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Topical operating experience report on emergency core cooling systems and auxiliary/emergency feedwater systems

Volume I: Main report
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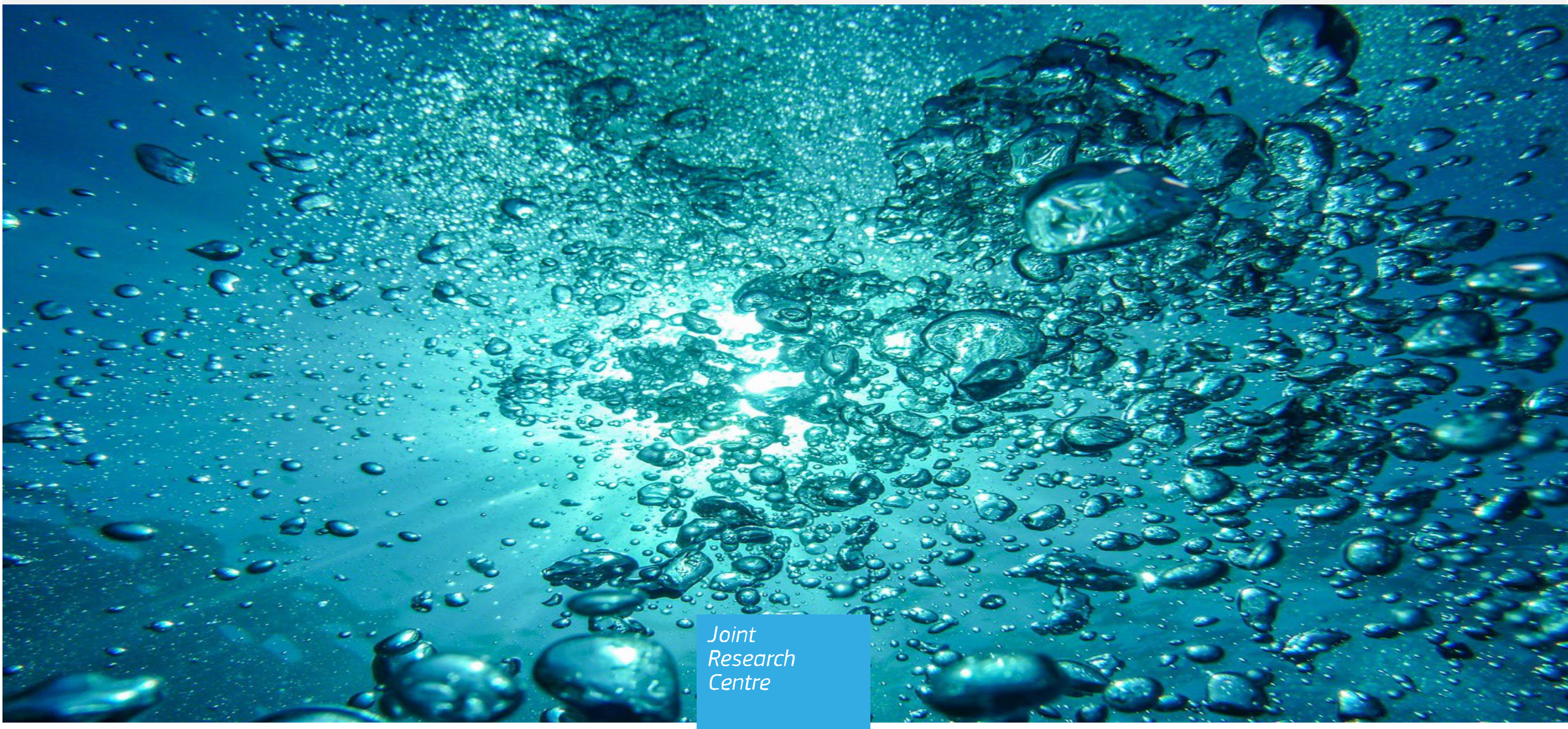

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TOER on Events related to ECCS and EFWS
Volume I: Main report

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Foreword

The European Network on Operating Experience Feedback (OEF) for Nuclear Power Plants, or ‘European Clearinghouse', was established by European nuclear safety regulators to promote the regional sharing of operating experience, the dissemination of lessons learned from nuclear power plants (NPP) operation, and the understanding of the role of OEF systems in the safe and reliable operation of existing and new build NPPs. The centralized office of the European Clearinghouse (CH) is operated by the Joint Research Centre (JRC) of the European Commission.

More specifically, the CH project aims to:

- improve NPP safety by strengthening cooperation between licensees, regulatory authorities and the staff of their Technical Support organizations (TSOs) in order to collect, communicate and evaluate information on reactor operational events and systematically and consistently apply the lessons learned in all the European countries taking part;
- establish European best practice for assessing NPP operational events using state-of-the art methods, computer aided assessment tools and information from various national and international sources, e.g. EU national regulatory authorities' event reporting systems and the International Reporting System for Operating Experience jointly operated by the IAEA and OECD-NEA;
- provide staff to coordinate the OEF activities of the European Clearinghouse and maintain effective communication between experts from European regulatory authorities and their TSOs involved in OEF analyses; and
- support the long-term EU policy needs on OEF by harnessing JRC and European TSO research competencies on the methods and techniques of nuclear events evaluation.

The European Clearinghouse (CH) regularly carries out in-depth analyses of events related to a particular topic (the so-called "topical studies") in order to identify and disseminate the lessons learned aiming at reducing the recurrence of similar events in the future.

The present study deals with events related to Emergency Core Cooling Systems (ECCS) and Auxiliary/Emergency Feed Water Systems (EFWS). Its results are presented in two reports:

- The Main report (Volume 1- this document) summarises the results obtained by the study, prioritising the recommendations and is intended for unrestricted public distribution.
- The Technical Annex (Volume 2) substantiates the recommendations presented in the Main Report, including details of the events reviewed. It is distributed to the organisations participating in the European Clearinghouse, as well as to authorised users of the IAEA´s International Reporting System for Operating Experience.

Abstract

Topical studies are a major product of the European Clearinghouse providing in-depth assessment of safety significant events and generic safety issues.

This is the first topical study from the European Clearinghouse on the topic of events related to Emergency Core Cooling Systems and Auxiliary/Emergency Feed Water Systems, taking into account recent events from nuclear power plants in Europe and worldwide. In this study, relevant events relating to the topic were identified and analysed. The results of this in-depth analysis of events from different countries with different types of nuclear reactors should enable the nuclear safety authorities of the EU Clearinghouse Member States to apply the general findings to their respective nuclear installations.

In total 21 high-level lessons learned have been derived from the selected events. These are discussed and grouped according to various criteria. Thus, this report provides a structured set of generic lessons learned, which may be utilised by regulatory bodies.

Executive Summary

Topical studies (or Topical Operating Experience Reports, TOERs) are a major product of the European Clearinghouse, providing in-depth assessment of generic safety issues. They are based on the analyses of hundreds of event reports. Their main objective is to identify meaningful lessons to be learned and subsequent recommendations that could be applied by supervisory authorities and NPP operators. Thus, these TOERs contribute to the continuous improvement of nuclear safety.

This topical study includes operating experience on “Events related to Emergency Core Cooling Systems and Auxiliary/Emergency Feedwater Systems” and follows the general approach of the topical studies performed under the EU Clearinghouse contracts.

The first step was the search for relevant events in the respective national event databases for NPPs of the Czech Republic, France and Germany. In addition, the International Reporting System for Operating Experience (IRS) was used. This database, jointly operated by IAEA and NEA, is the most important source of significant events from NPPs worldwide. After initial search and pre-selection, a manual screening was conducted to judge the individual events´ relevance for the study and led to the selection of 729 events.

The second step focused on the in-depth analysis of the selected events. The 729 events selected for the study, were grouped in different categories and code fields, describing key elements of the events such as: affected function (ECCS or EFWS), affected system, plant status, type of initiator/nature of event, detection mode of the event, root cause, corrective actions, consequences and safety relevance. Results of the analysis of this coding fields are discussed and illustrated in pie charts.

The most important part of the in-depth analysis is the derivation of high-level lessons learned. These are derived from the most important events within each category. All lessons learned have been assigned to categories and sorted by the predominant root cause. In the Technical Annex, some events are described in detail to illustrate with examples the lessons and recommendations proposed.

The report contains a total of 21 high-level lessons learned. These have been categorised according to the predominant cause they are tackling as follows:

- Design configuration (3)
- Qualification and quality assurance (5)
- Maintenance, Testing or surveillance (including procedures) (7)
- Operational procedures and documents (4)
- Training of staff (2)

Content

1 Introduction

This Topical Operating Experience Report (TOER) on “Events related to Emergency Core Cooling Systems and Auxiliary/Emergency Feedwater Systems[1]” has been developed by a consortium of Technical Safety Organisations (TSO) – the Czech SÚRO, the French IRSN and the German GRS - on behalf of the European Clearinghouse /1/, /2/. The main basis of the evaluation and assessment have been the national event databases of the Czech Republic, France and Germany. In addition, the international event database IRS (International Reporting System for Operating Experience jointly managed by the IAEA and the OECD-NEA) provided input from safety relevant events all over the world.

[1] The term “emergency/auxiliary feedwater systems” has been chosen because both terms, i.e. emergency feedwater system and auxiliary feedwater system are being used to identify the same or similar systems, depending on the reactor design.

2 Methodology and database screening

This chapter briefly explains the method used to analyse the various databases for events relevant to the study.

2.1 Methodology

The TOER on “Events related to Emergency Core Cooling Systems and Auxiliary/Emergency Feedwater Systems” is the first topical study on behalf of the European Clearinghouse on this topic. The scope agreed by the authors with the JRC includes the systems´ mechanical equipment such as pumps, tanks, accumulators, valves, piping, piping auxiliaries, etc. but excludes these systems´ power supply and their I&C with the exception of a few events. The reason is that failures of power supply and I&C may affect the ECCS and EFWS, e.g. unavailability of redundancies, but the causes for the failure are within the power supply and the I&C respectively. The current TOER considers a timeframe of 10 years, i.e. events from 1st January 2012 to 31st December 2021.

The development of the study was structured in four tasks:

1. Screening and selection of relevant events.
2. Analysis of the relevant events in such detail that
    - the events could be attributed to the various categories,
    - the affected systems could be identified,
    - causes of the events could be determined, and
    - lessons learned could be described.
3. Integration of the various events from the different databases to derive generic high-level lessons learned.
4. Compilation of the final report.

The consortium has analysed all the events screened per database The result of event categorization has been documented in a common list of events by adding several categories and code fields, describing key elements of these events such as:

- Affected function, i.e. ECCS or EFWS,
- Plant status,
- Detection mode of the event,
- Affected system,
- Affected component,
- Root cause(s),
- Corrective actions,
- Type of initiator / nature of event (actual, potential or actual / potential),
- Consequences of the event and
- Safety relevance.

2.2 Description of categories

The initial database search was performed using specific codes and guidewords appropriate to the language and structure of the respective database. After initial search and pre-selection, a manual screening was conducted to judge the individual events´ relevance for the study and led to the selection of 729 events.

To identify events, the consortium initially focused on systems, which are responsible for fulfilling the safety functions of emergency core cooling and emergency/auxiliary feedwater supply in their respective countries. In order to account for different reactor designs it was decided to categorize them based on the Manual for IRS Coding /3/. To distinguish between different ECCS functions especially, some of the codes which are subsumed as code 3.BG in the Manual for IRS Coding /3/ were explicitly stated as stand-alone codes. Thus, the relevant systems have been categorized according to the following codes:

- Reactor Core Isolation Cooling (BWR)
- Auxiliary and Emergency Feedwater
- Core Flooding Accumulator (PWR)
- Emergency Core Cooling (ECC) – High or intermediate pressure coolant injection system (PWR, PHWR)
- ECC - Low pressure core cooling system (PWR, PHWR)
- ECC - High pressure coolant injection system (mainly BWR)
- ECC - High pressure core spray system (mainly BWR)
- ECC - Low pressure core spray system (mainly BWR)
- ECC – Chemical and Volume Control System
- ECC – Commonly shared equipment between systems, e.g. piping etc.

For some reactor designs, the high-pressure emergency core cooling is performed by part of the CVCS pumps and valves.

Further categories, apart from the impacted function, i.e.

- ECCS,
- EFWS,
- ECCS/EFWS,

were derived from experience gained in previous TOERs. Therefore, the other categories and code fields were either directly based on the Manual for IRS Coding /3/

(e.g. component failed/affected), on a selection or high-level version of those (e.g. for root cause of events) or commonly agreed and derived from previous TOERs altogether (e.g. mode of detection, corrective actions).

3 Event screening results

3.1 Distribution of events over the timeframe considered

The timeframe considered in the current report covers 10 years, i.e. 1st of January 2012 to 31st of December 2021. Significant national operating experiences before 2012 were only considered if it is still of importance for ECCS/EFWS system design and operational safety today or in case of IRS, if the event was reported to IRS within the timeframe considered, but the actual event date was before 2012.

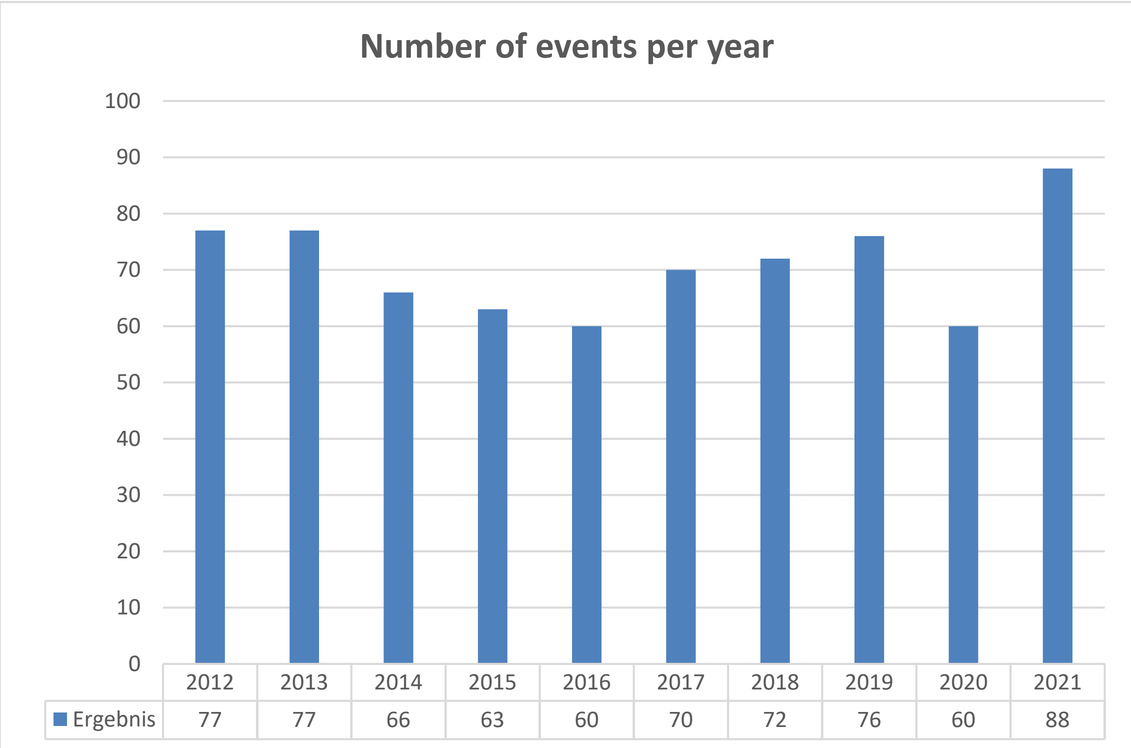

Fig. 3.1 - Number of events per year

There is no constant ascending or descending trend in numbers of reported events in time. The numbers vary between 60 and 77 events per year, the yearly average being around 70 events per year. A higher number of events (88) has been reported in 2021. Fig. 3.1 does not include 20 events, which happened prior to 2012, but were either reported later to the IRS database or were considered important for the study. All events were taken into account for the analyses and are present in further graphs. Due to the low number per year (1, 5 or 13 events) and due to not being within the initial timeframe they have been omitted to not skew the number of events per year for the timeframe considered.

The nature of event allows to distinguish whether the initiating event has really occurred or whether the event could limit or degrade the ability of the NPP to control a potential event as foreseen in the design. The latter type is coded as potential. The third choice “actual/potential” reflects those event reports that include several events which involved “actual” initiators as well as “potential” initiators or “actual” initiators which had the potential to further affect ECCS/EFWS. Fig. 3.2 shows the majority of the 729 events (~86 %) were actual events. Only around 4 % were potential. The remaining 10 % which relate to actual, as well as potential may be attributed either to Information Notices containing several events as well as events which had an actual, as well as a potential impact on ECCS/EFWS.

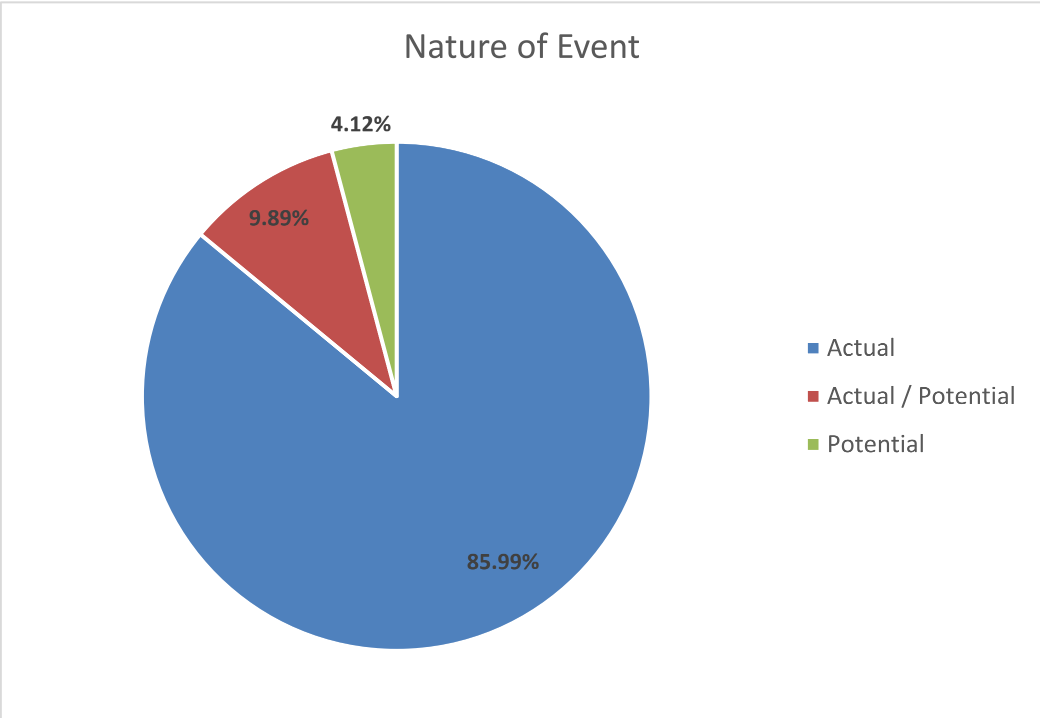

Fig. 3.2 - Nature of Event

3.2 Plant status and Detection of event

The plant status prior to an event indicates during which operational state the event was detected. Depending on the topic, in this case ECCS/EFWS, this gives an impression if an event might have impacted the safety function to be performed by the affected system, e.g. when the safety function is not independent of plant state, or in what way it might have impacted the safety function, e.g. loss of redundancy or not applicable due to safety function not required during the plant state.

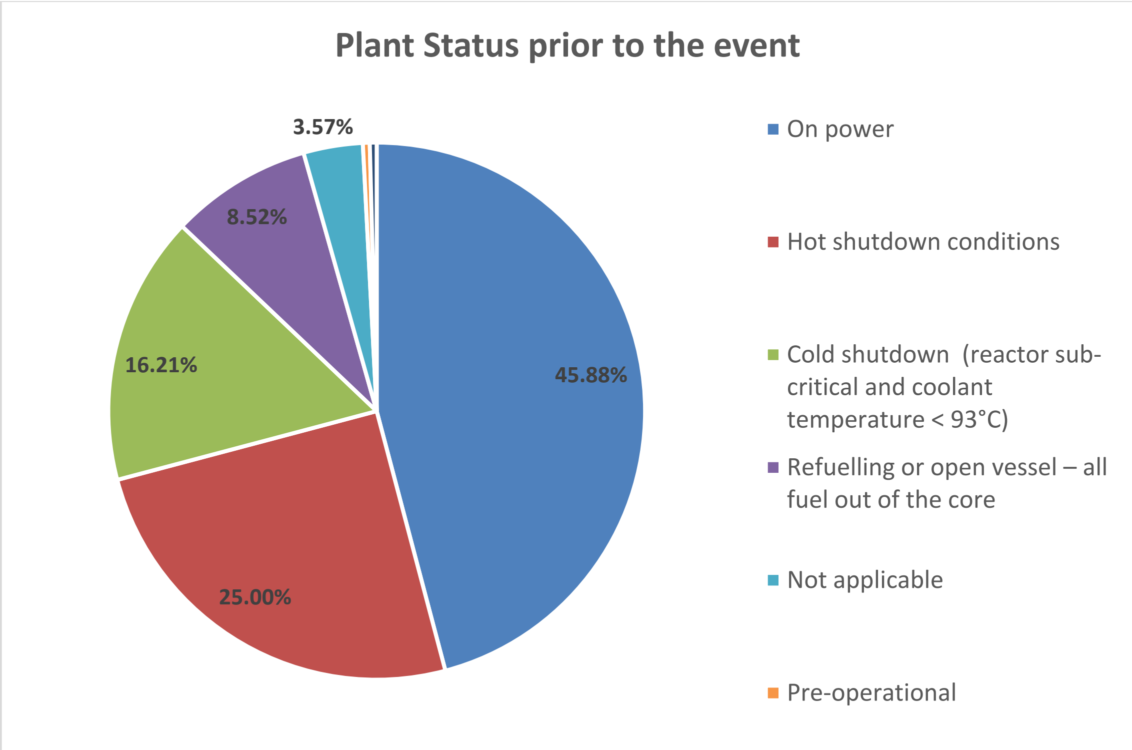

Fig. 3.3 - Plant status prior to the event

Most of the events (~70 %) actually happened (were detected) when reactors were on power or in hot shutdown as can be seen in Fig. 3.3. This underlines the importance of redundancy and diversity in the design of the ECCS/EFWS and of testing of these systems during operation of NPPs. Approximately 25 % of the events were reported during cold shutdown states, including refueling or open vessel with all fuel deloaded from the core. The “not applicable” state, which is around 4 % is chosen to indicate those event reports, were the plant state was independent from detection, e.g. reviews/analyses or not available in the report. Pre- and post-operational events were reported thrice each, which is why their overall contribution is negligible.

The mode of detection is given in Fig. 3.4. The highest contributing mode of detection is “Periodic/Functional testing” (36 %). In addition to alarms (~17 %) and reviews/analyses (15 %) a high number of events were detected during maintenance (14 %) or visual inspections during walkdowns (11 %). It indicates the importance of all these activities and their procedures.

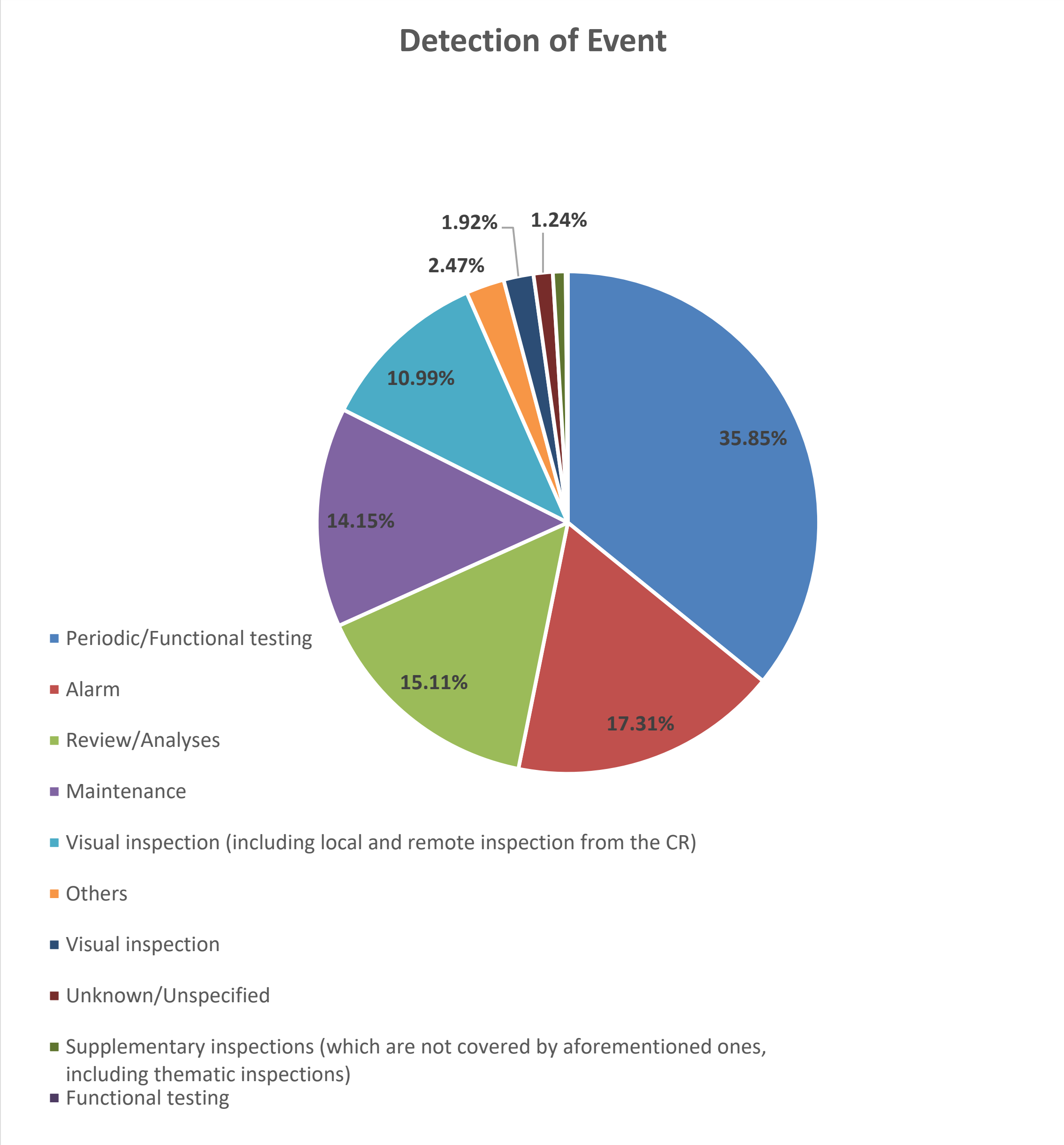

Fig. 3.4 - Detection of Event

3.3 Affected systems

The distribution of systems being affected in the relevant event reports is depicted in Fig. 3.5. From this figure, the overall distribution between "Auxiliary and Emergency Feedwater", as well as all the other ECCS related systems can be examined. The distribution between ECCS and EFWS differ only by approximately 10 %, meaning that albeit there is a difference, the reporting of events for both safety functions is fairly comparable and does not show a real trend of one safety function being more affected than another.

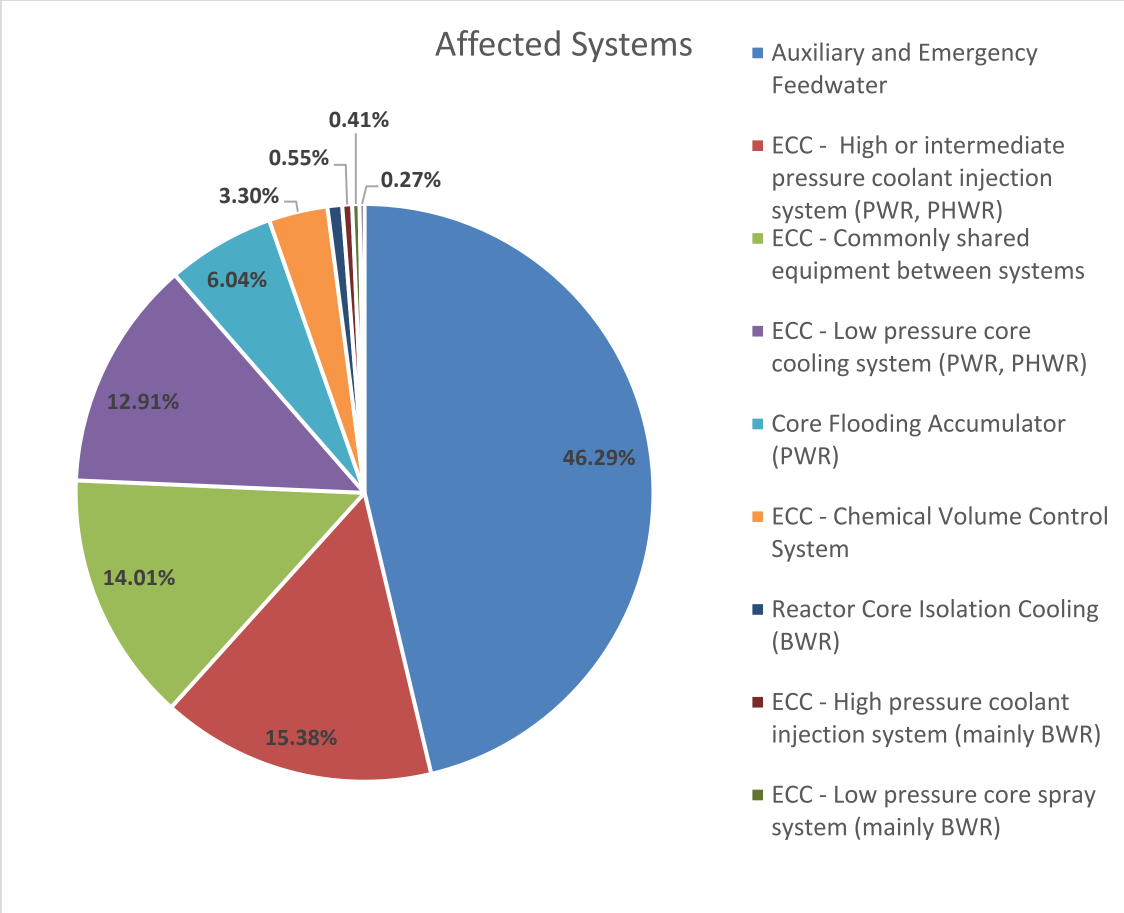

Fig. 3.5 - Affected Systems

In terms of the number of pumps, valves and piping connections, the ECCS systems at the NPPs evaluated in the study are generally more extensive than the EFWS systems. Nevertheless, the evaluation results showed ~46% of events related to auxiliary and emergency feedwater systems. This is likely caused by harsh environmental conditions in which the EFWS systems work. A large portion of components of these systems (pumps, most of valves, piping) is located in the turbine halls, where vibrations, dust, changes of temperatures and personnel movement are more intense as well as frequent compared to the nuclear island area. The equipment environment qualification should take this into consideration.

The distribution of affected Emergency Core Cooling Systems is fairly similar (~13-15 %) for PWRs, with the notable exception of "Core Flooding Accumulators" (and their corresponding systems), which make up only ~6 %. If the Chemical and Volume Control System is added, which is used in some PWR designs for medium/high safety injection too, "High or intermediate pressure coolant injection systems" are the most reported PWR injection systems with an accumulated share of around 19 %. When "Core Flooding

Accumulators”, which usually are used in the “medium” pressure range, is added the accumulated percentage amounts to roughly 25 %. BWR core cooling systems are less reported in comparison, due to the high number of French events, which only refer to PWR. The overall percentage of BWR events is ~2%. Out of these events, approx. half of them refer to the “Reactor Core Isolation Cooling”, thus contributing by ~1 % to the affected systems.

3.4 Affected components

The distribution of the affected components is shown in Fig. 3.6.

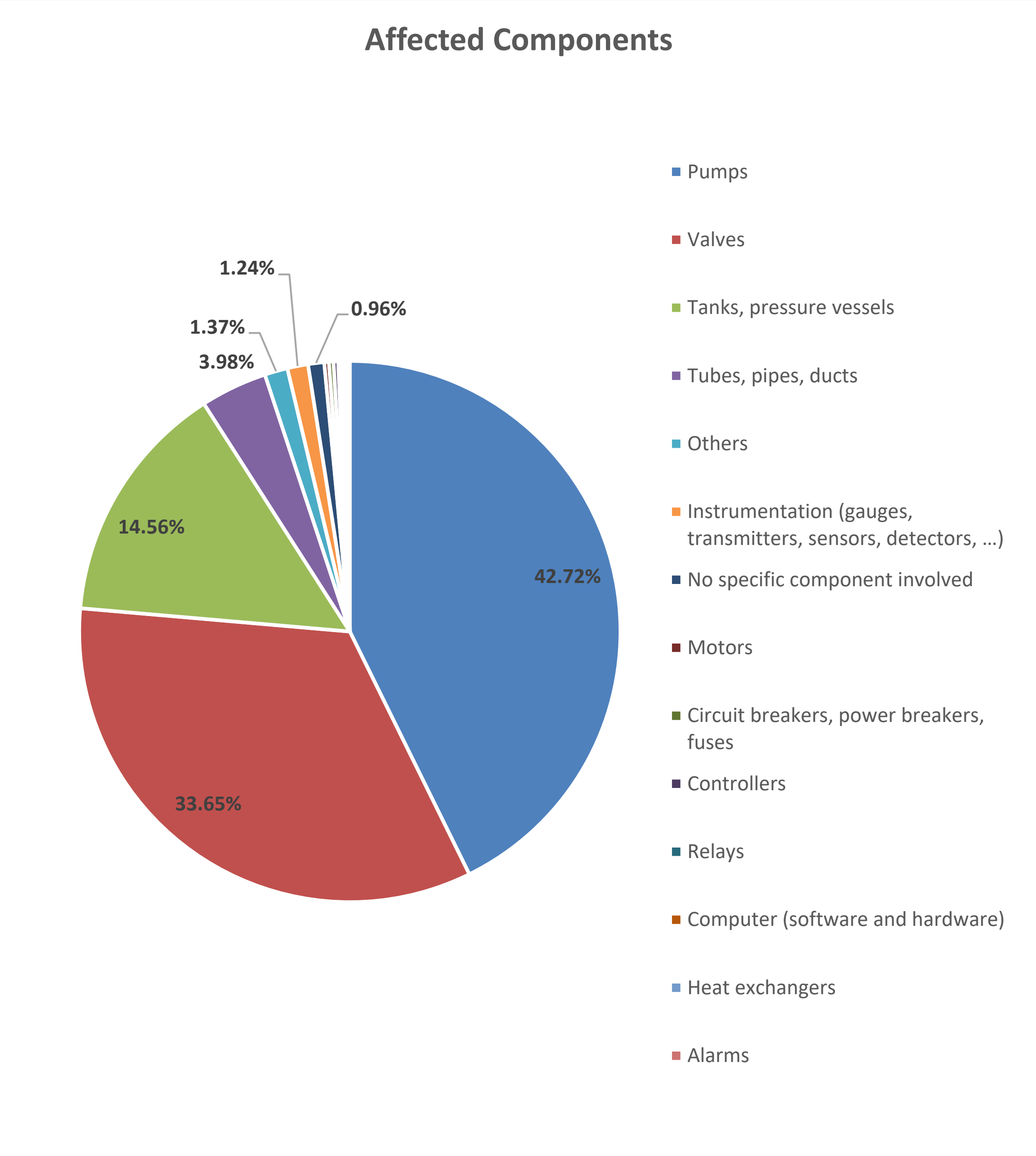

Fig. 3.6 - Affected components

Over 42% of events related to pumps and more that 33% of events related to valves indicate that rotating or in other mechanical way active components are the most vulnerable parts of the ECCS/EFWS. This highlights that testing and maintenance, specifically preventive maintenance, are crucial for ensuring their high reliability. Tanks and pressure vessels are the third most affected group of components (~ 15 %). Tubes, pipes and ducts were directly affected by a share of 4 %, while other components, e.g. motors, circuit breakers, controllers, computer, heat exchangers etc. were each affected only in one or two events, thereby being negligible compared to the aforementioned ones within the scope of the study.

3.5 Root Causes and Corrective Actions

The identification of the root cause is crucial for defining and implementing corrective actions which will effectively prevent a recurrence of similar events in the future, thus strengthening the safety of NPPs. The authors assessed the indicated root causes of the events and identified their incidence and relative distribution as shown in Fig. 3.7 and the distribution of corrective actions is shown in Fig. 3.8. For root causes, as well as corrective actions, only the most predominant ones were selected in this list to identify clearly common causes or practices between Czech, French, German and IRS events.

Human performance related root causes and causal factors are attributed to the majority of reported events. “Personnel work practices” (~42 %), “Work organization” (~7 %), “Written Procedures and documents” and “Personal factors” (each ~3 %), make up more than half the root causes. Equipment related causal factors are the second largest group. Here, “Equipment aging” (~17 %) and “Maintenance, testing or surveillance” (~12 %) and “Equipment (procurement) specification, manufacture and storage” (~1 %) amount to approximately 30 % of the root causes.

These indicate how the qualification of personnel, quality of procedures and work performed by the NPP staff and contractors are important for safety as further exemplified by the other root causes with contributions of less than 1 %.

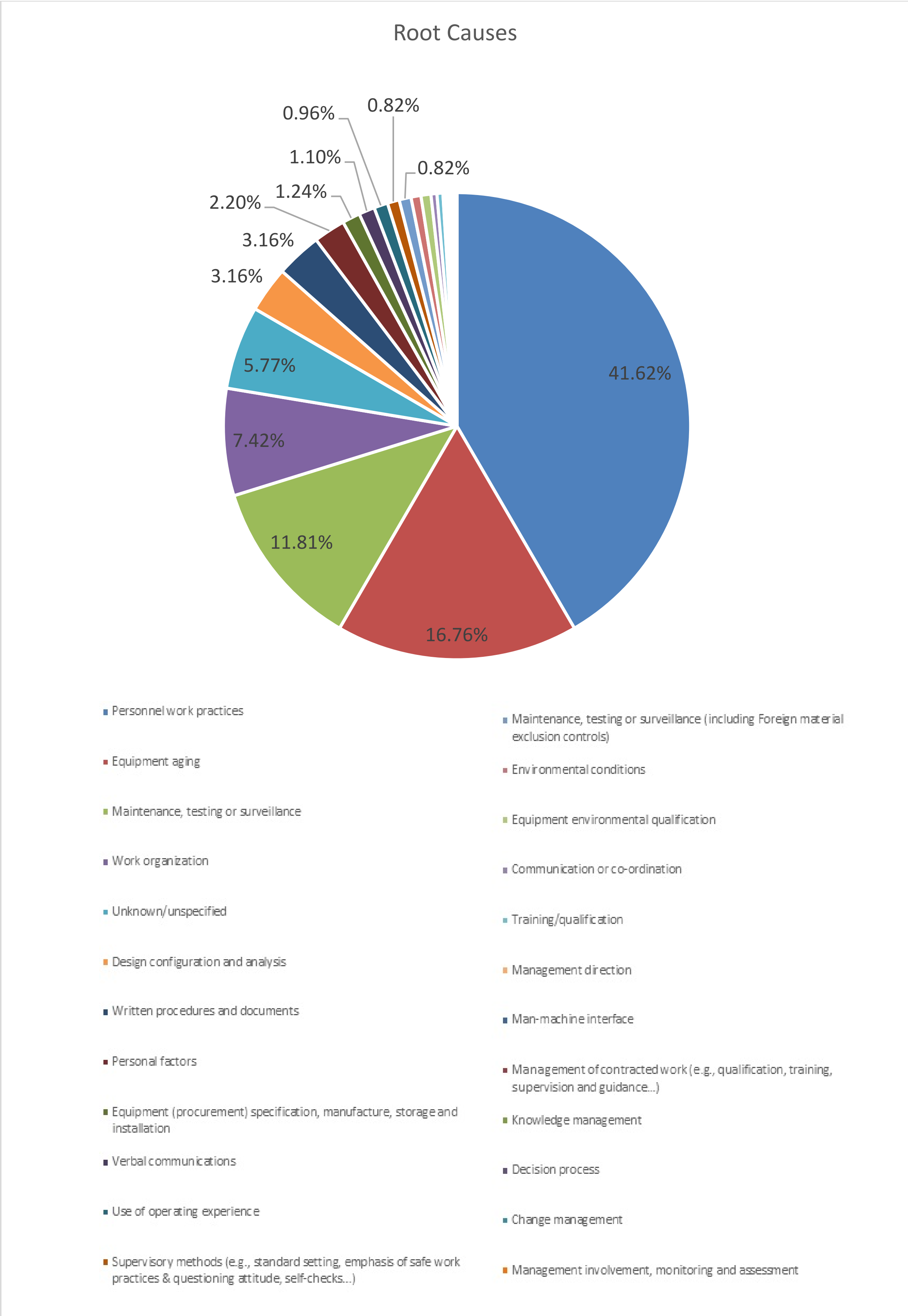

Fig. 3.7- Root Causes

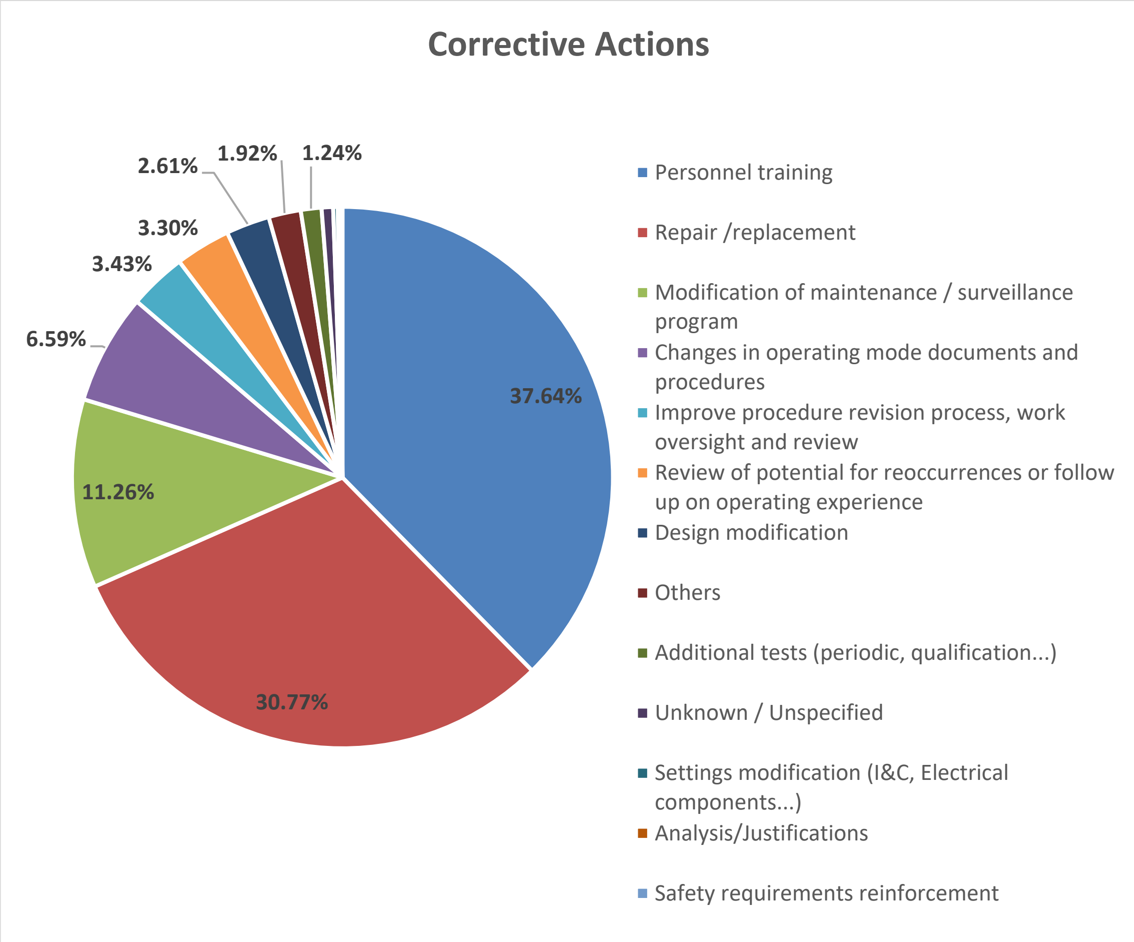

Fig. 3.8 - Corrective Actions

The corrective actions, indicated in the event reports, which make up more than 1 % address either human performance itself, e.g. “Personnel training” (~38 %), “Improve procedure revision, process, work oversight and review” (3,4 %) or aid personnel to make errors more unlikely such as for example “Changes in operating mode documents and procedures” (~6,5 %). The root cause of “Maintenance, testing or surveillance” is addressed by “Modification of maintenance/surveillance program” (~11 %).

The corrective action “Repair replacement” (~30 %) has the second largest share. Thus, Fig. 3.9 shows the root causes for which “Repair / replacement” has been identified in the event reports as corrective action. The root cause of “Equipment aging” makes up half of the share of corrective actions (~ 49 % of “Repair / replacement”, thus ~15 % of corrective actions overall), which fits its share of root causes (~17 %). Further root causes which are addressed by either repair or replacement are “Maintenance, testing or surveillance” (~20 %), “Unknown/Unspecified” root causes (12,5 %), “Equipment (procurement specification, manufacture, storage and installation (~3,6 %) or "Design configuration and analysis" (~1,8 %) as well as "Equipment environmental qualification" (~1,3 %). For human performance related root causes, e.g. "Personnel work practices", "Work organization" (~2,2 %) or "Personal factors" (~1,3 %).

"Repair / replacement" as corrective action does not seem to fully address the identified root cause. This is because only the predominant corrective actions were chosen, and because events often have several root causes and contributing factors.

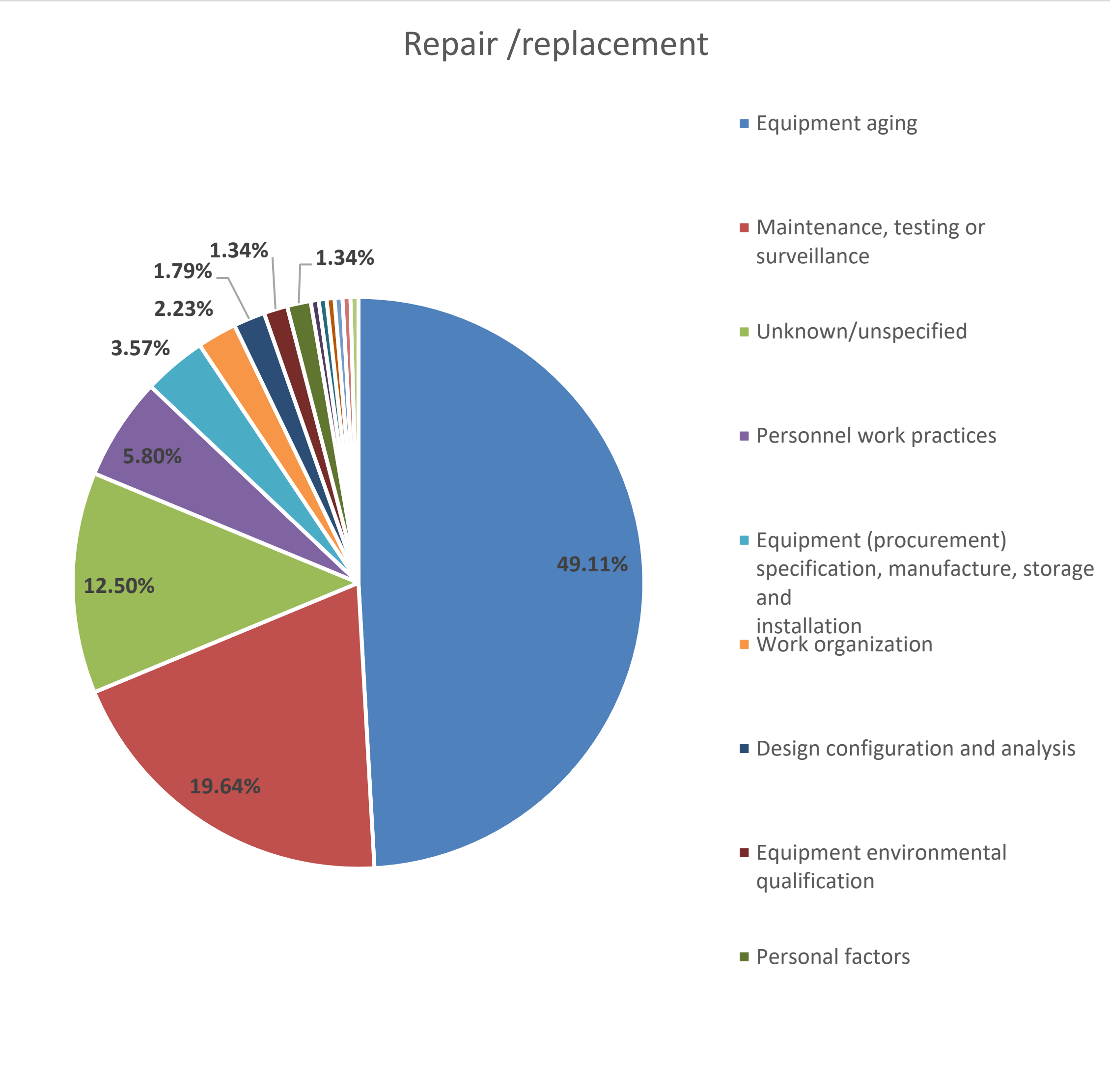

Fig. 3.9 - Repair / replacement associated root causes

3.6 Consequences and Safety Relevance

Fig. 3.10 illustrates the impact the reported events had on safety and operation of the NPPs. The safety relevance of events is given in Fig. 3.11.

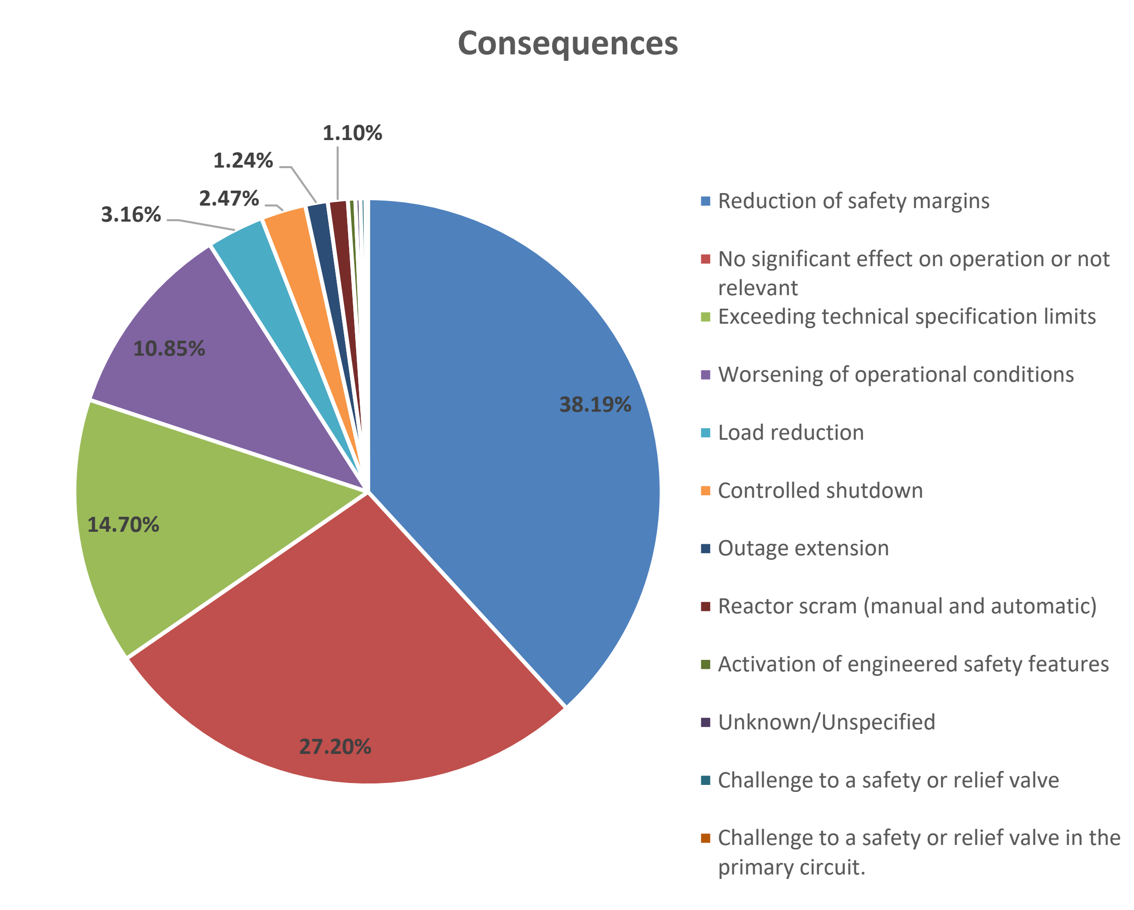

Fig. 3.10 - Consequences

More than 38 % of the reported events leading to reduction of safety margins, 14,7 % leading to exceeding technical specification limits, and more than 10 % leading to worsening of operational conditions show how sensitive the NPPs are to failures or malfunctions of ECCS/EFWS. In about 2,5 % of the events there was a controlled shutdown of the NPP and in less cases (~1 %) it resulted in a “Reactor scram (manual and automatic)”. Other consequences included “Load reduction” (~3 %) or “Outage extension” (~1,2 %) as a result of events.

About a quarter of the reported events (~27 %) had no significant effect on operation or were not relevant.

The common definition of safety relevance (see /5/) is related to the conditional core damage frequency (CCDF) of the event. This frequency can be assessed by precursor studies. The common definitions are:

- high safety significance: CCDF > 10 E-4
- medium safety significance: CCDF < 10 E-4 but > 10 E-5
- low safety significance: CCDF < 10 E-5 but > 10 E-6
- no safety significance: CCDF < 10 E-6

In /5/ there was a further principle of classification used that is easier to apply:

- high safety significance: more than one safety function affected
- medium safety significance: one safety function affected
- low safety significance: safety function redundancy affected
- no safety significance: no safety function safety function affected

This common definition is not applied in the same manner in different countries. For many events (esp. events reported to IRS) the CCDF is unknown to the authors. The authors have distinguished the safety relevance of the events with respect to the impact on plant safety. In most cases, this was done without an in-depth analysis using e.g. a probabilistic safety analysis, due to a lack of information provided. Thus, the evaluation of the safety relevance mainly depends on expert judgement.

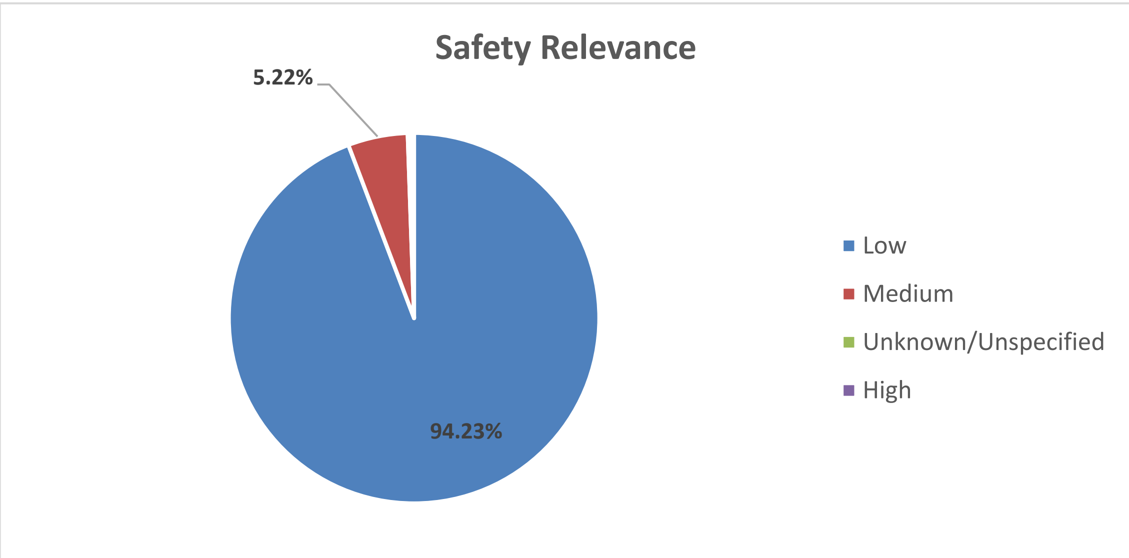

Fig. 3.11 - Safety Relevance

The analysis of the data shows that more than 94 % of the events are of low safety relevance, about 5 % of the events of medium safety relevance, high safety relevance and events with unspecified safety relevance amount to less than 1 % (only two events identified each).

The root cause distribution all 729 events (cf. Fig. 3.7), has been compared to the distribution of root causes for events with medium and high safety significance (40 events) to check for a correlation between root cause and safety significance. Since these showed to be insignificantly different no correlation between root cause and safety significance could be made.

A similar check has been made for the affected components: The distribution of the affected components of all 729 events, is insignificantly different if only the 40 events with medium and high safety significance are evaluated. Thus, no correlation between root cause and safety significance is visible.

4 Derivation of High-Level Lessons Learned

The formulation of high-level lessons learned derived from operational experience was based on a total of 729 events, which had been assessed as potentially relevant. In detail, the development was performed in four steps:

First, from the event list, low-level lessons learned as well as supporting causes/measures have been identified and compiled. Based on the overview obtained, a first categorization could be developed, corresponding to the predominant cause they are tackling.

In a second step, the low-level lessons learned and supporting causes/measures were assigned to these categories.

In a third step, for each category, information was reviewed in search of common concepts underlying the detailed insights. The findings led on the one hand to an adjustment of the categorization, and on the other hand to the further grouping of the low-level lessons learned according to these common concepts. This means that after the third step, the categorization was final, and within this, groupings with common concepts were established, which formed the basis for the last and fourth step.

Formulation of high-level lessons learned.

In this synthesis effort, high-level lessons learned have been defined in a way that they are neither too specific (so that they would have a too limited applicability) nor too wide (so that they could be considered as common sense, already known to everyone, and therefore not very useful).

High-level lessons learned have been elaborated by considering the following elements:

- The recommended actions in the event reports (what is recommended e.g. to prevent, to mitigate or to protect the NPP from recurring the same or similar events) including their purposes.
- The actual (observed) consequences motivating the recommended action based on event specific causes or specific lessons learned, which support or justify the high-level lessons learned.

The report contains a total of 21 high-level lessons learned. These have been categorised according to the predominant cause they are tackling as follows:

- Design configuration (3)
- Qualification and quality assurance (5)
- Maintenance, Testing or surveillance (including procedures) (7)
- Operational procedures and documents (4)
- Training of staff (2)

4.1 Design configuration

The events which have been classified within the “Design configuration” (DC) category comprise events where the root cause(s) specifically affect the “design configuration and analysis” of various components. Thus, root causes may be for example insufficient “design analysis quality”, wrong “materials selection”, insufficient “modifications engineering quality” or an inadequate “modifications engineering review process” which are all subcodes for “design configuration and analyses” in /3/. The specific events´ root causes taken into account may be covered by the aforementioned examples or may be of similar nature, where the design itself was specifically affected.

The specific lessons learned and corrective actions indicated by the events classified in the category “Design configuration” led to 3 high-level lessons learned.

Tab. 4.1 High-level lessons learned for design configuration events

Design configuration related high-level lessons learned
DC#1 – Design should be reviewed periodically for possible inaccuracies or inconsistencies with real state of technology
DC#2 – Design change and safety analysis should precede any replacement of technology by non-identical equipment
DC#3 – Environmental qualification of equipment and systems should be reviewed periodically

- **LL DC#1 - Design should be reviewed periodically for possible inaccuracies or inconsistencies with real state of technology**

Design (design basis specification) should be reviewed periodically for possible inaccuracies, which could negatively affect the operability of the systems important to safety. Procedures for such periodic reviews and adequate responsive remedial measures should be put in place.

- **LL DC#2 - Design change and safety analysis should precede any replacement of technology by non-identical equipment**

Replacement of equipment or system by different equipment or system should be preceded by a thorough safety analysis and be based on detailed design modification/change prepared in advance.

When preparing a design modification/change as a remedial measure triggered by event(s) affecting safety, thorough analysis of equipment/system working conditions/environment conditions should be carried out and experiences gained earlier should be taken into consideration.

- **LL DC#3 – Environmental qualification of equipment and systems should be reviewed periodically**

Environmental qualification of equipment and systems envisaged by the design should be periodically reviewed and when necessary remedial measures implemented to assure that the equipment and systems fit the real existing environmental conditions (temperature, radiation, vibrations, pressure changes...).

4.2 Qualification and quality assurance

The events which have been classified within the “Qualification and quality assurance” (QQ) category comprise events where the root cause(s) affect the topics of quality and quality assurance on a more generic level. This means, while events in “Design configuration” may also contain root causes addressing QQ which are specific to design, the events considered in this category relate to all kinds of QQ. These may comprise for example root causes related to: (i) processes and procedures, (ii) structures, systems and components (SSC), (iii) qualification issues (e.g. environmental qualification) and (iv) documentation associated with qualification and quality assurance.

The specific lessons learned and corrective actions indicated by the events classified in the category “qualification and quality assurance” led to 5 high-level lessons learned.

Tab. 4.2 High-level lessons learned for qualification and quality assurance events

Qualification and quality assurance related high-level lessons learned
QQ#1 – Regular Reassessment of Safety Function Classification Ensures Accuracy and Compliance
QQ#2 – Mandatory visual checks prior to interventions
QQ#3 – Ensuring Comprehensive Compatibility of Materials and Components for Maintenance Integrity
QQ#4 – Quality control and documentation on welding operations is needed to prevent the use of unsuitable materials
QQ#5 – Strict Adherence to Instructions Mitigate Routine-Induced Risks

- **LL QQ#1 - Regular Reassessment of Safety Function Classification Ensures Accuracy and Compliance**

A review combined with a new analysis of the safety functions/classification for all the equipment concerned (particularly for equipment that has been replaced or modified) could be useful at each ten-year inspection to check that the classification assigned is correct.

- **LL QQ#2 - Mandatory visual checks prior to interventions**

Although an intervention automatically requires a work permit from the operator, the analysis could be strengthened by adding a compulsory visual check at the boundary of the intervention zone to ensure that the status allows the intervention to be carried out.

- **LL QQ#3 - Ensuring Comprehensive Compatibility of Materials and Components for Maintenance Integrity**

Reinforce the check that all materials and components needed to be used during maintenance or modification activity on equipment are suitable and compatible (e.g. tools, spare parts, products, process…) with all the technical specifications required, from a mechanical, electrical, chemical, temperature, pressure, radiation point of view in order to maintain the total integrity of equipment and its function (e.g. avoid the use of “Teflon” which is not acceptable in presence of radiations).

- **LL QQ#4 - Quality control and documentation on welding operations is needed to prevent the use of unsuitable materials**

For all activity involving welding, associated documents should clearly precise and specify all necessary information (welding process, materials, tools, products, check points, quality control to perform) to ensure that it is well suited to the types of stress to which the circuit is subjected.

- **LL QQ#5 - Strict Adherence to Instructions Mitigate Routine-Induced Risks**

It is important to periodically remind staff awareness of the necessity, to carefully read and to strictly follow step by step (follow prescribed sequencing of required activities) all the instructions written in the document and procedures. In parallel, all the documentation needed for the right quality control and qualified procedure including all detailed information and instructions should be provided, in order to avoid the worker to take personal decisions.

4.3 Maintenance Testing or surveillance (including procedures)

The events which have been classified within the “Maintenance Testing or surveillance (including procedures)” (MTS) category comprise events where maintenance, testing and surveillance related activities were affected or contributed to the event, regardless of whether it concerned the preparation, implementation, or subsequent analysis of these activities. The identified root cause(s) may concern for example human errors, documentation, availability of suited spare parts/equipment and specialized contractor services, monitoring of activities and/or SSC conditions, as well as reviews of performed works/tests/inspection.

The specific lessons learned and corrective actions indicated by the events classified in the category “maintenance, testing or surveillance” led to 7 high-level lesson learned.

Tab. 4.3 High-level lessons learned for Maintenance Testing or surveillance events

Maintenance Testing or surveillance related high-level lessons learned
MTS#1 – Unsuitable test documentation leading to appearance of cracks on pipes
MTS#2 – Lack of information in documentation
MTS#3 – Human errors identified during periodic testing or maintenance work.
MTS#4 – Failure to test/validate a new process before using it on site
MTS#5 – Regular checks/walk downs
MTS#6 – Non-destructive testing and functional tests should be reviewed periodically
MTS#7 – Proactive Component Replacement Strategy based on operating experience feed-back

- **LL MTS#1 - Unsuitable test documentation leading to appearance of cracks on pipes**

Mechanical fatigue related to pipes and welding is a very sensitive topic, especially when located in the nuclear island. Therefore, the test documentation should be complete, reviewed and precise information should be added in order to avoid or minimize any risk of cracking.

- **LL MTS#2 - Lack of information in documentation**

Documentation relating to maintenance and testing should be improved and include all the detailed instructions and checks needed to recover the equipment successfully.

- **LL MTS#3 - Human errors identified during periodic testing or maintenance work**

More training sessions for operator/staff could help to reduce significantly the human error risk. These events highlight the importance to make operator/staff aware of the need to follow and scrupulously comply with the instructions described in the documents relating to maintenance and testing procedures. All personal initiatives should be discussed by the team only in case the information is not available in the documentation.

- **LL MTS#4 - Failure to test/validate a new process before using it on site**

Ensure that before using a new process (e.g. with new products, methods, tools, etc.), it has first been validated by appropriate analyses, tests and qualification, to avoid damage on equipment or structure in place.

- **LL MTS#5 - Regular checks/walk downs**

Regular checks/walks down should be performed and approved maintenance procedures and compatible qualified materials as well as equipment should be available to minimise the risk of unavailability of equipment important to safety.

- **LL MTS#6 – Non-destructive testing and functional tests should be reviewed periodically**

Non-destructive testing and functional tests envisaged by the design should be reviewed periodically for their sufficiency and adequacy. In addition, modifications/changes should be implemented to maintain the integrity of mechanical components, required redundancy and diversity of systems.

- **LL MTS#7 - Proactive Component Replacement Strategy based on operating experience feedback**

Based on the operating experience feedback of similar events, a list of components (e.g. with relays) could be identified to modify and adapt the frequency of replacement to prevent malfunction due to aging.

4.4 Operational procedures and documents

The events which have been classified within the “Operational procedures and documents” (OPD) category comprise events where operational procedures and operator actions were either causing or contributing to the event. Examples of root cause(s) may be comprehensiveness of procedures, procedure compliance with technical specifications, non-adherence to procedures or inadequate decision making (e.g. due to lack of guidance, information or oversight).

The specific lessons learned and corrective actions indicated by the events classified in the category “operational procedures and documents” led to 4 high-level lessons learned.

Tab. 4.4 High-level lessons learned for operational procedures and documents events

operational procedures and documents related high-level lessons learned
OPD#1 – Procedure robustness
OPD#2 – Procedure compliance with Technical Specifications
OPD#3 – Ensure necessary monitoring to correctly execute operational procedures
OPD#4 – Oversight and attention of operators

- **LL OPD#1 – Procedure robustness**

Ensuring the robustness of nuclear power plant procedures is crucial. Procedures need to encompass a thorough initial state assessment, including the availability of redundant equipment, especially during periodical tests. Furthermore, procedures should account for potential errors induced by modifications or delays. Additionally, operating documents must provide explicit guidance on equipment alignment, ensuring that e.g. specific pump configurations are checked to avoid unintended impacts on other system alignments.

- **LL OPD#2 – Procedure compliance with Technical Specifications**

Ensuring the effective compliance of operational procedures with technical specifications (TS) is paramount for nuclear power plant safety. This involves a comprehensive review of procedures to identify and rectify instances of TS non-compliance, inadequate TS, or deficiencies in plant design and operating procedures. By consistently evaluating and, if necessary, revising procedures, licensees can enhance the robustness of their operations and contribute to maintaining compliance with TS. In addition, it is important to provide sufficiently detailed and comprehensive operating instructions, as demonstrated by the need to amend them regarding phenomena such as stratification and its treatment.

- **LL OPD#3 – Ensure necessary monitoring to correctly execute operational procedures**

The effective execution of operating procedures in nuclear power plants requires that the necessary parameters are directly visible to control room personnel. These include, for example, the levels of the flooding basins and the temperatures of the EFWS tanks. Proactive monitoring improves situational awareness, enables rapid corrective actions and contributes to the overall reliability and safety of power plant operations.

- **LL OPD#4 – Oversight and attention of operators**

Comprehensive supervision of personnel during critical plant activities, such as start-up, is crucial. Rather than focusing only on specific tasks, a comprehensive approach is required. This means looking at the whole situation and all the events together. A clear allocation of responsibilities is key to minimizing gaps in preparation and execution and thus ensuring robust and reliable personnel supervision in nuclear power plants.

4.5 Training of staff

The events which have been classified within the “Training of staff” (ST) category comprise events where the insufficient training or weak human performance in general were either causing or contributing to the event. Thus, the corrective actions taken in these events emphasized training-related measures. These may relate for example to additional training or to the improvement of existing training (content, periodicity, etc.).

The specific lessons learned and corrective actions indicated by the events classified in the category “training of staff” led to 2 high-level lesson learned.

Tab. 4.5 High-level lessons learned for training of staff events

Training of staff related high-level lessons learned
ST#1 – Regular performance of validated training programs
ST#2 – Integration of operating experience feedback in trainings

- **LL ST#1 – Regular performance of validated training programs**

Events stemming from human errors and incorrect training underline the need for continuous, validated training and reminders to ensure vigilance in critical areas. Hence, ongoing and periodic training is crucial for reinforcing correct practices, such as proper assembly direction. Thereby, training programs should include thorough checks on all actions, validation before demonstration, as well as reminders to strictly follow procedures.

- **LL ST#2 – Integration of operating experience feedback in training**

Operating experience from past events highlights the importance of prompt analysis, continuous familiarization with lessons learned, and fostering a safety culture through complementary training for NPP personnel. All relevant operating experience feedback should be integrated into training accordingly, thus training programmes need to be updated periodically.

5 References

/1/ Framework Contract 939770 “NL-Petten: Topical studies on nuclear power plants operating experience”, 2020

/2/ Terms of Reference - Offer: Topical Operational Experience Report (TOER) on Events related to ECCS and EFWS (Ref.: G.9/SHARPEN/220903), European Clearinghouse on Operational Experience Feedback, finally signed by the consortium 07.11.2022 (G.B836990)

/3/ IAEA/NEA Service Series 20 (Rev.1): Manual for IRS Coding 2022 Edition
https://www.iaea.org/publications/15056/manual-for-irs-coding

List of Abbreviations

BWR	Boiling Water Reactor
CCDF	Conditional Core Damage Frequency
CH	Clearinghouse
CVCS	Chemical and Volume Control System
DC	(Design Configuration)
ECC	Emergency Core Cooling
ECCS	Emergency Core Cooling System
EFWS	Emergency Feed Water System
EU	European Union
GRS	GRS: Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH
IAEA	International Atomic Energy Agency
IRS	International Reporting System for operating experiences
IRSN	Institut de Radioprotection et de Sûreté Nucléaire
I&C	Instrumentation and Control
JRC	Joint Research Centre
LL	Lessons Learned
MTS	(Maintenance, Testing and Surveillance)
NEA	Nuclear Energy Agency
NL	Netherlands
No.	Number
NPP	Nuclear Power Plant
OECD	Organization for Economic Co-operation and Development
OEF	Operating Experience Feedback
OPD	(Operational Procedures and Documents)
PHWR	Pressure Heavy Water Reactor
PWR	Pressure Water Reactor
QQ	(Qualification and quality assurance)
SSC	Structures, Systems and Components
ST	(Training of Staff)
SÚRO	Statní Ústav Radiační Ochrany
TOER	Technical Operating Experience Report
TSO	Technical Support Organization

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