuating figure.

It is possible to see all information pushing a special button.

IX.3.2.5. Fire situation

The fire somewhere in the unit causes as follows:The alarm in the central unit of fire alarm system, in the monitor in the working monitors and also via next info system to mobile telephones of emergency organisation. The graphic layouts are printed automatically.

IX.3.2.6. Detectors

Detector types:

- Multicriteria detectors
- Smoke detectors (optical)
- Special linear smoke detectors
- Push buttons

IX.3.2.7. Standards

The fire detection system itself fulfill EN-54 standards. Equipment is also tested according to IEC-standards (61000-4 proper parts of it).

Encapsulation of the components have been made according to IP classes: IP 20, 23, 41 and 34.

IX.4. EXPERIENCES

We are now in commissioning stage, so that it is perhaps too early to say anything. However, I can say that the project has managed according to the timetable and also the estimated cost has not been exceeded. The fault alarms has been lesser than we have thought.

IX.5. SUMMARY

The project has been very demanding. The aim was to get a new modern fire detection system as a standard product, but however so that it takes to account special features in our plant. We have a lot of develop work to be done and finally, the result can be stated after some years. We believe that our new system is better than the old one and that our plant safety is now better than before our project.

Annex X

ELECTRICAL IGNITION SOURCES IN NPPS: STATISTICAL, MODELLING, AND EXPERIMENTAL STUDIES

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Abstract. Electrical ignitions of fires in NPPs were studied by analysing statistical information from both nuclear and non-nuclear installations, modelling the most common simple physical ignition processes, and finally carrying out experiments on some of the modelled scenarios. Statistical assessment indicated cables to be a significant cause of electrical ignitions in all kinds of installations. Modelling of some relevant scenarios of cable fires and carrying out a number of experiments gave quantitative information on the circumstances and physical processes of the dangerous cable ignition situations.

X.1. INTRODUCTION

Since PSA analyses indicate cable fires in certain locations of Finnish NPPs might be a risk to nuclear safety, cable fires in general were studied to be able to assess the relative statistical frequency of them in NPPs, but also to understand in a physical sense both the ignitions mechanism possible and also the potential consequent fire spread.

An analysis on the causes of the electrical fires in NPPs was carried out [1] first by studying fire statistics both from nuclear and nonnuclear sources. Here, only some of the relevant data are described to base our cause. Second, a number of simple ignition experiments were performed to find out the physical processes leading to ignition and creating an environment for potential fire spread. Third, a literature review was carried out to find theoretical models for the phenomena observed. This was continued by adapting existing general theories to the specific environment and boundary conditions of our experiments to be able to design some of the experiments better and especially to be able to explain the experimental observations from deeper principles.

X.2. STATISTICAL ANALYSIS

X.2.1. Statistics on electrically induced fires in Finland

Fires recorded as electrically induced were collected from statistics on large fire accidents in Finland 1980–1993 based on unpublished material from the Federation of Finnish Insurance Companies. A fire accident was recorded as large, if the value of the material loss exceeded 100 ... 250 k€ (due to inflation and changes of definitions during the period the limit fell within these limits in prices of year 2000). Ignition mechanism as well as failed component was used without distinction in these statistics to express fire cause and the results are presented in Figure 1. Fire causes denoted as “electrical device” or “electrical” without further specification amount to 42 % of the cases, giving an indication of the uncertainty of the statistics.

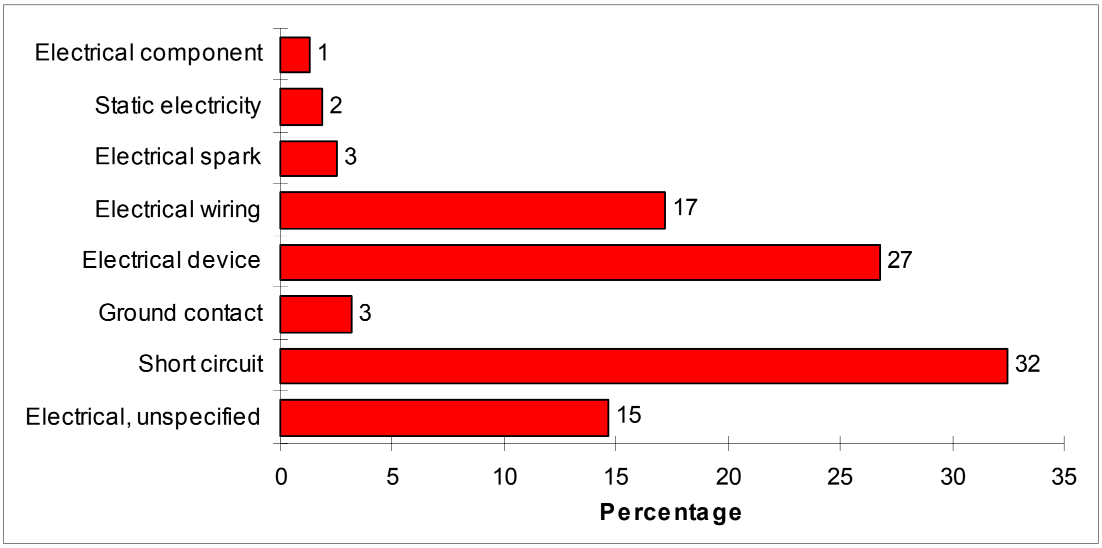

FIG. 1. Electrical fire causes recorded from large accidents in Finland 1980–1993. Total number of accidents in this figure is 157.

Electrical fire causes and the total number of fires in Finland during 1994 and 1995 as recorded in the Finnish national accident database ONTIKA [2] are presented in Table 1. The database ONTIKA contains information on accidents, which concern the fire and rescue authority. The fire officer in command at the fire scene is responsible for collecting information about the accident for ONTIKA. The fire cause recorded is often only a rough guess because the fire brigade does not perform fire investigations. This concerns especially cases where the fire course is not obvious, as in many fires of electrical origin.

TABLE 1. FIRE CAUSES IN FINLAND IN 1994 AND 1995 ACCORDING TO FINNISH NATIONAL ACCIDENT DATABASE ONTIKA [3].

Fire cause	**1994**		**1995**	
	number	**%**	**number**	**%**
Electrical fires				
Short circuit or ground fault	870	75	984	72
Loose connection	36	3	56	4
Overheating	54	5	73	5
Improper installation	17	1	11	1
Other electrical faults	186	16	236	17
Electrical faults, total	**1163**	**100**	**1360**	**100**
All fires				
Electrical faults, total	1163	13	1360	13
Lightning	287	3	306	3
Other known causes	6229	70	6798	67
Unknown	1191	13	1580	16
Total	**8870**	**100**	**10044**	**100**

X.2.2. IAEA and OECD/NEA AIRS database events on electrical fires

The database used here is the October 1997 release of version 1.1 of the Advanced Incident Reporting System (AIRS) Database [4]. It was provided by the Finnish Radiation and Nuclear Safety Authority (STUK) on the condition of confidentiality. The database contained 2591 reports describing incidents from the period 1974 - 1997. The corresponding total number of reactor years is 8656 4.

Electrically induced fires were searched using the "Free form search" method for the word "fire" in the event reports in the AIRS database. This search gave 275 documents containing "fire" or a variant of it obtained by stemming. These 275 reports were read through and 34 reports describing 39 fires originating from electrical faults were found. The described electrical fire incidents occurred in the period 1981–1996.

The description of what actually happened in the electrical circuits is incomplete in many of the reports leaving the failure mechanism and failed and/or ignited component unspecified. In some cases where fire causes are presented they are described as "possible" or "supposed".

The failed electrical component is not necessarily the first ignited component or material. The original electrical failure may occur in one device inducing other electrical faults in nearby electrical devices finally leading to fire. The chain of different faults may consist of several phases, as was the case in some of the AIRS-reported events.

Electrical failure mechanisms leading to ignition are presented in Table 2, failed electrical components in Table 3 and first ignited component or material in Table 4.

All unspecified or unclear mechanisms or components have been grouped as "unknown".
It is to be noted that the term "unknown" in the tables refers to an unknown electrical ignition mechanism or component and not to a totally unknown item.

TABLE 2. FAILURE MECHANISM LEADING TO IGNITION IN FIRES ORIGINATING FROM ELECTRICAL FAULTS AS DESCRIBED IN AIRS EVENT REPORTS [4].

Failure mechanism	**Number**	**%**
Overheating	5	13
Short	6	15
Ground fault	5	13
Arcing	7	18
Loose connections	3	8
Unknown	13	33
Total	39	100

4 D. Ruatti, IAEA, Private communication, 7 May 1998.

TABLE 3. FAILED COMPONENT IN FIRES ORIGINATING FROM ELECTRICAL FAULTS AS DESCRIBED IN AIRS EVENT REPORTS [4].

Failed component	**Number**	**%**
Cable	4	10
Switch, breaker	10	26
Contact, splice, terminal	6	15
Relay	2	5
Transformer	10	26
Slip ring in turbogenerator	1	3
Unknown	6	15
Total	39	100

TABLE 4. IGNITED COMPONENT OR MATERIAL AND CIRCUIT VOLTAGE IN FIRES ORIGINATING FROM ELECTRICAL FAULTS AS DESCRIBED IN AIRS EVENT REPORTS [4].

Ignited component	**Number**	**%**	**Voltage**		
			Power	**Control**	**Not mentioned**
Cable insulation	8	21	7	1	
Switch, breaker	4	10	2		2
Contact, splice, terminal	1	3	1		
Relay	2	5		2	
Oil	11	28	11		
Slip ring in turbogenerator	1	3	1		
Unknown	10	26	6		4
No fire*)	2	5	2		
Total	39	100	30	3	6

**) Two cases: 1. Scorching of cable insulation and risk of fire*
2. The electrical fault was interrupted within a few seconds by the over-current protection

As mentioned above, there is a significant degree of uncertainty in investigations of electrical faults. The ignition mechanism is unknown in 33% of the events, the failed component is unknown in 15% and the ignited component is unknown in 26% of the AIRS-event reports.
Among recognised ignition mechanisms arcing (18%), short circuit (15%), overheating (13 %) and ground fault (13%) are about equally frequent. Loose connections are mentioned in 8% of the events.

The failed component is usually a switch, breaker or relay (31%), i.e. a component with movable mechanical parts. The most frequent single component is transformer (26%).
The most frequent first ignited component or material is oil (28%) in correspondence with transformer as the most frequent single failed component. The second ignited component is cable insulation (21%). Cable was mentioned as failed component in 10% of the cases. This reflects the cases where the original fault has occurred in a switch, breaker, contact, terminal etc. igniting insulation of connected or nearby cable(s).

X.2.3. Conclusions from statistics on electrical ignition sources

The large amount of electrical fire causes recorded as unspecified electrical fault or appliance introduces uncertainty into the statistics. Further many of the specified ignition mechanisms and failed components are presented as “possible” or “supposed”. This should be taken into account when interpreting the results.

The ignition and fire is in many cases the result of a chain of faults rising difficulties in defining the true root cause. A loose connection may induce overheating in the circuit leading to ignition of combustible material, or the heating may destroy nearby insulation leading to short circuits or arcing. Overcurrent in a cable can in the same manner lead to either local overheating and ignition of combustible material, or lead to insulation failure and arcing or short circuit.

Another factor concerning the usefulness of the databases is the presence or absence of events that did not result in a fire although the risk of fire did exist (precursor events). Such events cause electrical fuses or breakers to operate because of electrical over-current, smoke alarm, short circuits- etc. This absence of precursor events as well as poor identifying of true root causes has been pointed out by Madden [5] concerning mainly Sandia and the Electric Power Research Institute (EPRI) fire event databases.

Despite these deficiencies some conclusions of electric ignition mechanisms, failed components and first ignited materials can be drawn.

X.2.3.1. Ignition mechanisms

Generally, electrical ignition mechanisms can roughly be divided in four groups:

(1) Short circuit, ground fault and arcing
(2) Overheating
(3) Loose connections
(4) Static electricity

The first group is the most frequent in AIRS database (46%), while overheating (13%) and loose connections (8%) are less frequently denoted as ignition mechanism.

One interpretation of the relative occurrence of these mechanisms is that they are not really the root causes. Reason for short circuit, ground faults or arcing may be an insulation failure, which can be due several causes, one of which is overheating. This in turn can be due to electrical overloading or loose connections heating the insulation. The precursors of the events are not easily detected until short circuit, ground fault and arcing occurs. The group of unknown electrical ignition mechanisms is notable (33% in AIRS database).

The same mechanisms are also present in the statistics on electrical faults in general (section 2.1) with short circuit/ground fault as leading ignition mechanism followed by overheating and loose connections. The comparison of nuclear and non-nuclear electrical installations is not straightforward a priori, because of a fairly large difference in quality and control of installations.

X.2.3.2. Failed component

Three specific groups of critical components in NPPs can be identified:

(1) Switches, breakers and relays
(2) Cables and contacts, splices and terminals
(3) Transformers.

Components such as circuit cards, resistors, capacitors, coils and diodes are responsible for a minor part of electrical fires in nuclear power plants.

The distribution of failed component related to different modes of operation show a clear concentration on power operation (69%), followed by construction phase (23%).

The distribution of failed component related to different locations points out transformer yards (21%) as a leading critical location followed by auxiliary building and unspecified 'other building' (14% each).

In non-nuclear electrical faults electrical cables and wiring, electrical distribution and components connected to wiring such as splices, plugs etc. are most frequent components specified. The reason for the difference using common sense could be referred to the much tighter control of quality of installations in NPPs.

X.2.3.3. First ignited component or material

The first material ignited could be identified to a reliable extent in AIRS database only.
Oil from transformers, breakers, etc. is the leading material (28%) followed by cable insulation (21%). The 'unknown' group is also here considerable (26%).

Because the remaining components in Table 4 are connected to cables, one can draw the conclusion that cable insulation is the most important combustible material in the initial stage of electrically induced fires.

X.2.3.4. Ignition probabilities

Two further elaborations on ignition of cables divided into two categories can be calculated on the basis of information in AIRS event reports (Table 4): (a) ignition frequency on a NPP, and (b) ignition frequency per length of cable.

The calculation of control and power cable fire frequencies assumes that the amount of control and power cable per plant unit is approximately the same in all nuclear power plants. This crude approximation is assumed to indicate at least an order of magnitude.

The approximate cable amounts in a Finnish nuclear power plant unit[5] are here used to obtain an order of magnitude. The amount of power and illumination cable is about 300 km and the corresponding amount of control and automation cable is about 1400 km per unit. No attempt to elaborate this order of magnitude value was made.

One can estimate power and control cable fire frequencies per plant (the unit is events per reactor year, 1/a) using values for cable insulation, where cable voltage was characterised ”power” in 7 events and ”control” in one event (Table 4) and the total number of reactor years corresponding to the AIRS database:

- Power cable 8·10-4/a
- Control cable 1·10-4/a

Assuming that the cable amounts mentioned above are on the average representative for all power plants in the AIRS database one obtains also the corresponding frequencies per unit of cable length (the dimension is events per meter of cable length during a reactor year, 1/m·a):

- power cable 3·10-9/ m·a
- control cable 8·10-11/ m·a

For estimating errors of the given results only statistical error can be estimated. The relative error associated with power cable fires can be estimated from the number of observed samples as √7/7 = 38 % [6]. No estimate using this method can be made about the lower limit for the control cable fire frequency because of only one observed event. More sophisticated methods are not attempted, because they are not thought to be worthwhile at this stage. The above mentioned control cable frequency could be considered as an approximate upper limit. It is not known, but estimated from the analysis of data acquisition process for the databases, that systematic errors are much bigger than this statistical inaccuracy.

X.3. IGNITION MODELING AND EXPERIMENTS

X.3.1. Loose contact and cold solder junction

For a loose contact or a cold solder junction a finite point or surface resistance R is created. If a current I is driven through this contact, a thermal power of Q = I2R is created over a very small volume of current carrying material. This will heat the material soon to high temperatures. We idealise the model to a wire carrying a current, and cooling into ambient from its bare metal surface. A loose connection is created in one cross section of the wire, where heat is produced at constant rate Q in a plane. By using linear heat transfer theory [7], the temperature rise $\Delta T(t)$ of the heated cross section in the wire is given by

5 K. Taivainen, Information on two TVO units at Olkiluoto, Finland, private communication April 24, 1998.

$$\Delta T(t) = q\sqrt{\frac{r}{2\pi kh}}\,\gamma(\tfrac{1}{2}, t/\tau) \qquad (1)$$

where q is the power density in the cold junction (W/m2), r the radius of the wire, k thermal conductivity of copper, and h effective heat transfer coefficient from the surface of the wire. To cover wide enough range we assume h = 25 ... 100 W/m2K. γ is the incomplete gamma function [8], and time constant τ is given by

$$\tau = \frac{r}{2}\frac{\rho c}{h} \qquad (2)$$

where ρ is the density and c the specific heat capacity of metal (copper). Asymptotically Equation (1) approaches a value

$$\lim_{t\to\infty} \Delta T(t) = q\sqrt{\frac{r}{2kh}} \qquad (1')$$

which is the maximum temperature for the given radius r and conductivity k of the metal of the wire, the effective heat transfer coefficient h and power density q in the cold junction.

In Figure 2 two limiting curves are calculated using Equation (1) to demonstrate temporal behaviour of a cold junction of a 1 mm2 copper wire. For a total temperature rise of 200 K (Equation (1')) 2.3 W is needed if h = 100 W/m2K. The final state is reached in about 30 s. Only 1.2 W is needed for the same temperature rise, if h = 25 W/m2K, but now more than a minute is needed to reach the final temperature. Generally only 1 ... 12 W is needed to heat a cold junction of a wire of 0.5 ... 4 mm2 cross section used in electronics to a temperature able to ignite combustible material nearby. Time constants τ were in the range 5 ... 160 s, respectively.

As shown from Figure 2, the steady temperature is the real indicator of the potential ignition. Therefore, different boundary conditions, like cable insulation, do not change drastically the rate determining factors given in Equation (1'). For that reason no more complicated boundary conditions are attempted for this linear configuration. Two-dimensional configurations with analog dissipating boundary conditions would be interesting, but they were not studied in this project. Of a special interest would be a loose joint between two layers of conductors on different sides of a printed circuit card, where the point like source is imbedded in resin. Since this material of the printed card is combustible and conducts heat badly as compared to metals, it might create a dangerous local hot spot, a potential ignition source. This is in principle the problem of constriction resistance treated widely in old electrotechnical literature.

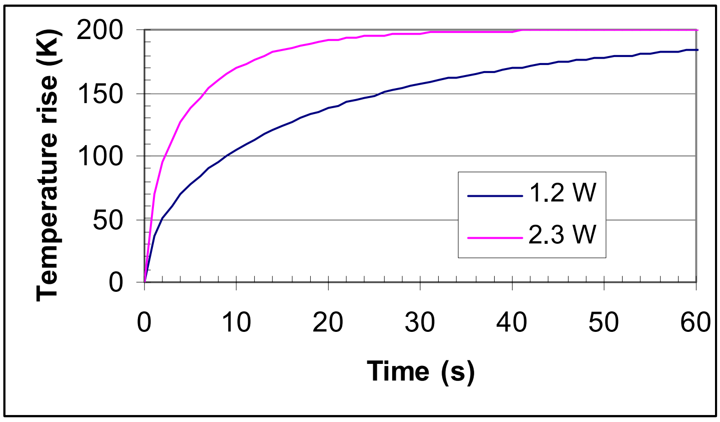

FIG. 2. Heating of a cold junction in a 1 mm^2 copper wire.

X.3.2. Heating from overloading

Consider an insulated cylindrical cable carrying a current in a metal conductor with geometry and notations as shown in Figure 3. If the cable is carrying an overload of current, the final temperature T2 is given by [1]

$$T_2 = T_0\left(\frac{1}{Bi} + ln\frac{b}{a}\right) \qquad (3)$$

where temperature T0 is calculated from

$$T_0 = \frac{I^2}{2\pi^2 \sigma k a^2} \qquad (4)$$

and the Biot number Bi from

$$Bi = \frac{bh}{k} \qquad (5)$$

In contrast to cold junctions rather high currents are needed to produce temperatures likely to lead to ignition of combustible insulation material as is shown in Figure 4.

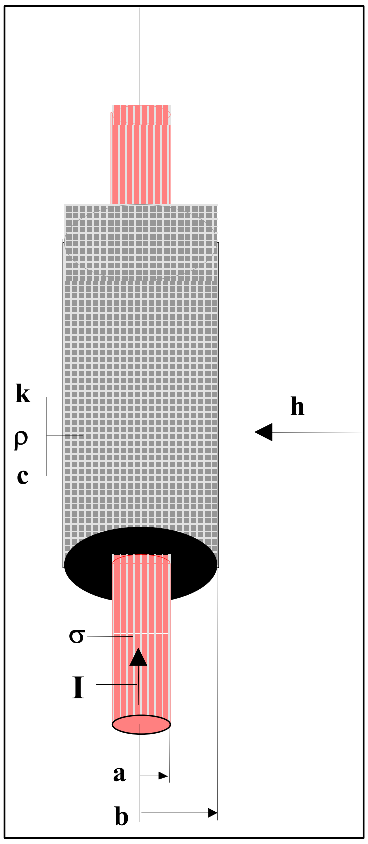

FIG. 3. Geometry and notations of an insulated cable heated by electrical current. a radius of conductor, b radius of cable, k thermal conductivity of cable insulation material, h effective heat transfer coefficient from the surface of cable, ρ density, c specific heat capacity, I electrical current and σ electrical conductivity.

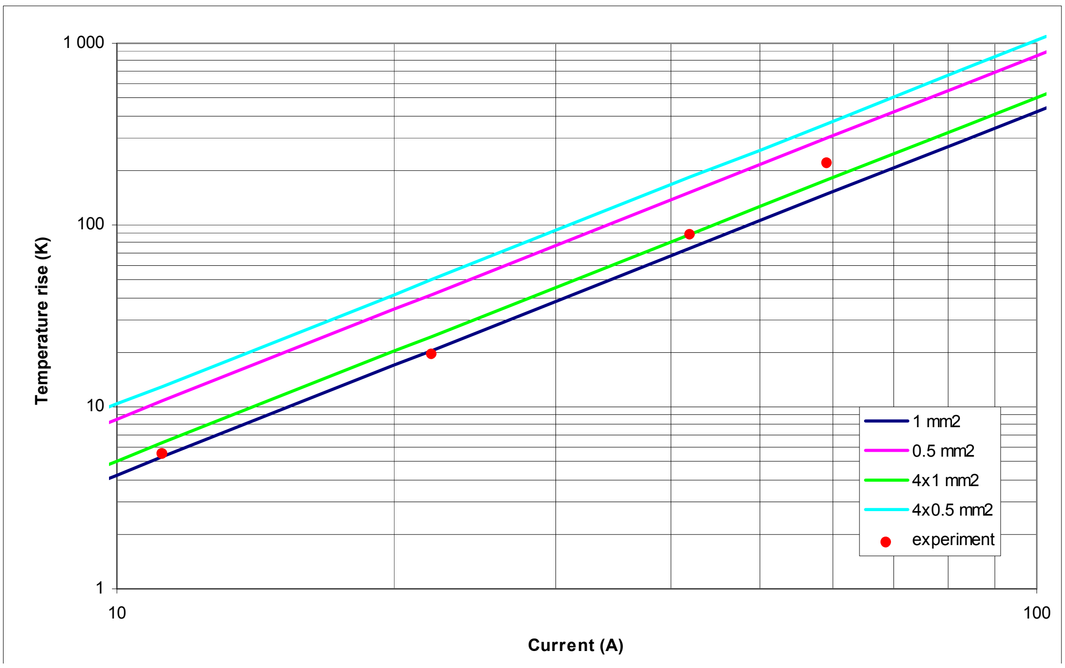

FIG. 4. Heating of cables from overcurrent. Full lines are theoretically calculated maximum temperatures for different types of cables, and the dots experimentally measured data from tests using a 4x1 mm2 cable [1].

Comparison of theoretical plots with measured points shows rather good agreement. The outcome from these series of experiments was that it is an unlikely mode of ignition. To produce an increase of temperature in excess of 200 K currents of the order of 60 ... 100 A are needed. Since most of the electrical instruments are protected for overcurrents using fuses, they are likely to trip, before high enough heating is obtained.

X.3.3. Electrical arcs

Short and ground circuit faults result very often in arcing, which are usually thought to be the most common reasons of ignitions of electrical origin. We also believed so in the beginning of the project, and carried out several series of experiments to ignite a cable in different configurations and using different electrical inputs for the arc. Ground and short circuits were thought to have so similar behaviour, that no separate ground circuit configuration was attempted.

Created arcs burned cable, but the process was so unstable it was practically impossible to create an arc lasting for more than 10 s. The experiments needed high currents we could not obtain from batteries. The second alternative was commercial welding machines. They did neither allow controlling the outer electrical conditions for the arc nor to measure quantitatively needed electrical parameters.

The reason for difficulties is believed to lie, in addition to some haphazard manner of tests, in easy, and fast melting process of copper wire, vibration of cable due to electromagnetic forces created by arc plasma flow, and flow of melting plastic and pyrolysis fumes. These are all factors, which during technical welding are avoided using either a coated welding rod or argon as protective inerting gas around a tungsten electrode. Also an eyewitness experience was that the created arcs were so strong, they blew out the flame, because of lacking electrical control of the discharging circuit.

It was noticed finally, too late for our experiments, that the release of power was much too fast and violent to lead to an accelerating flame. To be able to see the rate controlling factors a physical model of the arc was written collecting material from old literature [9]. The essential data were published more than hundred years ago by Mrs. Ayrton [10]. Using parameters she measured for different metals that the voltage I and current U of an arc of length l are bound to each other by

$$U = \alpha + \beta l + \frac{\gamma + \delta l}{I} \qquad (6)$$

where α, β, γ and δ are constants depending on the material of the electrodes. Table 5 gives values of these constants for carbon, copper and iron. These data are configuration depended but give good guidance for technical dimensioning of the arc.

TABLE 5. COEFFICIENTS OF AYRTON'S EQUATION FOR SOME MATERIALS [11].

Material	α **(V)**	β **(V/M)**	γ **(W)**	δ **(W/M)**
Carbon	45.75	3.33	35.7	19.31
Copper	26.61	2.22	32.49	18.65
Iron	15.01	9.44	15.73	2.52

Since the load outside the arc is mainly resistive, the stable points of the arc are determined by plotting a loading line on Figure 5. For zero current the voltage is the battery voltage E, and for zero voltage the current is a short circuit current

$$I_s = \frac{E}{R_s + R} \qquad (7)$$

where Rs is the inner resistance of the battery and R is the resistance of the outside load (within the arc).

The operating points of the arc are determined by the points where the arc characteristics crosses the loading line. The low current cutting point P1 is not stable and therefore the currents grow to the higher value P2.

Combining the loading line and Equation (6) the voltage U2, and current I2 of point P2 are given in terms of Ayrton parameters by

$$\boldsymbol{U_2 = \tfrac{1}{2}\left(E + \alpha + \beta l - \sqrt{(E - \alpha - \beta l)^2 - 4R_s(\gamma + \delta l)}\right)} \qquad (8)$$

$$\boldsymbol{I_2 = \frac{1}{2R_s}\left(E - \alpha - \beta l + \sqrt{(E - \alpha - \beta l)^2 - 4R_s(\gamma + \delta l)}\right)} \qquad (9)$$

In Figure 5 the voltage of the arc is plotted as a function of current for some gap widths of copper electrodes, and indicating some loading lines with given output resistance Rs.

In Figure 6 the output power is plotted as a function of spark current using two parameters determined from outside: the spark length l, and power source output impedance (mostly resistive) Rs. The stable operating point (P2 of Figure 5) of an arc of a given length is the crossing point of the arc length line, and output resistance parabola. For example for a 2 Ω resistance and 1 mm spark gap the power is 600 W.

The maximum value of the spark gap for a pair of electrodes, and power source is obtained in the point where the two points P1 and P2 merge, i.e. the loading line becomes a tangent to the voltage-current characteristics of the arc. In Table 6 some values of the maximum spark lengths are given as a function of the voltage and resistance of the power source as calculated from Ayrton's Equation (6). The values of the voltages were chosen to represent common control voltages of control electronics in our NPPs.

TABLE 6. SOME VALUES OF THE MAXIMUM SPARK LENGTHS (MM) ARE GIVEN FOR THREE ELECTRODE MATERIALS AS A FUNCTION OF THE BATTERY VOLTAGE AND ARBITRARY 2 Ω OUTPUT RESISTANCE OF THE POWER SOURCE AS CALCULATED FROM AYRTON'S EQUATION (6).

Battery voltage (V)	Carbon	Copper	Iron
24	-	-	0.6
36	-	2.9	1.8
48	-	6.1	3.0
73	5.9	15	5.8

In the operation point, where P1 and P2 merge, the power output is the minimum possible given by

$$P_{min} = (\gamma + \delta l)\frac{E + \alpha + \beta l}{E - \alpha - \beta l} \qquad (10)$$

The output resistance of the power source corresponding to this minimum power and maximum spark length is

$$R_s^{max} = \frac{(E - \alpha - \beta l)^2}{4(\gamma + \delta l)} \qquad (11)$$

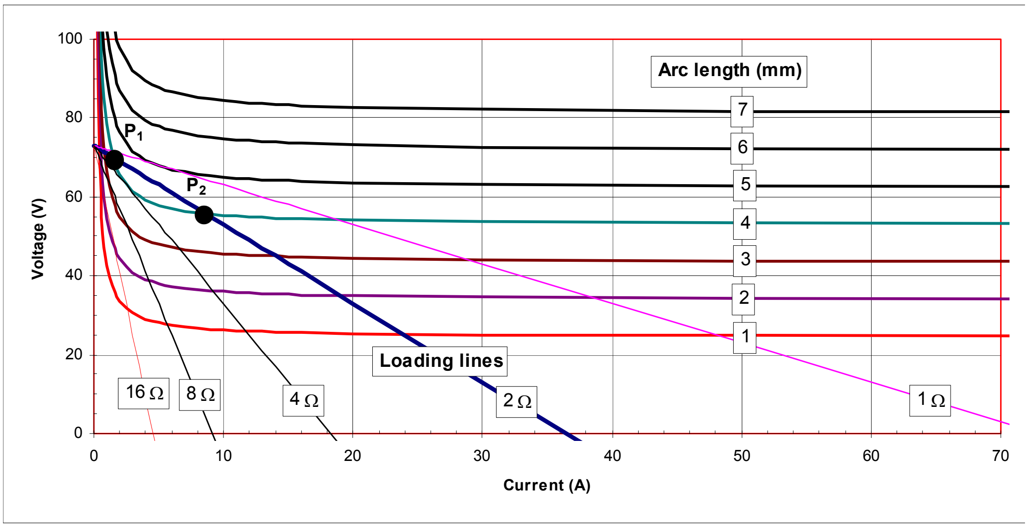

FIG. 5. The voltage of an electric discharge over copper electrode arc gap as a function of current. Crossing points with loading line indicate operating points, where only P_2 is stable [9].

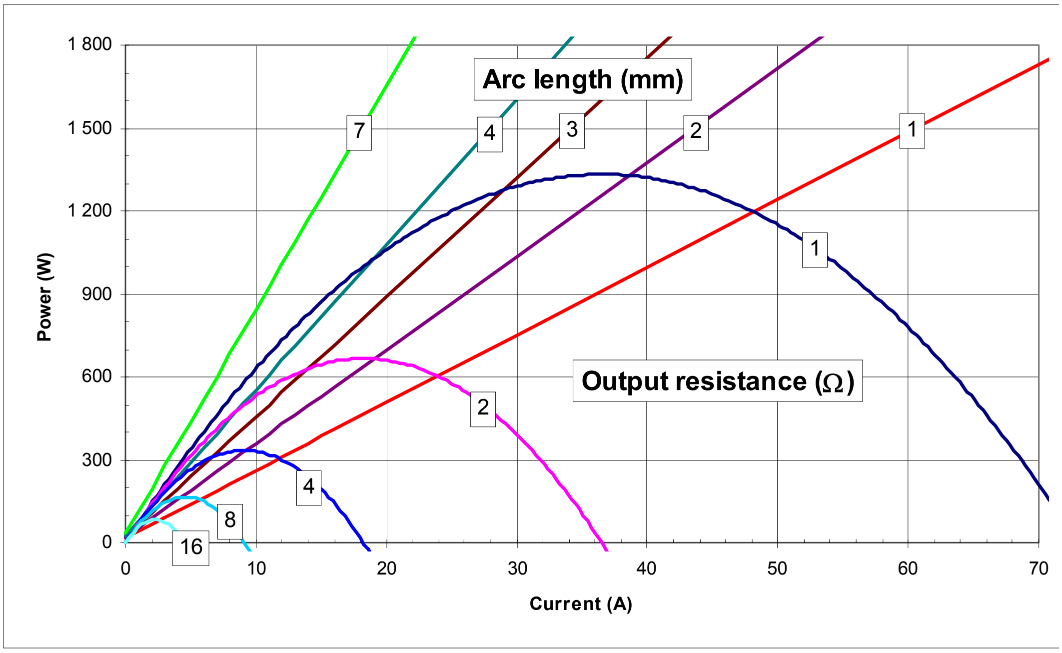

FIG. 6. The power dissipated by an electric discharge over copper electrode arc gap as a function of current for different output resistance of the energy source [1].

In Figure 7 minimum power Pmin (left) and maximum source impedance Rsmax (right) are plotted as a function of battery voltage E for three different electrode materials. One sees for Figures 6 and 7, that arcs produce intensively heat in a small volume and act as point source ignitors. However, the amount of produced heat might be so big, that a flame is blown off, and no sustained ignition is obtained. This might happen for example in a faulty cable, where the first ignited fuel is the cable insulation. If the output resistance of the power source is properly chosen, the dissipated power reduces so much that favourable conditions for ignition might be created. Figure 7 indicates, that for low battery voltage E, the minimum power tends to be rather high, and is likely to blow off the flame from flammable material surface. For higher battery voltages the power decreases if the source impedance is properly high as given by the right hand plot of Fig. 7. The ultimate minimum value of the dissipated power under any circumstances is the numerical value of Ayrton's parameter γ given in Table 5. Thus the minimum power for a stable spark between copper electrodes is about 32 W. The spark length in millimetre region has practically no effect on the dissipated minimum power.

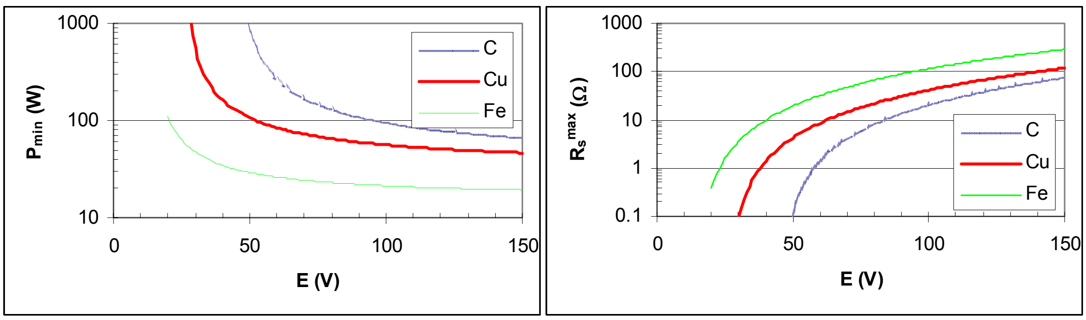

FIG. 7. Dissipated minimum power Pmin (left), and maximum source impedance Rsmax (right) as a function of battery voltage E for three different electrode materials.

As a summary, ignition of cables or flammable material of electronic components is possible from a spark or short circuit. The governing parameters describing ignition are the rate and the amount of heat released during arcing. Arc ignitions are electrically very fast phenomena and might be also violent leading to blow-off of ignitable material. It is possible to have a stable, and small enough spark provided the source voltage of the power source is high enough (above 50 V), and the source impedance is in the region of 1 ... 100 Ω. This is rather untypical for a real power source, but might be encountered inside circuits of electronic equipment.

X.3.4. Self-ignition

Three different experiments were carried out for PVC cable bundles in a furnace to find out their potential for self-ignition [12]. The temperature of the furnace was rised continuously at a slow rate, and the temperature inside the cable bundle was recorded. The temperatures, where the first signs of reactivity of the cable material occurred, were all above 200°C. Since that is higher than the melting temperature of PVC insulation material, the issue was not pushed further. The conclusion is that for small cable bundles ($19 \times 4 \times 1.0\ mm^2$) the self-ignition of PVC cables is an unlikely cause of ignition. At melting temperatures other modes like sparking and spurious contacts are disturbing the circuitry much more.

X.3.5. Ignition of printed card from overloaded electronic components

Ad hoc experiments were carried out using microcircuits or power transistors on printed circuit boards. They were gradually overloaded, and voltage, current, and power dissipation were measured. The components were placed under the hood of a cone calorimeter, and standard measurements were carried out.

Three experiments were carried out with power transistors. The surface of the printed circuit board ignited in two experiments, leading to distinct flaming fire of duration 25 and 70 s, respectively. The flames went out when the conductor to the transistor broke due to overloading. Maximum rate of heat release was 450 W in these power transistor experiments.

Seven experiments were carried out with microcircuits and tantalum capacitors. Capsules of microcircuits and tantalum capacitors ignited and burned with a small flame for 5 ... 30 s in some of the experiments without igniting adjacent components or circuit board. The rate of heat released from these components was below the detection level of the cone calorimeter. Other observed effects on microcircuits and capacitors were sparking, slight smoke production and breaking of component capsules.

The experiments indicate that of the present components power transistor was the only component with potential to ignite adjacent combustible material.

X.4. CONCLUSIONS

This paper reviews electrical ignition phenomena from a wide perspective through statistical, modelling and experimental tools. It is believed a rather comprehensive concept of electrical ignition phenomena has been described. It can be noticed statistically, that defective cables leading to short circuit and ground shorts, as well as loose connections leading to overheating are the most common reasons of electrical ignitions in general. In NPPs they are not the most common cause but still a significant factor. There is a rough indication, power cables have 8 times higher ignition probability per plant, and 40 times higher probability per cable length than control cables.

For modelling an overheated cable a mathematical model has been proposed, which compares favourable with a limited set of experimental data, but can be applied only at rather low temperatures as compared to melting temperature of cable insulation. Self-heating of cables is described using existing theory. Experiments on PVC cables showed both these modes are possible but improbable causes for initial ignition.

Literature review of physical models of electrical arcs established conditions where ignition of cables might be possible. Limited set of tests under poorly controlled conditions succeeded not producing long lasting arcs amenable of sustained ignition. This is in contrast to statistical observations where arching is one of important causes of ignition. The reason for experimental failure is believed to be too violent of release of energy, which blew off the flames. Models for low power arc as well as for loose contact/cold solder joint were proposed and shown to be possible ignition sources under certain fairly common circumstances.

Laboratory tests of electronic components heavily or destructively overloaded did not generally lead to ignition of adjacent material because of sudden release of energy and subsequent destruction of the component. Only power transistors heavily mounted on printed cards seemed able to start ignition of the card. The phenomenon can be modelled as a piloted ignition. It is believed based on the experience from arc and loose contact modelling that also the first series of overloading experiments were too fast and violent for optimum ignition. Slight overload, heating the environment, but allowing the component itself still to operate, might create more favourable situations of fire ignition.

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REFERENCES

[1] KESKI-RAHKONEN, O., MANGS, J. & TURTOLA, A. 1999. Ignition of and fire spread on cables and electronic components, VTT Publications 387, VTT, Espoo. 102 p. + App. 10 p.

[2]. ONTIKA - PALO- JA PELASTUSTOIMEN ONNETTOMUUSTILASTOINTI - JÄRJESTELMÄ, SYSTEEMISUUNNITELMA [ONTIKA - Accident data reporting system of the Rescue Department, a system plan], VTTK, Valtion järjestelmät, Espoo, (1991), 68 p. + 109 p. app. (in Finnish, unpublished).

3] TAMMINEN, A. 1996. Sähköpalojen henkilö- ja omaisuusvahingot [Life and material losses in electrically ignited fires]. Master's thesis. Tampere University of Technology, Department of Electrical Engineering. 84 p. + app. 7 p., (in Finnish).
[4] INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA). 1997. Advanced Incident Reporting System (AIRS) Database, October 1997 release of version 1.1. Vienna, Austria: International Atomic Energy Agency. CD-ROM.
[5] MADDEN, P.M. Fire safety rulemaking issues confronting regulatory change in the United States. SMiRT 14, Fifth Post Conference Seminar n:o 6: Fire Safety in Nuclear Power Plants and Installations. Lyon, France, 25-29.8 1997. 18 p.
[6] BEERS, Y. 1953. Introduction to the theory of error. Addison-Wesley, New York, 65 p.
[7] CARLSLAW, H.S. & JAEGER, J.C. 1959. Conduction of Heat in Solids, Clarendon Press, Oxford, Second Edition, 510 p.
[8] ABRAMOWITZ, M. & STEGUN, I.A. 1972. Handbook of mathematical functions. New York: Dover. 1046 p.
[9] FINKELNBURG, W. & MAECKER, H. 1956. Elektrische Bögen und thermisches Plasma. In S. Flügge (ed.). Handbuch der Physik, Band XXII. Berlin: Springer. P. 254 - 444, (in German).
[10] AYRTON, H. 1895. The Electric Arc. The Electrician 35, 419.
[11] HAGENBACH, A. 1927. Der elektrische Lichtbogen. In H. Geiger and K. Scheel (eds.) Handbuch der Physik, Band XIV. Berlin: Springer. P. 324 - 353, (in German).
[12] BOWES, P.C. 1984. Self-heating: evaluating and controlling the hazards. London: Department of the Environment, Building Research Establishment, Her Majesty´s Stationery Office. 500 p.

Annex XI

FIRE IMPROVEMENTS AT IGNALINA NPP

Abstract. The paper describes the design and administrative actions taken at Ignalina NPP in relation to fire protection in recent years. The lesson learnt from operational experience is carefully described for future use.

XI.1. INTRODUCTION

Ignalina Nuclear Power Plant is Lithuania's only nuclear power plant. INPP dominates electricity production in Lithuania; in 2000, INPP contributed 74.4% of total generated output. Consequently, the Lithuanian economy is heavily dependent upon this plant. INPP was built as part of the Soviet Union's North-West Unified Power System. It consists of two units, commissioned in December 1983 and August 1987. Both units of INPP are Soviet designed RBMK reactors, and are different from those operating in Russia and the Ukraine. They have a larger nominal capacity 4800 MWth (1500 MWe) per unit, but currently each is restricted to 4200 MWth. Immediately after the Chernobyl accident, the first international programmes of safety evaluation of the RBMK concept were undertaken, and a significant number of bilateral initiatives were also started. A number of technical areas were identified for short-term safety improvements, as well as for further in-depth safety analyses.

A Grant Agreement was signed in London in 1994 between the Lithuanian Government, the INPP and the European Bank for Reconstruction and Development (EBRD) on behalf of the Nuclear Safety Account (NSA). The grant funds a project of safety upgrades in order to support the implementation of the Safety Improvement Programme (SIP), so that the safety of the plant can be improved in the period up to final closure. The Lithuanian authorities agreed, (as a condition to the Grant Agreement), that the operation of both units at INPP would not be prolonged beyond the time when their reactor channels will have to be changed. In addition, an in-depth safety assessment of the plant was undertaken, and a Safety Analysis Report (SAR/RSR) was produced and reviewed. A Panel of international nuclear safety experts was selected by agreement between the Lithuanian Authorities and the EBRD to monitor the study, review its results and make their recommendations.

Before 1994, INPP did not have a formal Operating Licence. Since then, VATESI has regulated plant operation by an annual operating permit that was issued following the submittal of specified documents by INPP. However, in accordance with the agreement with EBRD, a Licence for the continued operation of Unit 1 should be issued in 1998. The annual permit system has been applied since 1994, and the final such permit was granted by VATESI for Unit 1 to operate from the 1998 restart to the decision date for the Licence for continued operation.

Because of delays in preparation of the SAR and the practical difficulties of performance of safety improvement measures on time, the decision date for licensing of 17 May 1999 was adopted. At that time, not all the planned measures had been completed, and Unit 1 of INPP was required to shut down safely. However, all necessary and required measures have now been implemented and VATESI issued 1999 July 29 the License to continue operation of Ignalina NPP Unit 1.

ORGANISATION RESPONSIBLE FOR FIRE PROTECTION SUPERVISION

Ministry of Internal Affairs (technical area)
and VATESI (nuclear safety area)

Fire Protection Department of Ministry of Internal Affairs (Vilnius)

Visaginas Town and INPP

Militarized Fire Protection Department

IIIrd Fire brigade (Visaginas, 11.0km)	**IInd Fire brigade (INPP, 6.0km)**	**Ist Fire brigade (INPP, 0.3km)**

XI.2. MAIN REGULATION FOR INPP FIRE PROTECTION

VD-B-001-0-97	***General regulation for NPP safety***
VD-E-11-2001	***Requirements to NPP fire protection (draft)***
RPST-01-93	***Lithuanian Republic Fire Protection Regulations: (Blue book) General fire safety regulation***
RPS-IAE	***Fire Safety Rules for Ignalina NPP: (Yellow Book) Specific fire safety regulation for INPP***
VSN 01-87	***Fire Prevention Standards for NPP Design.***
	Standard Provision for maintenance of NPP automatic fire detection and extinguishing systems
RD53,05 002 90	***Standard program for fire safety training of NPP personnel***
RD53,05 003 90	***Program for NPP major preventive measures and fire safety control***
TN-34-00-046-85	***Automatic water fire protection systems standard***
TN-34-00-039-85	***Automatic fire protection systems alarm standard***
IAE-PTO	***Technical regulation for operation of INPP RBMK-1500 reactors***
QA-2-006	***Fire protection. Management of procedure***

- The nuclear plant design shall provide the means for protection the plant against fire (Item 1.2.21. “General regulations for nuclear power plant safety”) VD-B-001-0-97
- Item 1.3. The fire protection NPP should reveal and to estimate sources of fire danger, to define measures of prevention of fires, methods and means of detection of a fire (Requirement to NPP fire protection, draft N12 of the document of VATESI)
- Item 3.3.1. For the justification and specification of the design concept of fire protection of NPP and definition of its adequacy to the established requirements operating organisation should ensure realization of the all-round fire hazard analysis (FHA) (Requirement to NPP fire protection, draft N12 of the document of VATESI).

Principles of fire protection were implemented in the design of the INPP and justified in the documents (a) the technical safety justification of reactor installation (TOB RU) and (b) plant (TOB AS).

The Ignalina NPP was designed according to Russian rules and standards in the late 1970s and early 1980s. During operation, when considering improvements in safety, it was found that these standards fell below those of international practice, and new standards were required. Ministry of Internal Affairs and VATESI, taking into account international experience and IAEA Guidelines, developed these.

XI.3. HISTORY of the INPP FIRE IMPROVEMENTS

In comparison with the design documentation developed in the late 70s and early 80s, much fire protection work has been carried out at Unit 1and 2, and more is in progress.

The fire protection measures have been carried out according to agreed Programm (by MIA and VATESI), and comply with the newly developed standards. Elements of the Fire Protection Programm covered areas:

- Fire Prevention
- Fire Detection and Alarm System
- Fire Extinguishing Systems
- Mitigation of Fire Effects

XI.3.1. Measures according to the ORDER of USSA N6 from 1988

(1) Cable routes have been coated with a fire protective covering in rooms which are not equipped with automatic Fire fighting systems and which do not meet the requirements of the regulations.
(2) Reconstruction of the automatic fire alarms and replacement of the receiving station and sensors by a modern type has been completed.
(3) Replacement of iron valves for steel ones has been completed.
(4) A different SS cable separation has been completed with a fire resistance 1.5 hours.
(5) An automatic fire extinguishing installation change-over has been completed.
(6)A reconstruction of the penetrations in cable rooms with a fire resistance of 1.5 hours has been completed. Ones with a 1.5 hours resistance are replacing the doors.
(7) Separation of the main corridors into 60 m. sections with anti-smoke doors has been completed.

XI.3.2. Modifications have been performed with VATTENFALL (Sweden, started 1992)

(1) Replace of old release-valves in cable sprinkler systems and oil sprinkler systems
(2) Improvement of physical separations between the turbine building and the intermediate buildings by installation of the fire classified doors
(3) Change of plastic floors covering in safety related rooms and corridors
(4) Change of doors in safety related rooms, into classified fire doors with a fire resistance rating of 2 hrs. (and more)

XI.3.3. Modifications have been performed according to program B-5 of EBRD

(1) Fire protection with “Konlit-150U” material with a fire resistance 1.5 hours has been completed for transient air ducts going through safety related rooms.

(2) Cable penetrations in safety related cable rooms have been sealed by paste KS-1 and KS-5. (Asbestos cord has been replaced in the cable penetrations).
(3) The load bearing metal trusses of blocks G-1 and G-2 roof covering have been coated with anti-fire paste SP-30 and SP-A with a fire resistance of 30 min.
(4) The G-1 and G-2 metal load carrying columns are being coated with anti-fire paste SP-A with a fire resistance of 1.5 hours.
(5) Additional FA has been installed in rooms with SW and ICC equipment.

XI.3.4. Modifications have been performed according to safety improvement program (SIP-2)

The "Safety analysis report of the Ignalina NPP" (SAR) has recommended further improvements in fire safety. These recommendations, and those of the SAR review (RSR), were included in the Safety Improvement Program of INPP, SIP-2.

It is important to point out at the outset that there are many aspects of the Ignalina NPP fire protection program that are consistent with Western practices. INPP might be qualitatively compared with Western NPPs of similar age. The results of the fire protection review are presented in three groups, including:

- Protection of reactor safety
- Fire protection in general
- Results based on review of Barselina Probabilistic Safety Analysis (PSA).

Within each group a number of analyses are summarized along with finding and recommendations for improvement of fire protection system at Ignalina NPP.

SAR 6-FP-6: Implementation of measures to remove combustible materials in MCR-O and adjacent rooms their fire load
SAR 6-FP-9: Development of the project and installation of fire sensors and alarms in the rooms SWS and ICC's equipment location
SAR 6-FP-10: Installation of an additional fire alarm system in the different rooms (Emergency Deaerator AF pumps, ECCS pumps, Unsalted water and TH)
SAR 6-FP-12: Development of the design and fire detection sensors installation and alarms in the rooms of EDAF, ECCS, UWDS pumps
SAR 6-FP-14: Replacing plastic floor materials for non-combustible covering in rooms
SAR 6-FP-23/RSR: Fire hazard analysis - completed in part for rooms with safety systems components.

XI.4. FIRE HAZARD ANALYSIS (Ist Level)

Because no fire hazard analysis (FHA), corresponding to western approaches, had been carried out, VNIPIET and the experts of INPP carried out a FHA for unit 1 of INPP during 1998.

The reasons for and results demonstration:

- The necessity to carry out additional measures to improve fire protection;
- Adequacy of the existing fire protection measures (taking into account additional measures) to guarantee the nuclear safety of NPP.

The analysis included only rooms with safety system components of Unit 1 (but not rooms with safety related system components, as recommended by IAEA Guidelines and the documents of VATESI on fire safety) which provide for shutdown, cooldown, and the monitoring of radioactive releases into the environment.

The FHA, which was performed for 531 rooms of Unit 1, has demonstrated the high resistance of Unit 1 to fire as an initiating event.

The main conclusion of the FHA report is that Safety Systems at Unit 1 in any fire conditions (type and locations at Plant) are ready to do:

(1) The safe shut down of the reactor and it's maintaining in this condition, is provided during accident and after it.

(2) Residual heat removal after reactor shutdown and during accidents.

(3) No increase the level of radioactive material release beyond the operation and accident limits.

Annex XII

FIRE EXPERIENCE IN NPPs AND THE LESSONS LEARNED IN JAPAN

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Abstract. The paper describes the design and administrative actions implemented at some Japanese plants in relation to fire protection in recent years. The lesson learnt from fire events and operational experience is carefully described for future use.

XII.1. INTRODUCTION

With the fire accident in Browns Ferry Nuclear Power Plant in 1975 as a trigger, detailed regulations were started to be formulated for fire protection in nuclear power plants (NPPs) in Japan. "Examination Guide for Safety Design of Light Water Nuclear Power Reactor Facilities" was amended in 1977 in addition of "Guideline 5: Design Consideration against fire", and "Examination Guide for Fire Protection of Light Water Nuclear Power Reactor Facilities" was established in 1980. This guideline, based on the principal policies of "shut down the reactor" and "prevent uncontrolled release of radioactive materials" to ensure NPP safety as a whole, employed multi-barrier concept comprising of countermeasures for fire prevention, fire detection and extinguishment, and mitigation of fire effects.

XII.2. FIRE PROTECTION AT NPPS IN JAPAN

As described above, fire protection at NPPs in Japan has been basically taken according to "Examination Guide for Fire Protection of Light Water Nuclear Power Reactor Facilities". A more specific guideline for actual design has been established in JEAG 4607, "Fire protection guideline for NPPs" by the Japan Electric Association with a commitment by Ministry of Economy, Trade and Industry (METI). Similarly, this specifies undertaking fire protection design by combining appropriately three countermeasures as shown below; "fire prevention", "fire detection and extinguishment", and "mitigation of fire effects", corresponding to the safety significance of the function requirements.

Fire prevention

- Use noncombustible or fire retardant materials
- Take preventive countermeasures against igniferous or flammable materials (prevention of leakage and leak expansion, consideration for layout, ventilation, and restriction of accumulation etc.)
- Prevent overheat due to over-current in electric equipments
- Prevent fire due to natural phenomenon (thunder, earthquake etc.)

Fire detection and extinguishment

- Allocate fire detectors and extinguishing systems appropriately (design, test and inspection, etc.)
- Take countermeasures against failures, malfunction of equipment and/or operator
- Secure extinguishing function against natural phenomenon (earthquake, freezing, typhoon, etc.)

Mitigation of fire effects

- Take countermeasures to mitigate fire effects (assumed fire and its countermeasures)
- Ensure the reactor safety

These specifications are basically concerned with the design of the system with the high safety significance for the fire protection. The protections for maintenance work during inspection are in principle based on the management by the utility.

XII.3. FIRE EXPERIENCE IN JAPAN

In Japan, 51 NPPs (PWR: 23 Units, BWR: 28 Units) are now in operation. The first plant, Tokai NPP, started its commercial operation in July 1966. The number of the events reportable by Law and METI notification with generating fire or smoke is only nine events to date.

All of nine events are summarized in Table 1 in terms of general description, cause and countermeasures.

In the second event, occurred at Tokai NPP in November 18, 1967, a work was started by worker without noticing that the gas circulator lubricant strainer was not switched over, because of the fracture of switching handle pin for the strainer. This resulted in blowout of lubricant, leading to ignition of lubricant by contacting the gas circulator turbine casing above the filter. Countermeasures were taken including putting a clear switching indication and attaching a test cock on the strainer.

The forth event, occurred at Fukushima Daiichi Unit 1 in August 31, 1985, was a fire of cable in bus-bar power box for start up due to the short circuit around the cable terminal because of the infiltration of rain water through outdoor duct seals. Countermeasures were taken including changing cable ducts with more water proof and fire resistant ones, changing cables with fire retardant ones, and enhancing inspection of ducts.

The sixth event, occurred at the same NPP Unit 6 in January 13, 1988, was a naturally occurred ignition in the turbine building air supply plenum caused by the problem in layout of turbine lubricant tank vent pipe. Countermeasures were taken including relocating vent pipes and revising manual to prohibit feeding steam to air heater when the feed air fan is stopped, because it contributed to the ignition by raising the temperature in the plenum.

The eighth event, occurred at Hamaoka Unit 3 in September 7, 1996, was a fire of insulating holder due to the short circuit with arc by the degradation of insulation capability of bus duct with the deposition of salt and dusts. The ventilation of the room where the bus duct was installed used a full intake system, and the bus duct itself was a ventilation type, by which outdoor air containing salt could directly contact with insulating holder, leading to the event. Countermeasures listed in the Table 1 were taken.

The final and latest event occurred at Fukushima Daini NPP in January 19, 1999. As the waste oil feed pump was started while operating the air preheater of the solid waste incinerator, the signal of oil incineration air flow rate control was changed from gas oil flow rate to waste oil flow rate and the feed air flow rate was substantially reduced. This led both to increasing of incineration temperature, and to reduction of cooling for the air preheater. As a result, the inner, intermediate and outer cylinders were melted and penetrated. The countermeasure was taken to modify the control circuit so as to be able to operate waste oil circulation and incinerator itself independently and in parallel.

Four remaining events (first, third, fifth and seventh), almost half of all events, occurred due to improper work management.

The first event, at the Tokai NPP in November 26, 1966, occurred due to insufficient safety and insulation countermeasures for charging of the equipment during maintenance work.

The third event, at the Fukushima Daiichi Unit 1 in March 25, 1977, occurred due to the insufficient protection for the fusion work resulted in a fire due to sparks dropping on vinyl and scaffold.

The fifth event, at the Fukushima Daiichi Unit 2 in January 8, 1986, occurred due to the reduction of ventilation because of plugging of a local exhauster and a cracking in the insulator of the floor light used for the work.

In the seventh event, occurred at the Tomari NPP in March 25, 1995, a volatile and combustible cleaning agent was used while the temporal duct for ventilation was drawn up, which resulted in ignition with non-explosion proof type temporal light.

The countermeasures to be taken for these four events were considered to put the work management and the safety education in practice, though specific countermeasures may be different for each case.

XII.4. SUMMARY

As a result of the study on fire events at NPPs in Japan, the followings are concluded as the lessons learned. The number of fire events with generating fire or smoke is only nine events, which means fire protection has been appropriately taken.

However, almost half of events were caused due to improper management of the maintenance work, not fault on the design, and accordingly, more careful management of work and safety education by the utility is expected.

TABLE 1. FIRE EVENTS AT NPPS IN JAPAN I1/5 J.

No.	Date	NPP	Description	Cause	Countermeasures
1	1966/ 11/26	Tokai	During a periodical inspection, a worker contacted the end of a plier with bus bar of a circuit breaker when removing bolts locking line stud on the switchboard, which resulted in arc generation. A worker was burnt on his face that takes two months to heal. The fire was extinguished using dry-chemical extinguishers.	Insufficient safety countermeasures for charging of the equipment and insulation countermeasures of tools used resulted in generation.	Apply sufficient protection for charging of the equipment. Put an insulating tape on tools used. Put education for safety work into practice.
2	1967/ 11/18	Tokai	During a rated power operation, when cleaning and inspecting the lubricant filter of gas circulator, blowout lubricant infiltrated through the gap in thermal insulator of gas circulation turbine above the filter, and ignited by contacting the turbine casing. One operator died in whole body burn, and four were burnt.	A work was started by worker without noticing that the strainer was not switched over, because of the fracture of switching handle pin for gas circulator lubricant strainer, which resulted in blowout of lubricant.	Put a clear switching indication and attach a test cock on strainers.

TABLE 1. FIRE EVENTS AT NPPS IN JAPAN I2/5 J.

No.	Date	NPP	Description	Cause	Countermeasures
3	1977/ 03/25	Fukushima Daiichi Unit 1	During periodical inspection, when cutting with acetylene burner to repair work platform in the reactor cavity, fire was occurred by the spark. The fire was extinguished by watering using hose after using fire extinguishers. No one injured.	The insufficient protection for the fusion work resulted in a fire due to sparks dropping on vinyl and scaffold.	Provide protective arrangement for welding and fusion work. Strengthen work management and re-education for the work.
4	1985/ 08/31	Fukushima Daiichi Unit 1	During periodical inspection, a fire was occurred at the upper part of the 6.9 KV bus-bar power box for start up near the electric equipment room in the turbine building, and a fire alarm sounded. The fire station was notified because the fire was not extinguished by dry chemical extinguishers. Finally, the fire was extinguished by pouring water after removing a lid at the corner of the outdoor cable duct above the bus-bar circuit breaker. No one was injured.	Because of the degradation of the seal at the cover seam of outdoor cable ducts, rain water infiltrated through the gap and along the cables and cable ducts, which resulted in short circuit around the cable terminal, leading to a fire of cable.	Change cable ducts with more water proof and fire resistant ones. Change cables with fire retardant ones. Enhance inspection of ducts.

TABLE 1. FIRE EVENTS AT NPPS IN JAPAN I3/5 J.

No.	Date	NPP	Description	Cause	Countermeasures
5	1986/ 01/08	Fukushima Daiichi Unit 2	During a periodical inspection, when workers go out of the water chamber after liquid penetrant test for the water chamber diaphragm of the feed water heater, combustible gas was ignited, leading the fire in the water chamber. Two workers were burnt.	As the ventilation was reduced due to the plugging of a local exhauster, combustible gas vaporized from developers for liquid penetrant test remained at the bottom of the chamber. And a terminal was unstable because there was a crack on the insulator in the socket of the floor light used for work. As a worker was caught with the cable of the floor light, wires contact, resulting in short circuit and ignition of the combustible gas by the arc.	Use floor light of explosion-proof type for the work using combustible gas in confined area. Inspect floor light and plugging of a filter of the exhauster before starting work. Put work management into practice.
6	1988/ 01/13	Fukushima Daiichi Unit 6	During a rated power operation, a fire alarm sounded in the feed air fan room in the turbine building, and smoke was found. While notifying to the fire station, utility onsite firemen fought by themselves at first, and then followed the assignment by the fire station men after they arrived. No one was injured.	Residual oil in the effluent from the turbine lubricant tank vent pipe above the inlet of feed air fan had been deposited on the filter and deteriorated, while steam was supplied to air heater to control room temperature. Therefore, the temperature at the plenum was increased and the deteriorated oil was heated by oxidation, which leads to naturally occurred ignition.	Relocate the turbine lubricant tank vent pipes. Revise manual as to stop the feed air fan after stopping the feed of steam to air heater.

TABLE 1. FIRE EVENTS AT NPPS IN JAPAN I4/5 J.

No.	Date	NPP	Description	Cause	Countermeasures
7	1995/ 03/24	Tomari Unit 1	During a rated power operation, a fire was occurred in the bituminization apparatus condenser tank when workers were cleaning inside the tank. Four workers were injured.	A volatile and combustible cleaning agent was used while the temporal duct for ventilation was drawn up, which resulted in ignition with temporal light of non-explosion proof type.	Stop the using of combustible cleaning agents for the cleaning inside a tank. Use explosive-proof type lights as well as take care of ventilation when using combustible solvent at the place where air may not flow. Put work management into practice.
8	1996/ 09/07	Hamaoka Unit 3	During a periodical inspection, a fire alarm sounded at the power supply room for emergency diesel generator and a smoke was found at the bus duct. Operators and the stuff of fire station arrived later, extinguished the fire using extinguishers. No one was injured.	The ventilation of the concerned room used a full intake system, and the bus duct itself was ventilation type, which result in the deposition of salt and dusts in the intake on and subsequent deterioration of an insulating holder, leading to short circuit with arc. The medium and cover of the bus duct were melted by intermittent arc, and the insulating holder fired.	Close ventilation openings and change bus ducts to the non-ventilation type. Use local cooler in the concerned room to reduce the intake. Put a insulating tape on the medium. Enhance inspecting insulation of bus ducts.

TABLE 1. FIRE EVENTS AT NPPS IN JAPAN I5/5 J.

No.	Date	NPP	Description	Cause	Countermeasures
9	1999/ 01/19	Fukushima Daini	During a rated power operation, a fire alarm sounded at the solid waste incinerator and something firing was found, identified to be a deposit. Operators and the stuff of fire station arrived later, extinguished the fire. No one was injured.	As the waste oil feed pump was started for circulation operation while operating the air preheater at the preheating mode, the signal of oil incineration air flow rate control was changed from gas oil flow rate to waste oil flow rate, and the feed air flow rate was substantially reduced. This resulted in unbalance between gas oil flow rate and air flow rate, leading to increasing incineration temperature and reducing cooling for the air preheater, subsequently to the temperature of inner cylinder higher than the melting point of a stainless steel. As a result, the inner, intermediate and outer cylinders were melted and penetrated.	Modify the control circuit so as to be able to operate waste oil circulation and incinerator itself independently and in parallel. Add protective interlock not to cause abnormally high temperature in case of a potential reduction of feed air flow rate.

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Tezuka, H.	International Atomic Energy Agency
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Consultants Service Meeting

Vienna, Austria: 21–24 May 2002

Technical Committee Meeting

Vienna, Austria: 9–13 July 2001