IAEA-TECDOC-1932

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IAEA-TECDOC-1932

Operating Experience from Events Reported to the IAEA/NEA Fuel Incident Notification and Analysis System (FINAS)

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OPERATING EXPERIENCE FROM EVENTS REPORTED TO THE IAEA/NEA FUEL INCIDENT NOTIFICATION AND ANALYSIS SYSTEM (FINAS)

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INTERNATIONAL ATOMIC ENERGY AGENCY
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FOREWORD

The Fuel Incident Notification and Analysis System (FINAS) is jointly operated by the IAEA and the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development (OECD/NEA). The system is an important tool for international exchange of operating experience for nuclear fuel cycle facilities. FINAS reports contain information about events of safety significance that have occurred at nuclear fuel cycle facilities and describe the root causes and lessons identified from each event. These reports are discussed in the regular meetings of the FINAS national coordinators and are included in the system database.

The FINAS national coordinators, at their biennial technical meetings in 2016 and 2018, recommended a review of the operating experience from events reported to FINAS. This publication presents the findings of that review, including the root causes, safety significance, lessons identified and corrective actions developed from the events reported to FINAS up to November 2019. The discussion in this publication also covers information on operating experience feedback from other nuclear installations that are relevant to nuclear fuel cycle facilities as well as a description of the elements of an operating experience programme as established by the IAEA safety standards.

This publication will be of use to operating organizations, regulatory bodies, technical support organizations and designers of nuclear fuel cycle facilities, and any other organizations or individuals involved in the safety of these facilities.

The IAEA wishes to thank the contributors to this publication for their efforts and valuable assistance. The IAEA officers responsible for this publication were A.M. Shokr, J. Rovny and T. Michaelson of the Division of Nuclear Installation Safety.

CONTENTS

1 INTRODUCTION

1.1 BACKGROUND

The Fuel Incident Notification and Analysis System (FINAS) is jointly operated by the International Atomic Energy Agency (IAEA) and the Nuclear Energy Agency of the Organization for Economic Co-operation and Development (OECD/NEA). The system is an important tool for international exchange of operating experience for nuclear fuel cycle facilities. FINAS reports contain information about events of safety significance that occurred at nuclear fuel cycle facilities and describes the root causes and lessons learned from the events. FINAS was originated in 1992 as a paper-based system and was developed into a web-based system in 2008. Event reports are discussed in the regular meetings of the FINAS national coordinators and are included in the system database. Secured access to the database is provided to Member States participating in the system.

IAEA Safety Standards Series No. SSR-4, Safety of Nuclear Fuel Cycle Facilities [1], recognizes the importance to safety of establishing operating experience feedback programmes, which are not limited to reporting events, but also have to consider all factors that could affect or aid in enhancing safety. Recommendations for establishing, implementing, assessing and continuously improving an operating experience programme for nuclear installations are provided in IAEA Safety Standards Series No. SSG-50, Operating Experience Feedback for Nuclear Installations [2].

The event reporting has to be connected with operating experience feedback programmes to ensure that the lessons learned from previous events are widely applied with the aim of continuously improving safety.

During their biennial meetings, FINAS national coordinators have recommended collecting and disseminating, via an IAEA publication, the operating experience from the events reported to FINAS.

The terms used in this publication are to be understood as defined and explained in the IAEA Safety Glossary [3]. In accordance with Ref. [3], the term ‘incident’ is defined as any unintended event, including operating errors, equipment failures, initiating events, accident precursors, near misses or other mishaps, or unauthorized acts, malicious or non-malicious, the consequences or potential consequences of which are not negligible from the point of view of protection and safety.

1.2 OBJECTIVE

The objective of this publication is to summarize operating experience feedback from the events reported to FINAS, including root cause(s), lessons learned, and corrective actions taken to prevent the occurrence of similar events in other nuclear fuel cycle facilities.

The publication is intended for use by operating organizations of nuclear fuel cycle facilities, regulatory bodies, technical support organizations, vendor companies (such as designers, engineering contractors and manufacturers) and research establishments.

1.3 SCOPE

This publication contains an analysis of the events reported to FINAS until November 2019 with a focus on their root causes, safety significance and lessons learned. It covers all types of nuclear fuel cycle facilities as defined in para. 1.3 of SSR-4 [1], during various stages of their lifetime from construction to decommissioning, and for which a relevant experience feedback was reported to FINAS.

The publication also provides the key lessons learned from the recent events in nuclear power plants that are relevant to nuclear fuel cycle facilities. Reference to other publications that cover events that have occurred in nuclear fuel cycle facilities is also included. An outline of a proposed operating experience programme is provided, which could be used to develop an operating experience programme for nuclear fuel cycle facilities as recommended by SSG-50 [2].

1.4 STRUCTURE

Section 2 of this publication describes FINAS with its key features. Section 3 provides an overview of the events reported to FINAS. Section 4 discusses the experiences with events reported to FINAS, including their root causes, safety significance, lessons learned, and corrective actions established to address the causes of these events. The conclusions drawn from the analysis of events reported to FINAS are summarized in Section 5. The annex provides a description of the main elements of an operating experience programme in accordance with the IAEA safety standards.

2 THE INCIDENT REPORTING SYSTEM FOR NUCLEAR FUEL CYCLE FACILITIES

2.1 WHAT IS FINAS?

FINAS is a global contact network and forum that enables the nuclear fuel cycle facilities community to share and review information on lessons learned from reported events on a worldwide basis. The main objective of FINAS is to assure proper feedback on events of safety significance.

Some of the events reported to FINAS are also rated in the International Nuclear and Radiological Event Scale (INES; see Section 2.4.3 for further details).

In accordance with the FINAS guidelines [4], the types of facilities included in FINAS are defined as any type of installation dealing with the nuclear fuel cycle other than nuclear power plants and research reactors or radioactive waste disposal facilities. These include facilities engaged in activities such as uranium and thorium mining and milling, refining, conversion, enrichment, fabrication of nuclear fuel, radioisotope production, fuel handling and spent fuel storage, reprocessing of spent fuel, predisposal waste management, decommissioning, nuclear fuel cycle research and development. Fuel transportation from or to nuclear fuel cycle facilities is not considered part of the reporting system, although individual States may make their own determination to report on specific cases.

Recommendations on the safety of nuclear fuel cycle facilities is provided in the following IAEA Safety Standards Series publications:

- No. SSG-5, Safety of Conversion Facilities and Uranium Enrichment Facilities [5];
- No. SSG-6, Safety of Uranium Fuel Fabrication Facilities [6];
- No. SSG-7, Safety of Uranium and Plutonium Mixed Oxide Fuel Fabrication Facilities [7];
- No. SSG-42, Safety of Nuclear Fuel Reprocessing Facilities [8];
- No. SSG-43, Safety of Nuclear Fuel Cycle Research and Development Facilities [9], and
- No. SSG-15, Storage of Spent Nuclear Fuel [10].

Recommendations on measures for criticality safety in these facilities is provided in IAEA Standards Series No. SSG-27, Criticality Safety in the Handling of Fissile Material [11].

2.2 BENEFITS OF FINAS

As a platform for sharing operating experience of nuclear fuel cycle facilities worldwide, the overall benefit of FINAS is the improvement of safety of nuclear fuel cycle facilities. This is achieved when operating experience is exchanged among the facilities in participating States to help prevent occurrence or reoccurrence of serious incidents or accidents. The operating experience can be included as input to corrective action programmes enabling an efficient implementation of adequate safety and security enhancing actions.

Given that individual States generally experience a small number of events at their facilities, the centralization of data from several States can yield enough input for operating organizations and others to analyse potential scenarios, justify and make risk informed decisions. FINAS can be used to gain insight into various issues with safety significance and to assist in the prioritization of areas where further resources or research may be directed.

The operating experience in FINAS can also give indications on which procedures, work processes and quality methods are important to safety, thus supporting the application of a graded approach for fulfilling the relevant safety requirements to these facilities.

The continuous process for exchanging operating experience in FINAS and the related root cause and causal factor analyses are key parts of an effective operating experience programme for nuclear fuel cycle facilities. The cumulative knowledge available for review and analysis can also provide input to improvement of, for example:

- Safety assessment and safety review processes;
- Design of new nuclear fuel cycle facilities or modifications to existing facilities;

– Operational safety programmes, including criticality safety, conduct of operations, maintenance, and radiation protection;
– Ageing and obsolescence management, configuration management and facility life-time extension;
– Safety culture programmes;
– Training and qualification programmes;
– Identification and implementation of measures to mitigate the consequences of events.

The lessons from FINAS are taken into consideration when developing and revising the IAEA safety standards related to the safety of nuclear fuel cycle facilities.

2.3 HOW DOES FINAS WORK?

2.3.1 Event reports

According to paragraph A-36 of SSG-50 [2], “Membership of FINAS is open to States with at least one of the following:
(a) One or more nuclear fuel cycle facilities in operation;
(b) A nuclear fuel cycle facility that is not in operation but has not been decommissioned;
(c) A project to build a nuclear fuel cycle facility.”

Each participating State designates a national coordinator who is responsible for event reporting to FINAS. Reporting an event to FINAS is voluntary. Guidelines are available to the users of FINAS [4]. Events that meet one or more of the following criteria could be considered as appropriate for reporting to FINAS:

– The event itself is serious or important in terms of safety due to an actual or potential significant reduction in the facility’s defence in depth;
– The event reveals important lessons that could be used to prevent its reoccurrence as a more significant event under aggravated conditions or to avoid the occurrence of a serious or important event in terms of safety;
– The event is a repetition of a similar event previously reported to FINAS, which highlights a continuing need for further improvement.

Reports to FINAS can be submitted as preliminary, which can contain the details known at the time of reporting. This is followed up by a main report. There are two different types of main reports: (1) a standard report, associated with a single event, and (2) a generic report, associated with a set of events.

The report contains the title and the date of the event, an abstract, a narrative description of the event, a preliminary safety assessment (what were the direct causes, consequences and implications), a root cause analysis, corrective actions, and lessons learned. The written report is often supported by other illustrating documents (e.g. drawings and sketches). The national coordinator also identifies the categorization codes for the important aspects of the event [4].

2.3.2 Sharing information

FINAS is part of the web-based incident reporting common platform of the IAEA NUCLEUS portal, as illustrated in Fig. 1. The FINAS guidelines [4] include detailed information on the use of the system. Once a new report is posted in FINAS, the registered users are informed by email and can view the reports.

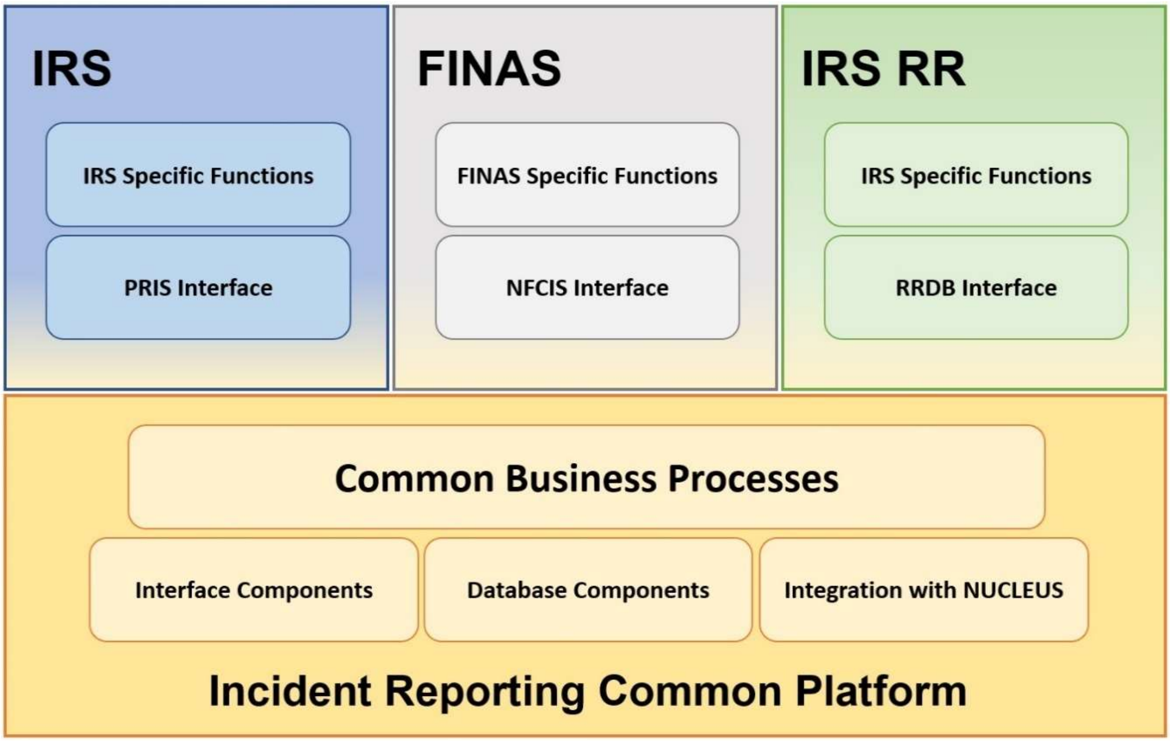

Figure 1. IAEA's incident reporting systems for nuclear installations.

Parties involved in operation and management of FINAS are:

– The participating States;
– The Joint IAEA/NEA Technical Committee of the FINAS national coordinators;
– IAEA and NEA expert working groups on operating experience;
– The Joint IAEA/NEA FINAS Secretariat and the Joint IAEA/NEA FINAS Advisory Committee.

2.4 HOW IS FINAS USED?

2.4.1 Meeting of national coordinators

Biennial meetings of national coordinators are held with the purpose of exchanging information on reported events. The participants also discuss ways to improve the functioning of FINAS. These meetings serve to strengthen the mechanisms for the exchange of experience in the assessment of events and in improvements made to reduce the frequency of similar events.

2.4.2 Restricted access

Access to the reports in FINAS is restricted and is limited to the national coordinators and authorized persons of the participating Member States, the IAEA and the OECD/NEA via the IAEA NUCLEUS portal. The restriction encourages the participating Member States to disclose the event details, while ensuring the confidentiality of facility specific information.

2.4.3 Connection between FINAS and INES

The IAEA and the OECD/NEA also jointly maintain the INES. INES was introduced in 1990 and its primary purpose is to facilitate communication and understanding between the technical community, the media and the public on the safety significance and the associated radiation risk of nuclear and radiological events. States may use INES on a voluntary basis to rate events that have occurred within their territory and that could have resulted, or did result, in a release of radioactive material into the environment and in the radiation exposure of personnel and the public. INES is not a notification or reporting system. The INES User's Manual [12] provides further guidance on the proper use of INES in public communication. It is expected that the events related to nuclear fuel cycle facilities and communicated through INES are also reported to FINAS.

2.5 WHAT HAS BEEN ACHIEVED?

As of June 2020, 36 Member States are participating in FINAS; they are listed in Table 1. A total of 289 events have been reported to the system. The oldest report is from an event that occurred in December 1992. The database is updated on a regular basis.

TABLE 1. MEMBER STATES PARTICIPATING IN FINAS AS OF JUNE 2020

Argentina	Czech Republic	Japan	Romania	Ukraine
Armenia	Egypt	Kazakhstan	Russian Federation	United Kingdom
Australia	Finland	Lithuania	Slovakia	USA
Belgium	France	Mexico	Slovenia	Uzbekistan
Brazil	Germany	Netherlands	South Africa	
Bulgaria	Hungary	Norway	Spain	
Canada	India	Pakistan	Sweden	
China	Indonesia	Peru	Turkey	

Over the years, FINAS has developed from a database of information to a platform for the exchange of operating experience, discussion and analysis on the events. This has been achieved through regular

FINAS meetings, and other meetings and informal contacts [4]. The analysis of the events is not only used to determine generic and common causes, but it provides also important feedback and reference to the planning and execution of other IAEA activities relating to the safety of nuclear fuel cycle facilities.

3 OVERVIEW OF THE EVENTS REPORTED TO FINAS

The events reported to FINAS are characterized using a set of keywords (codes) defined in Appendix C of the FINAS guidelines [4] for the purpose of facilitating event retrieval. There are nine groups of keywords, as follows:

1. Reporting categories;
2. Facility status prior to the event;
3. Failed/affected systems;
4. Failed/affected components;
5. Cause of the event;
6. Effects on operation;
7. Characteristics of the incident;
8. Nature of failure or error;
9. Nature of recovery actions.

Within each of these groups, more detailed keywords are found that designate typical structures, systems and components (SSCs), root causes, consequences, and the like. The usage of keywords simplifies searching and retrieving information on events. The national coordinators apply the applicable keywords when entering an event report on the web-system. Keywords from multiple groups can be selected as can more than one keyword from within each group. This makes it possible to categorize an event based on several root causes, causal factors and other attributes. The events reported to FINAS up until November 2019 are analysed with the help of these keywords and an overview of the analysis is presented below.

A representative subset of these events is discussed in Section 4. Some of the events are mentioned in more than one section, depending on the direct cause and other characteristics of the event.

a) The reporting category of an event identifies the category into which an event falls in accordance with the FINAS guidelines. It is also to be noted that an event may fall into more than one reporting category, and hence some overlap in the distributions is unavoidable.

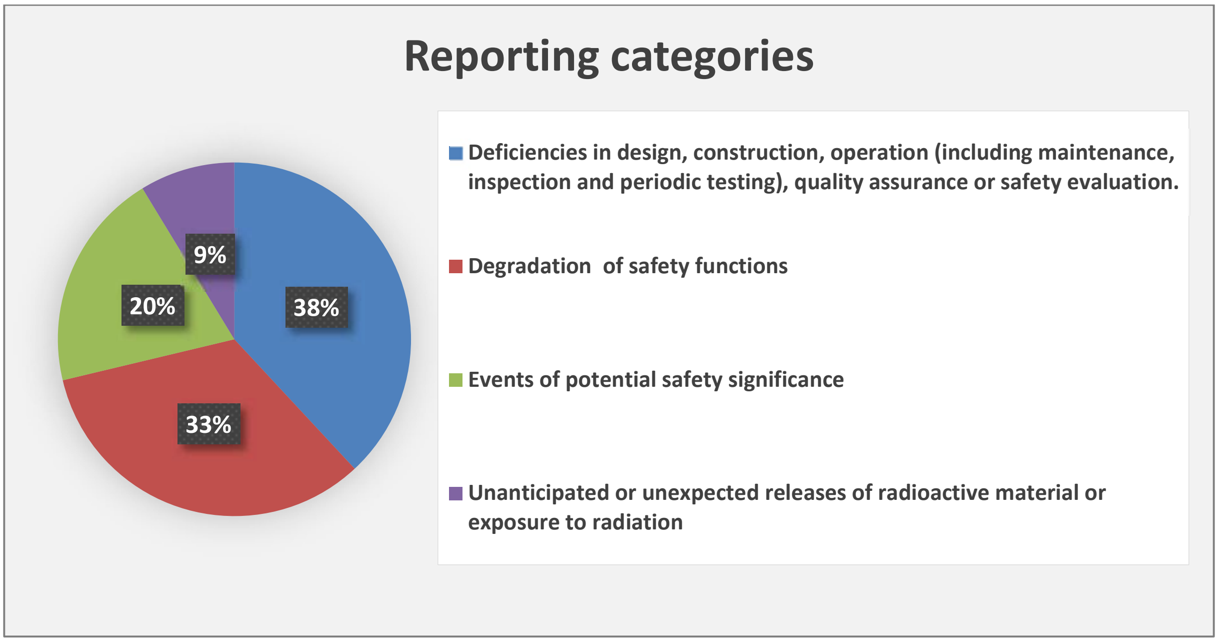

Figure 2. Distribution of the analysed events by reporting categories.

Among the events analysed, the largest number (38%) were reported in the reporting category 'deficiencies in design, construction, operation (including maintenance, inspection and periodic testing), quality assurance or safety evaluation', followed by 'degradation of safety functions' (33%). 20% of the events were reported in the category 'events of potential safety significance', and 9% of the events were reported in the category 'unanticipated releases of radioactive material or exposure to radiation'. Figure 2 shows the distribution of events based on reporting categories.

b) The analysis of the event reports according to characteristics of the events showed that the largest number of events (46%) were characterized by 'radiological and chemical hazards'. The radiological hazards included releases of radioactive material, degraded shielding, radiation exposure and degradation of monitoring of radioactivity. The chemical hazards involved releases of hazardous chemical material, degradation of reactivity control and degradation of monitoring of process chemistry. A total of 20% of events were characterized by 'degradation or loss of confinement', followed by 'reduction of defence in depth' (19%). Included in the latter category were events that involved loss or significant degradation of safety functions, loss of on-site or off-site power, exceeded operational limits and conditions or violation of safety procedures, false alarms and/or haphazard evacuation and risk of significant physical injury. The analysis of events resulted in a (9%) distribution of 'criticality events or accidents', and a (6%) distribution of 'discovery of major condition not previously considered or analysed'. The events in the last category revealed significant failure modes and conditions that were not conceived of in the safety analyses. The safety aspects of these events varied in nature and involved conduct of operation or safety programmes (e.g. maintenance and ageing management), and bore consequences that were of potential safety significance (e.g. fires and explosions, interruption or cut-off of electrical power supply). Figure 3 shows the distribution based on characteristics of the events.

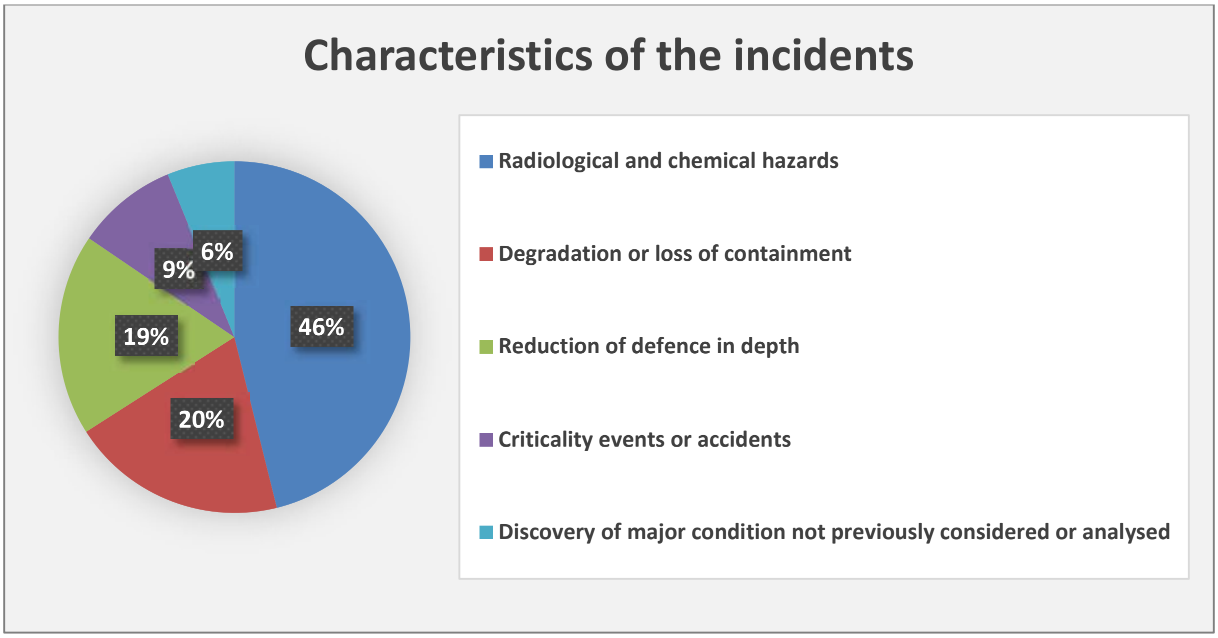

Figure 3. Distribution of the analysed events by their safety aspects.

c) The analysis of the nature of failure showed that the distributions of 'multiple failures' and 'single failures' were equal (representing 39% each). However, since most of the 'repetitive failures' (9%) were also 'multiple failures', the actual distribution of 'multiple failures' can be considered to be larger than that of the 'single failure'. 'Significant or unforeseen interaction of events' contributed to (8%) of the distribution. The failures in these events were associated with abnormal process conditions, and failures of safety systems due to ageing, which resulted in unsafe situations such as fires, or releases of nuclear material and/or hazardous chemicals. Events reported for 'common cause failures' (5%) were the least frequent. This category of events includes failure of wiring in lifting equipment, fire, and loss of ability of components to perform their intended function due to ageing, as well as inadequate consideration of human factors that initiated common cause failures. Figure 4 shows the distribution of nature of failure.

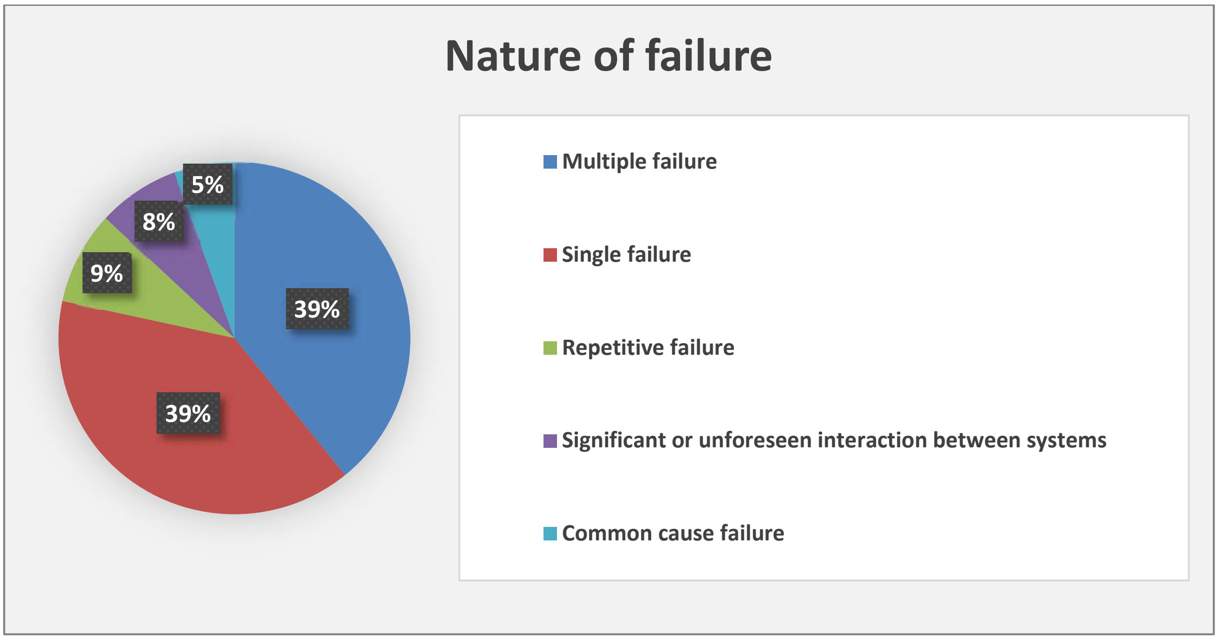

Figure 4. Distribution of the analysed events by nature of failure.

d) The analysis of events showed that the 'primary process systems' (e.g. systems for handling and transport, feed and delivery, dissolving, liquid or gas extraction, calciner/fluidized furnace, separators), were the most failed or affected systems (24%) along with 'containment and shielding' (e.g. structures, building confinements or containments, pool liners, static and dynamic confinement or containment, ponds and pools, dry chambers). The analysis also showed that 'fire protection, instrumentation and control, electrical power supply and other systems' (e.g. furnace, pelletisation press, pipe bridge, filters) and 'radiological and chemical control systems' (e.g. reagents feed, encapsulation and vitrification equipment, incineration, compaction, radiological and chemical monitoring) were equally affected (20% each). 'Criticality control systems' (e.g. detector, neutron absorber, or other physical systems) were failed or affected in 12% of the analysed events. Figure 5 shows the distribution of failed or affected systems.

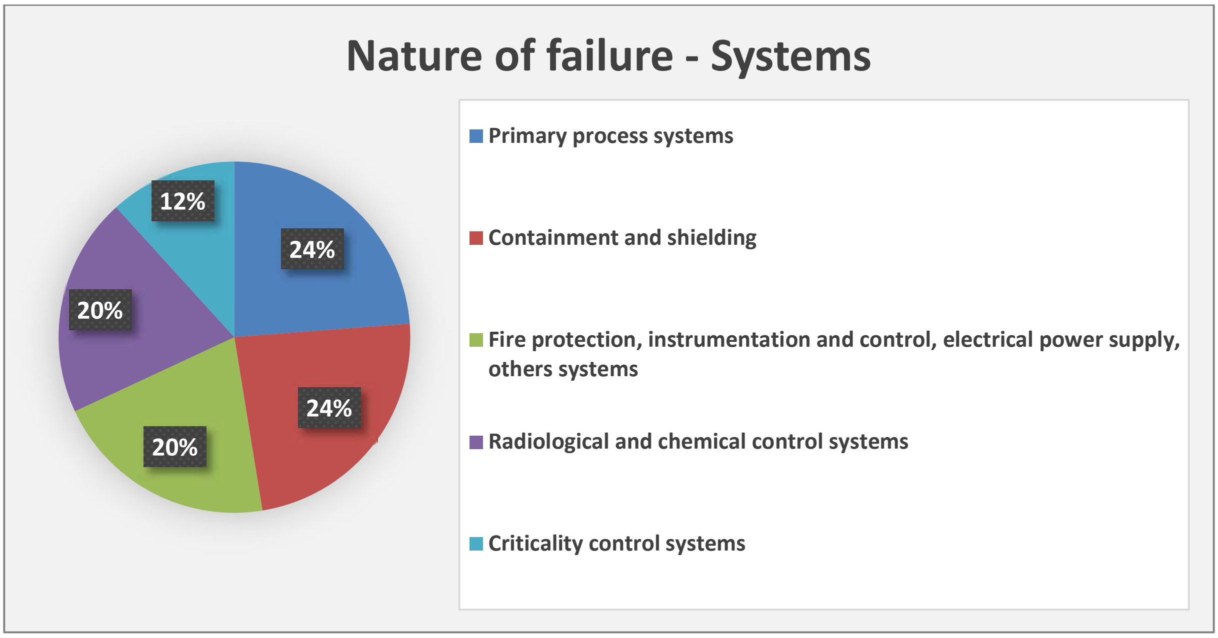

Figure 5. Distribution of the analysed events by failed or affected systems.

The analysis of failed or affected components showed that the distribution was 64% for ‘mechanical’, 24% for ‘instrumentation, control and computer based components’, and 12% for ‘electrical’ components. Figure 6 shows the distribution of failed or affected components.

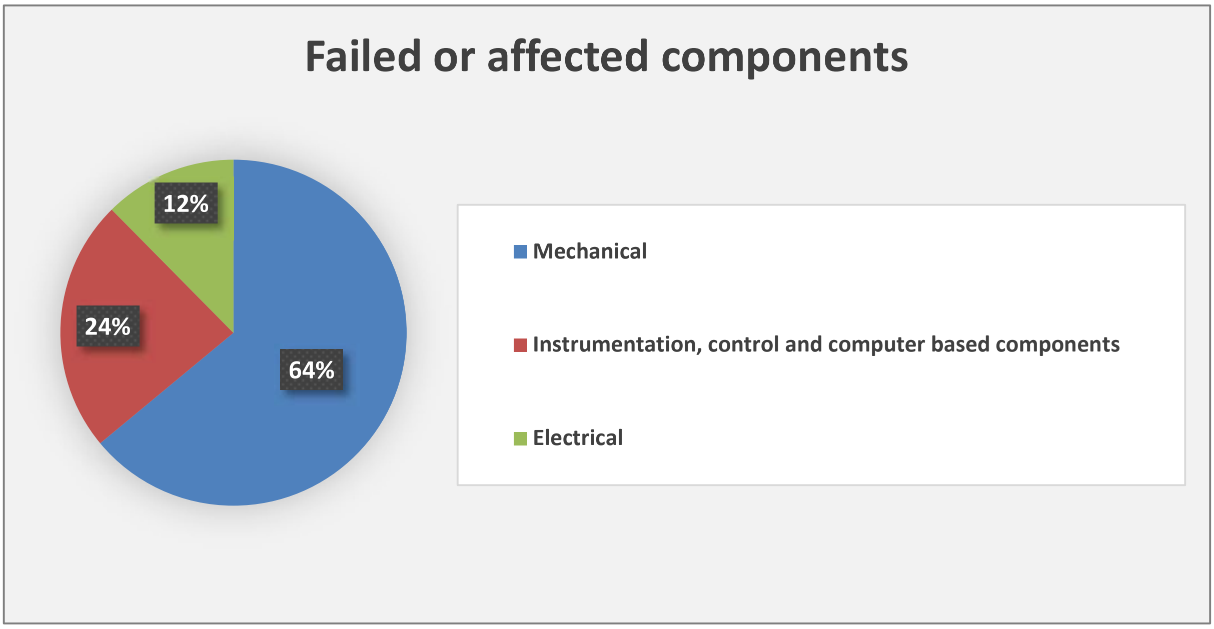

Figure 6. Distribution of the analysed events by failed or affected components.

e) The analysis of the causes of the events showed that ‘human factors’ (38%) is the biggest contributor to causes of events, followed by ‘design, modification and quality assurance’ (25%) and ‘maintenance, inspection, periodic testing, ageing and obsolescence’ (23%). In several events, deficiencies in the control of modifications of safety significance were a contributing causal factor associated with either design or quality assurance, and therefore deficiencies in the control of modifications were attributed to these categories. 'Management of safety' was identified as the main cause of 14% of the events considered in this analysis. It is important to note that events under the category 'management of safety' include events caused by deficiencies in safety culture, and that a majority of these events occurred several decades ago. There has been no discernible trend in the number of safety culture related events reported during the time period of this overview, but the number of such reported events yearly has remained low for the last decade. Figure 7 shows the distribution of causes of the events.

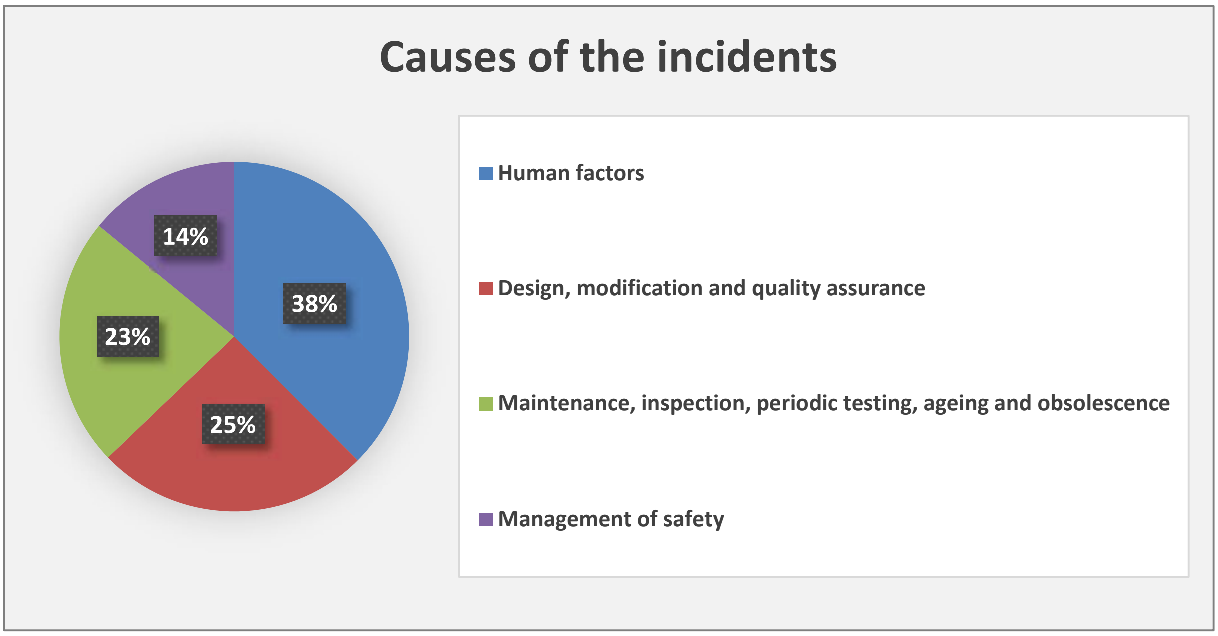

Figure 7. Distribution of the analysed events by cause.

4 EXPERIENCES WITH FINAS

The events reported to FINAS have been grouped into topical subjects based on the issues presented in the reports. In most cases, the event grouping was self-evident from the title of the incident report, while in other cases it was deduced from the information available in the reports. Many events have multiple root causes and causal factors associated with them and some events can traverse several stages of the lifetime of nuclear fuel cycle facilities, e.g. when errors propagate from construction to commissioning. For these reasons, some of the events are discussed in multiple parts of this section.

The reports provided to FINAS are based on investigations by States employing tools and techniques such as cause and effect analysis, task analysis, change analysis and barrier analysis. Further information on event investigation methods is provided in Ref. [13]. Information on safety reassessment methods for nuclear fuel cycle facilities can be found in Safety Reports Series No. 90 [14].

In the following sections, some near misses are also presented alongside actual incidents and events. Near misses can provide examples of events that were avoided by the caution and questioning attitudes of personnel, strict adherence to the operating procedures, and through other safety measures. These and other experiences presented in this publication can provide valuable operating experience feedback that an operating organization can utilize to improve safety at nuclear fuel cycle facilities.

4.1 EXPERIENCE WITH DESIGN

4.1.1 Summary of the root causes

A significant number of the events reported to FINAS were caused by deficiencies in design. These deficiencies were closely linked to shortfalls in quality control aspects of design, improper selection of material, inadequate seismic qualification of equipment, erroneous evaluation of design safety margins, and erroneous identification of technical specifications of the electrical power supply and instrumentation and control systems.

In one event, a stainless steel dissolver containing uranyl nitrate ($UO_2(NO_3)_2 \cdot 6\ H_2O$), plutonium and fission products leaked due to corroded welds on the upper part of the dissolver. Additionally, the containment leak detection system installed inside a leakage tank was not sufficiently sensitive to detect leaks of low rate, partly due to evaporation of droplets. The operator's corrective actions included the re-evaluation of the safety of the design of each relevant process, including the selection of corrosion resistant materials.

In another event a crane was designed to maintain the lifted load and structural stability during a seismic design basis event. According to the safety analysis of the facility, the stresses applied on the crane would always be less than, or equal to, the allowable stresses, with account taken for the design basis seismic loading condition. However, reworked calculations showed that the stresses applied were greater than allowable. According to investigations, the crane trolley seismic restraints had failed to prevent the overload. Upon inspecting the restraints (to reassess the design safety margin), the operator of the facility discovered that they had never been installed.

In one event the ventilation system unexpectedly shut down during scheduled maintenance due to inadequate design of the power supply. An electrical fault caused by new electrical protection settings applied to one modified fan impacted the start-up sequences of all the other fans to the point of cessation. Then a sequence of automatic actuation caused several fans, which are connected to the same power supply, to start simultaneously. This resulted in high demand for electrical current, which in turn tripped thermal overload protection switches causing an unexpected partial shutdown of the facility's ventilation systems.

Some other events were also caused by ventilation system failures. In these events, failure of electrical power supply and instrumentation and control systems were the main direct causes. Other events occurred due to failures in the auxiliary parts of the ventilation systems, such as monitoring and remote alarm equipment. Some of these events involved the release of airborne radioisotope gases (e.g. ruthenium), as the design of the ventilation and scrubber systems included only filters for solid particulates.

In another event that occurred during the annual cleaning of a wet scrubber system at a fuel fabrication facility, an excessive amount of low enriched uranium was discovered in inlet ducting. Over the years, several modifications had been made to the original design and to systems that input to the scrubber, and configuration control was not maintained. Invalid assumptions were made about possible accumulation of fissile material, including an incorrect assumption about the safety margin against criticality. This event could have been prevented if a thorough review of the safety case had been performed.

Several other reports recounted events with unintended accumulation of fissile material as well as events with failures of criticality accident alarm systems. In one of these events, the operator discovered that the criticality accident alarm system might not function as intended under design basis accident conditions, because the alarm system (used Geiger-Mueller detectors) would become electronically saturated in a high radiation field.

4.1.2 Safety significance

The events in this category resulted in degradation or loss of confinement or containment, reduction of defence in depth, potential criticality, radiological and chemical hazards exposure to personnel and the environment. In one event, improper selection of containment material and deficient technical specifications for instrumentation provided during the design phase led to potential radiological releases due to leakage of a liquid containing fissile products.

Inadequate seismic qualification of items important to safety made one facility vulnerable to radioactive releases and personnel injuries due to impacts from potential dropped heavy loads and falling equipment.

The events associated with the loss of availability of ventilation systems resulted in reduction of defence in depth, but no radiological doses to personnel. However, depending on the operational status and the amounts of inventories processed at the time of the events, the outcome of those events could potentially have had detrimental consequences to the personnel and the environment due to the loss of the dynamic confinement function against airborne radioactive materials.

In several other events, improper design led to significantly reduced margins to criticality accidents due to accumulation of fissile material, or significantly reduced possibilities to mitigate the consequences of a potential criticality accident due to shortcomings in the specification of criticality alarm systems. In other cases, the criticality margins were reduced due to lack of independent review of the safety analysis.

4.1.3 Lessons learned

The analysis of the events reported to FINAS indicated the following lessons to be learned:

- The design and modification of SSCs has to be subjected to a rigorous quality control covering review, verification, validation and approval of the design. Such a process has to take into account the environmental service conditions and the relevant ageing mechanisms for these SSCs, including presence of corrosive media and high radiation fields;
- Provisions, including administrative and engineering measures, for timely identification and removal of accumulated fissile material have to be incorporated in the design and the proper function of these provisions have to be periodically checked during the lifetime of the facility;
- Use of verified and validated tools for safety analysis as well as performing independent reviews of the safety case are vital for ensuring safety. The lessons learned from these events also confirmed the importance of periodic safety reviews of the facility, including review of the validity of the assumptions that have been originally considered in the design and safety analysis of the facility;
- Attention needs to be given in design to potential interaction of SSCs important to safety with those that are not important to safety (e.g. auxiliary systems). Similarly, interaction with electrical power supply and instrumentation and control systems also need to be considered;
- Considerable attention has to be given to the design of processes and SSCs, including ducts, to avoid accumulation of material. The technical specifications of the instrumentation associated with these processes and SSCs have to be adequately established to ensure the capability of the facility to timely detect small accumulated quantities (and leaks) before the predetermined safety margins are jeopardized;
- A number of events indicated that some designs may have unknown deficiencies for a long period of time before they surface and cause an event. This shows the importance of conducting an effective verification during commissioning to identify these hidden deficiencies. It also shows the importance of a periodic evaluation of the assumptions in the safety analyses to account for operating experience gained from events observed since the last review of the safety analyses. It is important to consider events that occurred at the facility as well as those events that have occurred at other facilities. An effective way to systematically evaluate experience is to consider each event report as an input to the corrective action programme of the facility;
- With respect to the previous point, attention has to be given to the specifications of the criticality alarm system (e.g. sensitivity, measurement range, and minimum detection level), and to the environmental service conditions of the detectors thereof (e.g. radiation fields).

4.2 EXPERIENCE WITH QUALITY ASSURANCE

4.2.1 Summary of the root causes

Inadequate quality control, including during manufacturing, construction, and testing of components before installation, was a major contributor to several events at nuclear fuel cycle facilities. Some of these events are discussed below.

Several event reports described issues with the quality of concrete in the construction process of new nuclear fuel cycle facilities. In one of these events, a regulatory inspection noted that the chemical composition of the concrete (in a concrete batch production facility operated by a contractor) did not correspond with the design technical specification. Excessive amounts of plasticizer and water had been added to the concrete without previous analysis or procedural guidance, and this action was not documented. In response to this event, the operator conducted a thorough quality control of batching operations, and verified the adequacy of the operating and testing procedures of the concrete batch production facility. In another event report, from the same site, a concrete reinforcement steel bar failed during construction. A post-event quality audit of the steel supplier identified inadequate:

- Quality audits of contractors and suppliers;
- Surveillance programme of the fabrication of rebar;
- Verification of adequacy of design of SSCs, including those that are commercially available;
- Implementation of timely corrective actions for non-conformances adverse to quality of SSCs, including use of specified engineering codes and standards.

Another report recounts two instances of uranium hexafluoride (UF_6) releases observed during pigtail operations on a full cylinder. These releases were visible as small wisps of smoke after pressuring the pigtail above the atmospheric pressure. In both instances, cracks in valve packing nuts were observed. A metallurgical examination showed that the two failed nuts exhibit intergranular cracking. Further investigation indicated manufacturing deficiencies, including in heat treatment of the nuts, and the following potential causal dependencies:

- Excessive stresses imposed by cycles of varying temperatures, aggravated by successive retightening of the nuts;
- Thermal expansion of polytetrafluoroethylene packing rings;
- The presence of UF_6, hydrofluoric acid, and cracking facilitated by nascent hydrogen.

Another event report described a test of electrical cables contained within protective stainless steel jackets, which were designed to withstand a fire event at a nuclear fuel cycle facility. The results of the test showed that if galvanized supports are in contact with the stainless steel jacket, the jacket and the cable could degrade during a fire. This would challenge the ability of the facility to achieve safe shutdown. Another fire test was performed using stainless steel supports so that no cable jackets were in contact with galvanized material. In this case, no cable jacket degradation was observed. These tests showed the need to revise the technical specifications of the material used for supports.

In another report, an investigation determined that the event occurred due to inadequate verification of the newly procured respirator cartridge filters after they were received from the supplier. Corrective actions associated with this event include strengthening the quality control process of purchased components that are important to safety, and establishing a training programme on quality control that addresses topics including the identification of counterfeit, fraudulent and substandard components (see also Section 4.10).

Several events reported to FINAS dealt with counterfeit, fraudulent or substandard fire protection equipment such as fire sprinklers, fire hose and dry chemical hand-held fire extinguishers. These events were all categorized as near misses, as the issues were detected before the equipment was needed to mitigate a fire.

4.2.2 Safety significance

Shortfalls in the quality control of concrete structures resulted in delays in the construction of the facility. If these issues had gone unnoticed, there would have been inadequate application of defence in depth concepts to the facility, which could have ultimately resulted in harmful effects to personnel, and the public.

Deficiencies in quality control during manufacturing process resulted in a loss of UF_6 confinement, which could have a significant impact on the performance of the facility's safety systems. Such an event could have severe consequences to the personnel and the public.

Insufficient fire protection provided to power cables revealed a significant reduction in the ability to safely shutdown the facility or to provide available safety functions in the event of a fire.

The safety of the facility was jeopardized by the lack of adequate verification of quality, and a lack of checks for counterfeit, fraudulent or substandard equipment for fire protection upon receiving the equipment from suppliers. In the event of a fire, the defence in depth of the facility could have been degraded through single and multiple failures and the main safety functions could have been challenged, which could have led to inadequate protection against spread of radioactive contamination.

4.2.3 Lessons learned

The analysis of the events reported to FINAS indicates the following lessons to be learned:

- Inadequate quality control during manufacturing and construction could lead to events with safety significance. Using approved quality control procedures during manufacturing and upon the receipt of components would contribute to effectively managing safety of the facility. The management system of the facility has also to cover manufacturing of components and construction phase of the facility;

- Audits of the management system of suppliers and contractors, and adequate control of contractor's work are essential to ensure safety. This element has to be a part of the management system of the facility;
- Rigorous procedures for the identification of non-conformances and their safety significance, and timely implementation of relevant corrective actions is vital for ensuring the effectiveness of management system and for improving safety. These items toned to be within the scope of quality audits;
- Personnel dealing with the procurement of SSCs important to safety have to be made aware of the effect of inadequate quality management on safety during initial training and reinforced by reoccurring follow-up trainings.

4.3 EXPERIENCE WITH HUMAN FACTORS

4.3.1 Summary of the root causes

A review of the events reported to FINAS showed that 38% of the events can be attributed to human factors. The analysis of these events showed that these events are mainly caused due to inadequacies of procedures, violation of procedures, personnel errors, or lack of adequate consideration of ergonomic factors in design and operation of the facilities. Many of these events also showed deficiencies in safety management of the facility, including declining safety culture. Section 4.4 discusses events that are attributed to deficiencies in management for safety. Attributes associated with human factors were also identified in several FINAS reports, where the primary causes of the events are different. These events are discussed in other sections of this publication.

In a nuclear fuel cycle facility, the operators continued to deviate from written operating procedures for several years before a criticality accident had occurred. Originally, there were no adequate written procedures. Later, procedures were developed by the manufacturing and quality management divisions and were not subjected to review by the safety division within the organization, which suggests that production was given priority over safety. Further discussion of this event is provided in Section 4.7.

In another event, deviations of safety significance were identified with operations involving shipping casks and liners that are used for processing irradiated equipment. The root cause of the event was inadequate procedures for draining and drying the casks and liners. The procedures did not include descriptions of any methods for quantifying the amount of water drainage from the cask or the liner. Additionally, the procedures failed to specify an accurate reference value for the pressure of a cask cavity, which is used to test and verify the dryness of the cask. According to the procedures, the test could be conducted at any pressure above a value of 10 mbar, while the safety analysis report specified that this test has to be conducted at that value (not above it). The test was conducted at 27 mbar, which allowed water to remain undetected in the cask.

Another event occurred at a plutonium fuel research facility due to inadequate procedures for recovery operations of a storage container holding legacy radioactive waste. The container was being opened inside a fume hood of an analysing room. The storage configuration consisted of a container housing a polyester can inside an inflated double-layered resin bag. After the storage container was completely opened, the double-layered resin bag was ruptured releasing nuclear material consisting of mixed oxide fuel (MOX) and uranium dioxide fuel (UO_2) powders. The direct cause of the resin bag rupture was inadvertent gas generation due to the interaction between alpha radiation from plutonium and epoxy resin in the container over the course of 21 years. The resin had not ruptured earlier because of the support that was provided by the wall of the storage container and its lid. The root causes of the event were identified as:

– Failure in dissemination, across the organizational units, of the procedures for handling nuclear fuel material, although procedures were available. Failure in incorporating operating experience feedback from previous events in the facility, as similar events had occurred earlier;
– Inadequate understanding of the hazards associated with handling unsealed plutonium.

Another event was caused by improper training and qualification of the facility personnel. At the end of the yearly maintenance period, contractors were preparing the restart of a workshop where vitrification of liquid high-level radioactive waste is carried out. During the preparatory steps, one of the operating personnel erroneously pushed a button in a console ordering the transfer of 800 liters of nitric acid instead of 80 liters. The acid overflowed across process equipment leaching off highly radioactive calciner, resulting in contamination of the adjacent surfaces.

Another event occurred at a MOX fuel fabrication facility designed to accommodate an array of interconnected gloveboxes outfitted with transfer mills and scales for handling and weighing fissile material. As one of the scales was un-operable, the operating personnel decided to use the scale of an adjacent glove box, applying a temporary procedure that had not undergone safety analysis and was later determined to be inadequate. An information technology interface was used to keep track of the actual masses of nuclear material inside the jar containers and the transfer mills. In order to perform the "delayed weighing", two manual data insertions (based on calculations) were made. The interface assumed a full material transfer from the mill to the jar, while in fact the material transfer was only partial. The fact overlooked by the operating personnel was that the milling process, together with the specific characteristics of the nuclear material, could generate agglomerates and lead to partial draining of the mill. The two data insertions were also poorly reported in a shift logbook and, therefore, the next shift had no reason to abstain from initiating a new batch for operation. This resulted in accumulation of the fissile material accumulation to a level that was above the established safety limit. Additionally, the movement of the jar was interrupted due to a mechanical fault in the conveyor. The causes of the event were identified to be lack of adequate procedures, deficiency in establishing temporary procedures, insufficient documentation and traceability of operators' actions, and human error.

In another event, the facility's supervisor found that four drums were located in non-appropriate positions in a storage area, violating the geometrical configuration required for criticality safety. The operating personnel moved the drums in order to make more space in the working area. The causes of this event were identified as lack of configuration management, human error, and lack of adequate training of facility personnel.

In another event which occurred at a facility undergoing commissioning, work improperly conducted on a valve led to the release of 7 m^3 of concentrated nitric acid. The events occurred due to inadequate work permit procedures and inadequate training of the involved personnel. Another event occurred at a fuel fabrication facility due to human error and inadequate maintenance, causing the formation of hydrogen fluoride and the release of UF_6 (see also Section 4.5 for further discussion of this event).

Other event reports showed the potential radiological consequences that could arise from insufficient communication between personnel carrying out tasks of safety significance and involving radiation exposure. These events also showed a lack of clear definitions of roles and responsibilities in performing these tasks, and a lack of managerial supervision.

4.3.2 Safety significance

In many events in this category, the operating personnel lost focus on the work being conducted. The operating personnel were not fully aware of the safety significance of their actions and failed to understand the risks associated with the task being carried out.

In several events, operators used only gloves as protective equipment where remote handling equipment would have been more appropriate for dealing with radioactive material. The order of magnitude of the radiation doses received were several tens of mSv.

Some human errors led to a loss of confinement or containment and resulted in radiation exposure between 10 and 200 mSv to three personnel in an event where the resin bag of a storage container ruptured.

The most severe event in this publication was a criticality accident that led to the deaths of two personnel, increased radiological doses to other personnel and high radiation levels reaching beyond the boundaries of the facility. The emergency response involved evacuation of the public from the vicinity of the facility. There were also other events where criticality safety margins were degraded without any configuration reaching criticality.

The consequences of some of these events could have been more severe or even fatal in more unfavorable circumstances (e.g. if personnel would have been exposed to the hydrogen fluoride that resulted from the release of UF_6).

4.3.3 Lessons learned

Many of the events associated with human factors could have been avoided, or could have resulted in significantly much less radiological consequences, if adequate operating procedures describing the associated risk, work activities and step-by-step work instructions had existed, or if the operating personnel had followed the approved procedures.

The lessons learned from these events confirm the importance of identifying and minimizing the risk of human error and its impact on the facility and personnel through the performance of safety analysis and development of operating procedures.

Potential for human errors cannot fully be eliminated. Fostering a questioning attitude, adherence to the approved operating procedures and compliance with operational limits and conditions are of a fundamental importance. Modification of operating procedures of safety significance has to be supported by safety assessment.

The use of simple human performance or error prevention tools, such as questioning attitude, peer-checking, job briefings, situational awareness (and, where relevant, the use of advanced methodologies requiring verification and validation) can further prevent events at nuclear fuel cycle facilities or lower the adverse consequences of such events.

Conditions at workplace can also generate errors. Inadequate consideration of human factors and ergonomic principles in design (e.g. lack of adequate instrumentation or process mimics) and during operation of a facility (e.g. inadequate work permit procedures) can also lead to human errors. The analysis of the events identified the following error precursors: lack of knowledge, inaccurate risk perception, irreversible actions, and overconfidence. Most of these human errors could be avoided if the limitation of human capabilities are considered in the design and in establishing operating procedures. They could be also avoided if adequate training, including on safety culture, is provided to the operating personnel.

It is also essential to promote and develop a strong culture for safety that encourages operating personnel to exercise high standards of safety and recognize and correct conditions adverse to safety. Reinforcement of lessons learned from events at the nuclear fuel cycle facility, and operating experience from other nuclear fuel cycle facilities are essential for safety improvements (see also Section 4.4 for discussions on management for safety).

4.4 EXPERIENCE WITH MANAGEMENT FOR SAFETY

4.4.1 Summary of root causes

A review of FINAS reports showed that deficiencies in management for safety was the principal root cause of many events. These deficiencies were linked to inadequate management systems, lack of effective communications of management expectation for safety, inadequate supervision, and declining safety culture. In several of these events, these causes were also linked to shortfalls in human performance, including an improper questioning attitude and ineffective use of the approved procedures.

One of the most important examples of deficiency in management for safety, which caused a significant event, was the criticality accident in a conversion test building at the site of a fuel fabrication facility (see also Section 4.7 for further discussion of this event). In this event, the procedures for handling fissile material were developed and put into operation without adequate analysis by criticality safety specialists. The operating personnel were not adequately trained in implementation of the procedures before they were approved and they were not fully aware of the risk associated with the task covered by the procedures. In addition, there was inadequate management supervision during the implementation of the procedures. Inadequate emergency procedures were also identified during the event investigation. One of the corrective actions that was established in response to this event was the establishment of national regulations on verification of compliance of the operators of nuclear fuel cycle facilities with the regulatory requirements.

In another event, a leak of hydrogen fluoride occurred when the operator of a UF_6 conversion process was performing preventative maintenance on a pressure transmitter on top of a hydrogen fluoride transfer tank. The subsequent investigation revealed that the causes of this event were: inadequate work planning, deficiencies in work permit process, and lack of management direction and supervision during preparation and implementation of the activities of major safety significance.

In one event, drums containing solid low level radioactive waste were loaded with ^{235}U in amounts exceeding the value allowed by the pre-established limits on criticality safety for an interim radioactive waste encapsulation and storage facility. The investigation that was performed on the root causes of this event showed a lack of adequate management system processes and inadequate operating procedures. In addition, the investigation also showed inadequacy of the established administrative control for criticality safety within the facility.

In another event, the operating personnel of an enrichment facility discovered that several SSCs important to safety were not covered by the maintenance programme and had never been subjected to any maintenance activity since they were commissioned. The maintenance programme and activities were carried out by contractors. The root causes of this event were determined to be deficiency in management for safety, lack of management system processes on the control of contractor's work, and inadequate assessment of risk. Analysis of the event also showed declining safety culture and failure to communicate management expectations with respect to safety.

In one event, during the annual maintenance operation in fuel fabrication facility, an excessive amount of low enriched uranium was discovered in the inlet duct of the wet scrubber system, constituting an increased criticality risk. The causes of the event were identified to be deficient questioning attitude, inadequate management supervision, and inadequate control of configuration management.

Another event resulted in a significant outflow of uranium bearing effluent at a uranium recovery facility. The direct cause of the event was erroneous maintenance of a motorized valve. Inadequate design of that valve was identified as a contributing factor. The inadequacy of design was identified before the event, but no adequate action was taken. A loss of means of confinement occurred in this event due to multiple operational failures which led to the lack of protection against a single initiating event. The investigation of this event showed a number of deficiencies in management for safety, including the failure to take timely corrective action to address the identified safety related non-conformances, inadequate management supervision, and declining safety culture. Following this event, the operating organization established a programme for developing and maintaining a strong safety culture.

In one event, a criticality safety limit was breached at a MOX fabrication facility due to erroneous addition of extra fissile material into the process (more than the amount allowed by the operational limits and conditions), accompanied by inappropriate use of a temporary procedure. In this event, the operating personnel did not document what actions were performed and did not inform the following shift about any of the actions that they had taken. This event showed deficient management for safety, inadequate communication between operating personnel on issues important to safety, and declining safety culture.

Another event occurred at a uranium reprocessing facility, which led to the erroneous distribution of a high uranium content radioactive liquid into an effluent monitoring tank. In the routine established by the facility many years before the event, the reprocessing flow rate of the safety and production lines are measured and compared at the beginning of each start up. Based on the outcome of this measurement, a decision is made whether to continue the facility start-up. On the day of the event, the measurements showed that the flow rate of the production line was not meeting the established criteria (because the difference in flow rate between the safety and production lines was about 10 times greater than allowable). The operating personnel attempted to restart the facility several times, but the issue was not resolved. A decision was made to add substitute uranyl nitrate into the process line to resolve the issue. Instructions to attempt a restart was not included in the operating procedures, nor was the addition of uranyl nitrate. No assessment of the risk of these actions were performed. The direct cause of the reprocessing flow rates mismatch was later discovered to be due to erroneous installation of the orifice plates in the flow rate measurement instrumentation. This error had been present for ten years before the time of the event. During these ten years, the operating personnel and the management of the facility adopted a kind of “workaround” solution to the issues, without identifying the cause of the instrumentation malfunction and taking the necessary corrective actions.

4.4.2 Safety significance

The events described above resulted in a criticality accident, radiological overexposure to operating personnel, and release of radioactive material inside the facility and to the environment.

Deficiencies in management of safety, including lack of adequate management system processes, improper questioning attitude, and lack of effective communications resulted in significant consequences (e.g. a criticality accident, which led to the death of two personnel, high radiation dose exposure to other several operating personnel, and high radiation levels outside facility's site boundaries). For the criticality accident, urgent protective actions included the evacuation of the public in the vicinity of the facility.

4.4.3 Lessons learned

The analysis of the events reported to FINAS indicated the following lessons to be learned:

- Effective leadership and management for safety are crucial for developing and maintaining a strong culture for safety. This is of a particular importance in nuclear fuel cycle facilities owing to the potential risk that production culture will override a priority on safety in commercial facilities;
- Effective leadership and management for safety have to continue to be demonstrated at all levels of the organization, including clear communication of expectations with respect to safety. Otherwise, "workarounds" may become the norm and other objectives (e.g. productivity or desire to reduce costs) may take priority over safety;
- Some management system processes can become ineffective or even invalid if the facility conditions change. This may put the facility outside of the safe operation envelope that is defined by the safety case. Establishment of an integrated management system, including the performance of periodic reviews of the management processes important to safety is vital for developing and maintaining a strong culture for safety;
- Several events could have been prevented if senior managers had clearly demonstrated commitment to safety, and if supervisors had exercised adequate management oversight of activities important to safety. Some others could have also been prevented if adequate training, including on safety culture, had been conducted, or simple human performance tools had been used. The impacts of organizational factors and the interaction of human, technology, and organizational factors have been getting higher attention since some of these events were reported;
- Some events could have also been avoided if near misses had been adequately addressed, and if timely actions were taken to resolve the identified non-conformances of safety significance;
- Establishment of adequate procedures for communicating operational issues of safety significance (including recording actions in operation logs and giving verbal updates) in and between operation shifts is important for safety enhancement.

4.5 EXPERIENCE WITH MAINTENANCE, PERIODIC TESTING, AND INSPECTIONS

4.5.1 Summary of the root causes

A review of the events reported to FINAS showed that 23% of the events occurred due to deficiencies in mmaintenance, inspection and periodic testing, as well as the ageing of SSCs. Although some maintenance activities, and periodic testing and inspection can contribute to ageing management, they cannot fully address ageing issues. This section discusses events relevant to inadequate maintenance, periodic testing and inspection. Events that occurred due to the ageing of SSCs are discussed in Section 4.6.

In an event report, an unaccountable air leakage from holes in the ventilation system of several laboratories was identified during a walkdown of the facility. The investigation of this event showed inadequate maintenance and inspection of the ventilation ducts for several years. No radioactive material release was detected. In another event, during a walkdown of a radioactive waste treatment and conditioning facility, the automatic fire detection system was observed to be inadvertently switched off.

Improper planning of maintenance, including inadequate coverage of the facility's SSCs, inadequate maintenance schedule, and deficiencies in maintenance work management were also reported as primary causes of several events.

In an event at a fuel fabrication facility, a valve was incorrectly installed during a maintenance operation for a fissile material processing equipment, leading to inadvertent release of UO_2 powder during the post-maintenance testing.

Another report described an event where systems containing fissile material were not clearly specified in the maintenance procedures. The event occurred at a facility utilizing a uranium hexafluoride to UO_2 powder conversion process, where the UO_2 powder is collected and transferred into cooling hoppers purged with nitrogen gas to keep moist air out. The criticality hazard could have occurred if the steam of the conversion process would flow into the cooling hoppers during normal operation or maintenance. The first line of the double contingency control to prevent this hazard is a valve configuration that does not permit two valves to be open at the same time, to limit the flow rate of the steam. The second contingency control consists of moisture detectors in the cooling hopper nitrogen bleed line (with an alarm and an interlock) to shut out the steam and UF_6 supplies from the conversion process if moisture is detected. When maintenance was carried out, one of the two valves was incorrectly connected to its actuator. The post-maintenance testing showed that a direct path for steam entry to the hoppers could not be ruled out. The maintenance personnel acknowledged the triggered moisture alarm but failed to notice the interlock status. The process operators of the subsequent shift, however, observed that one of two hoppers contained approximately 36 kg of UO_2 powder while the safety limit for one hopper was 31 kg. The subsequent investigation showed that the moisture detector tripped the interlock because of the ambient air intrusion during troubleshooting, not because of steam intrusion.

In another event, a leak of hydrogen fluoride occurred when the operator of a UF_6 conversion process was performing preventative maintenance on a pressure transmitter located on the top of a hydrogen fluoride transfer tank. A nitrogen impulse line connected to the transfer tank was not fully isolated before disconnecting the transmitter. As a result, hydrogen fluoride was released into the work environment, putting the personnel present there in danger. The corrective actions associated with this event included the development of an improved maintenance process.

Another event occurred during the maintenance of an oxidation furnace in sintering area of a uranium fuel fabrication facility. The top cover of a vacuum cyclone was removed without checking that the motor was stopped. As a result, its confinement function was lost.

In another event, improper isolation of equipment prior to maintenance resulted in fissile solution spill. Investigations revealed that there were deficiencies in developing and maintaining management system processes, inadequate maintenance procedures, as well as inadequate procedures for criticality safety, radiation protection, fire safety, and chemical hazards control.

In another event, hydrogen fluoride was formed in a fuel fabrication facility as a result of an inadvertent UF_6 release caused mainly by inadequate maintenance and human errors. The maintenance was to be performed on equipment directly adjacent to a UF_6-to-UO_2 conversion system, without first making sure that a transfer pipe was emptied of remaining gaseous UF_6 when the heated conversion process was shutdown. Furthermore, a UF_6 cylinder valve was erroneously left open, which allowed residual UF_6 to solidify inside the pipe as it cooled down. When the pipe was reheated after the maintenance was complete, pressure increased due to expansion of UF_6. This resulted in the failure of a flange of the cylinder valve, allowing discharge of UF_6 and resulting in formation of gaseous hydrogen fluoride due to rapid hydrolysis of UF_6 by air moisture. Shortly after, a fire alarm in the workshop was triggered, followed by the triggering of more fire alarms and evacuation of the facility. A white hydrogen fluoride fog was noticed on the breathing air cylinders of the full body protective suits worn by operators who entered the facility after this event. The valve of the UF_6 cylinder was shut and the UF_6 leakage ceased. According to the investigations of the event, there was a failure in prior-maintenance checks concerning setting relevant equipment in fail-safe mode.

4.5.2 Safety significance

In many events in this category, the workers were not fully aware of the safety significance of their actions and failed to understand the risks associated with work to be carried out, including lack of awareness of presence of fissile material in the systems under maintenance.

The events caused degradation or loss of confinement or containment, potential criticality, spread of radioactive contamination or hazardous chemicals within the facility, and to the environment.

The event with the deficient ventilation system resulted in reduction in defence in depth and potential uncontrolled release of radioactive material to the environment.

In several events, the accumulation of fissile material and the degradation of measures of criticality prevention occurred due to inadequate maintenance. In more unfavourable circumstances, e.g. if personnel had been exposed to hydrogen fluoride resulting from release of UF_6, the consequences could have been severe health effects including fatality of personnel.

4.5.3 Lessons learned

The analysis of the events reported to FINAS indicated the following lessons to be learned:

- The scope and content of the preventive maintenance programme needs to be periodically reviewed and, as needed, revised, taking into account the facility's operation historical data as well as the operating experience from the facility and other similar facilities;
- Walkdowns of the facility, including during shutdown periods, in accordance with approved procedures can help identify non-conformances in operation and maintenance and significantly contribute to enhancing the safety of the facility and to protection of personnel from undue radiation and chemical hazards;
- Errors in maintenance or periodic testing can lead to events with major safety significance, including criticality or loss of the confinement function. Specialized (and continuing) training of maintenance personnel on the specific safety features, facility design, and the implication of maintenance work on safety is essential to reduce the likelihood of events;
- Inadvertent presence or accumulation of fissile material in equipment undergoing maintenance has been observed in numerous events. Measures need to be in place to protect personnel from radiation exposure and to prevent spread of radioactive material during maintenance operations. Measures have to be assessed and included in the relevant maintenance procedures;
- Lack of effective communication between maintenance and other facility personnel (e.g. operators or criticality safety staff), can lead to events of significant safety consequences;
- Checks and verification activities before and after maintenance are as important to safety as the maintenance itself. Quality checks of completed maintenance work have to be an integrated part of the maintenance procedures.

4.6 EXPERIENCE WITH AGEING OF STRUCTURES, SYSTEMS AND COMPONENTS

In 2017, specific guide words for ageing and obsolescence were introduced for the first time in FINAS. This means that the ageing contribution to the root causes of events in this publication may be understated. In addition, several events for which ageing was the main root cause were reported to the system (before 2017) under other event categories (for example under deficiencies in design, or in quality assurance). These events were described in this publication under the categories where they were originally reported.

4.6.1 Summary of the root causes

The causes of events under this category were mainly related to the lack of establishing an effective and proactive ageing management programme, including a lack of understanding ageing mechanisms, improper selection of material (during operation and maintenance), lack of establishing appropriate environmental service conditions for the SSCs, and inadequate actions for monitoring and assessing ageing degradation and obsolescence in the SSCs.

In one event, a mishandling operation led to a broken polymethyl methacrylate and lead pane, which was incorporated in the facility design to limit neutron exposure of personnel during inspections of new fuel rods). Investigations revealed that the failure was caused by fatigue of these components. The components were constructed of an organic material, and the mechanical strength degrades with time and use, including repetitive impacts and vibration.

In another event, seismically activated solenoid-operated isolation valves repeatedly failed during periodic testing. The operator's evaluation indicated that weakening of the core spring and the relatively low cycling and testing frequency of the solenoids contributed to the valve's failure. Further investigations also showed that, in some locations at the facility, the environmental service conditions (e.g. temperature, humidity, and fluid corrosiveness) contributed to the failure of the solenoids to perform their intended function. The corrective actions associated with these vents were to replace the valves with ones that are suitable for the environmental service conditions of the facility and to modify the maintenance programme of these valves.

In another event, a failure in a process valve allowed flow of radioactive liquid into a vessel ventilation system and a scrubber, thereby activating a gamma monitor alarm. An emergency situation was declared and the facility was shutdown. The investigation showed that the failed valve had reached the end of its service life. The same event had occurred over a period of several years with other similar valves in the facility. A process for operating experience feedback was established at the facility but was not effectively utilized. The maintenance programme of such valves was not revised to take such repetitive failures into account. The facility operator, after the last failure of this kind, performed an assessment of the service life of the remaining valves and revised their maintenance schedule.

In another event, during production of UO_2 powder, insulation for an electrical resistance component designed for heating a flexible metallic spiral tube was damaged due to service wear. A hole occurred at a hotspot caused by localized overheating of the spiral tube internals. This failure mechanism was aggravated by the fact that the pipe was subjected to thermal stresses in a location subjected to mechanical cyclic tension. As a result of this event, a significant amount of uranium was spilled.

Another event was caused by degradation of the welds of a discharge hopper in a conversion furnace. As a result, UO_2 powder leaked out.

In another event affecting a liquid radioactive waste system at a reprocessing facility, cracks developed in a valve's gasket. This caused a leak inside a shielded space that housed valves and joints. The already installed leakage-collection trays were not enough to contain all liquid, which proceeded to seep through a gap and on to the floor.

In some other events, ventilation ducts were corroded to the point of non-monitored discharge into the environment. In another event, a false alarm of the criticality detection system in a fuel fabrication facility was triggered. Obsolescence of the detection system was evaluated to be the cause of that event.

4.6.2 Safety significance

The events in this category caused degradation or loss of confinement or containment, spread of radioactive contamination and fissile material inside the facility, reduction in defence in depth and uncontrolled discharge of radioactive contamination to the environment.

4.6.3 Lessons learned

The analysis of the events reported to FINAS indicated the following lessons to be learned:

- Aging degradation of SSCs can result in release of radioactive material or hazardous chemicals to the environment;
- Establishment of an effective ageing management programme as early as possible in the lifetime of the nuclear fuel cycle facility significantly contributes to preventing events. This programme has to include, among others, measures to minimize degradation of SSCs due to time and use, monitoring and trending of ageing degradation, and implementation of refurbishment and modernization to mitigate ageing effects;
- The facility's programmes, such as maintenance, periodic testing, inspection, equipment qualification, the keeping of operating records, and periodic safety reviews can be used to establish and continuously improve ageing management. Maintaining the environmental service conditions for the SSCs within the specifications established by design, including during construction and operation of the facility, has significant impact on the minimization of ageing degradation;
- Even a new facility can face premature ageing effects (e.g. for electrical and instrumentation and control systems), and therefore, they have to be also considered in manufacturing, fabrication, storage, and construction activities of the facilities;
- Corrosion is one of the main ageing mechanisms in nuclear fuel cycle facilities. This has to be taken into account for maintenance planning, periodic testing and in-service inspections. Consideration in design (including in design of modifications) for ease of access to SSCs facilitates these activities and contributes to improving operational safety;
- Evaluation of operation performance (e.g. operability checks and performance tests) can be used to predict ageing degradation of SSCs. Additionally, the service lifetime of the SSCs has to be evaluated, ideally during design, and has to be considered in the maintenance programme.

Contingency plans, including assurance of the availability of adequate spare parts, have to be in place, particularly for SSCs important to safety. Degradation of the spare parts in storage has to be also considered.

4.7 EXPERIENCE WITH CRITICALITY EVENTS

4.7.1 Summary of the root causes

A review of the events reported to FINAS shows that 57 events were related to degradation of criticality safety margins or to criticality accidents. FINAS reports showed that the causes related to these events are mainly related to inadequate safety analysis, inadequate or ineffective use of procedures, or deficiencies in demonstrative controls, modifications, or the ageing management of SSCs. Discussion of these events is provided in this section.

One of the most significant criticality accidents occurred in a conversion test building at the site of a fuel fabrication facility in 1999. The analysis of this event was discussed in various publications, see Refs [15–18]. The direct cause of the criticality accident was the accumulation of fissile material in an unfavourable geometry. The root causes included deficiencies in operational and business management, safety regulations and licensing procedures. An example of a causal factor was that the operators were allowed to deviate from the approved procedures. Deviations from the procedure had begun several years before the operating organization developed a new operating procedure. The new procedures were approved by the manufacturing and quality management divisions of the operating organization, without review of the safety management division. This was apparently done to improve production efficiency. The accident resulted in exposure of three personnel to radiation doses in the range of 3 – 17 Sv. Two of them died, and many other persons (including personnel and local residents) were exposed to lower radiation doses. The local residents within a 350 m radius of the facility were evacuated, and it was recommended that the people within a 10 km radius of the site stay indoors.

Another report describes several events involving incomplete analysis of credible abnormal conditions and inadequate implementation of safety controls. In one event, the operating personnel of a fuel fabrication facility discovered, during a routine inspection, a small amount of moisture inside a feed container of unfavourable geometry designed to feed fissile material to a dry conversion system. One of the two components that were installed to prevent presence of moisture was found to be inoperable, while the availability of both is required.

Several reports showed inadvertent accumulation of fissile materials that had led to reduction of criticality safety margins. In most of these cases accumulation of fissile material was not considered by the safety analysis or was not subjected to monitoring during the operation phase of the facility. One of these events occurred at an ammonia recovery facility where fissile material had accumulated in a stripper column. The event was caused due to the lack of identification by the criticality safety assessment of accumulation of fissile material, in addition to inadequate operating procedures. The corrective actions that were taken by the operating organization included modification of the system, revision of the safety analyses, and revision of operating procedures.

A number of reports indicated a lack of communication between criticality safety personnel and other personnel. Several events occurred because maintenance personnel did not understand equipment boundaries defined in the criticality safety analysis or because criticality safety specialists had not reviewed maintenance procedures given that the presence of fissile material was not expected.

In one event, the operating organization had performed a criticality safety analysis for a drum storage array and used the surface density method. The drums contained wet process radioactive waste originating from a laboratory. The criticality safety analysis established the limit on the maximum uranium content in an individual drum. Compliance with the double contingency principle for the array was checked by sampling and spectroscopic analysis. One day, a high radiation level was detected from a combustible radioactive waste bag containing laboratory filter paper. Investigation revealed that an acid dissolution process had not completely dissolved the uranium contents. The subsequent gamma spectroscopic analysis of the wet radioactive waste failed to explain the issue due to errors in the analysis methods (the instrument calibration did not adequately resemble the material being analyzed and the spectroscopic analysis did not account for the material self-shielding). Although the material configuration was not ultimately critical, its safety margins were reduced due to ineffective use of procedures and lack of adequate monitoring.

According to another report, an event was identified to be the result of inadequate management attention to the establishment or maintenance of the nuclear criticality safety programme.

In another event, deficiencies in training and qualification, the criticality safety control programme and management supervision contributed to an event where an elevated concentration of highly enriched uranium in a collection tank of radioactive liquid waste (a non-favourable geometry vessel using Raschig rings for moderation) was confirmed by a routine sample analysis. Contents of this tank are normally transferred to a second larger tank (a non-favourable geometry vessel not using Raschig rings) at a set maximum limit of grams of uranium per litre. The analysis of a second sample confirmed that a major exceedance of the limit had occurred.

The analysis of a second sample confirmed that a deviation had occurred in the radioactive waste collection system. Consequently, the operating personnel shutdown the radioactive waste processing area, isolated the radioactive waste collection tank, and recovered the uranium.

Another event was declared in a dry conversion process after realizing that original assumptions used in the evaluation of a credible accident sequence may have been non-conservative or invalid. The initiating event frequency involving a chemical hazard had been underestimated, because the type of event had occurred more often.

Several events involved deficiencies in the criticality accident alarm systems. These deficiencies were caused by the lack of coordination of maintenance work, inadequate operating procedures including those for modifications, and ageing. In one of these events, the criticality alarms were erroneously disabled due to maintenance error in electrical cables located in the same cable tray of the alarm system. In several events, false alarms were triggered due to malfunction or erroneous operation of the relevant uninterruptable power supply or because of failure of the electronic circuits due to ageing. In another event, the regulatory inspection discovered that the criticality alarm system was not subjected to periodic testing, including operability checks (for several years), and that the capability of the system was not evaluated following a major modification to the facility that involved change in the quantity and configuration of fissile material.

Several events occurred due to loading errors of spent nuclear fuel pools and dry storage casks. All these events involved erroneous fuel storage in a manner that is inconsistent with the safety requirements (the technical specifications), which led to reduction of criticality safety margins and/or heat removal capabilities. In one event, the limits on the maximum decay heat of the stored fuel were exceeded, as these limits were not adequately described in the fuel loading procedures.

In one event, in a facility that processes storage tanks with highly radioactive liquid uranium waste, inadvertent ^{235}U content in the waste was discovered. The direct cause of the deviation was an inadequate sampling and analysis procedure. Elevated uranium content in a precipitate phase of the radioactive waste led to a significant overestimation of its quantity in the tanks. In addition, cross contamination of samples (with high and low uranium content) led to incorrect interpretation of the sample analysis. The criticality risk was also insufficiently assessed.

4.7.2 Safety significance

Criticality accidents can have severe consequences that can cause death or exposure to high radiation doses to operating personnel and the public. Urgent protective actions associated with criticality accidents could include evacuation of the public in wide areas outside of the site boundaries of the facility.

Deficiencies in criticality alarm systems significantly challenge criticality prevention measures and the capability to implement adequate mitigatory actions in case of an emergency.

4.7.3 Lessons learned

The analysis of the events reported to FINAS indicate the following lessons to be learned:

– Several accidents occurred due to inadequate criticality safety analysis or inadequate programmes for criticality control during operation. This confirms the need to pay careful attention to, among others, the establishment of effective management processes for criticality control, including validation and verification of computational tools and methods, adequacy and effective use of the operating procedures, and avoidance (in design and during operation) of accumulation of fissile material in processes. Training of operating personnel on criticality safety aspects, including administrative controls, is vital for ensuring criticality safety;

– Several criticality related events occurred because processes or equipment containing fissile material were brought to conditions that had not been covered by the criticality safety analysis. Underestimation of the criticality risk associated with the ventilation and ancillary systems and low level radioactive waste or low concentration solutions containing fissile material has led to criticality accidents or reduction of criticality safety margins;
– Ageing of SSCs, including electronic components and alarm systems, can significantly challenge the facility's capability to prevent criticality accidents or to mitigate the radiological consequences of such accidents if they were to occur;
– Inadequate maintenance or periodic testing, or deficient planning or implementation of modifications of SSCs important to safety could lead to reduction of criticality safety margins or to criticality accidents.

4.8 EXPERIENCE WITH MODIFICATIONS

4.8.1 Summary of the root causes

The analysis of the events showed that inadequate control of modifications could lead to events with safety significance. Events in this category occurred mainly due to lack of adequate safety analysis modifications, including those related to operating conditions. In some cases, the modifications were not even justified.

In an event, 600 grams of plutonium dioxide (PuO_2) powder spilled from a full can into a glove box after a failed undocking from a filling device during the testing of a modification to a computerized process safety control unit. The undocking was ordered after detection of an abnormality in the can filling process. The direct causes of the event were plutonium dioxide powder accumulation in a pipe of the filling device, and a failure of a filling head sensor to trigger. Inadequacy in preparation and implementation of the modification was identified as the root cause of the event.

In another event involving modification of chemical parameters of a waste dissolution process, the safety analysis of the modification did not account for the changes in the procurement specifications and the actual modification of SSCs involved in the process, leading to significant reduction to criticality safety margins. In this event, the operating organization was unable to locate the safety case documentation of the modification.

In another event, a uranium bearing effluent treatment unit was modified, at a uranium recovery facility, in preparation to dismantle the unit. Because the modification work was disturbing the routine operations of the facility, the value of the effluent flow was modified. This action in part caused a sequence resulting in a significant outflow of the uranium bearing effluent. Lack of adequate safety analysis prior to the modification was identified as a cause of the event.

In another event, a fire broke in a process glove box at a nuclear fuel fabrication facility. Earlier, during a valve alignment procedure, a glowing ember was observed in an argon supply to a UF_6 cylinder. The argon supply line was not damaged but was replaced to ensure the integrity of the system. The equipment was then put into operation and the UF_6 cylinder was prepared for sublimation. In opening the cylinder to relive pressure, a heated high pressure release and a thermal reaction within the process containment followed. A flame was observable and a stainless steel braided and polytetrafluoroethylene lined hose glowed red. In responding to this event, the operating personnel activated a carbon dioxide flow to evacuate the UF_6 gas, which also performed well for fluorine gas that had formed inadvertently. The hose failed in several locations where the polytetrafluoroethylene liner was partially defective. There was no significant damage to any process equipment and no loss of containment.

In another event that occurred in preparation for the decommissioning of a facility, modifications were made for the purpose of establishing a vinyl containment system in a room to cut and packing the ventilation ducts. When cutting using an angle grinder, a fire broke out because spark arrester panels did not completely protect the vinyl containment system and its contents against incandescent particles. The operating conditions (e.g. minimization of combustible material) were modified without safety analysis.

In a number of events that have occurred at nuclear fuel cycle facilities, deficiencies in modifications led to releases of chemically hazardous material, which in some cases were associated with releases of radioactive material. These events are further discussed in Section 4.10.

4.8.2 Safety significance

The events in this category caused loss of confinement or containment and spills of fissile material inside the facility, reduction in defence in depth and component failures because of fires.

Modification of the process operation parameters without adequate safety analysis led to events with safety significance, including fire and reduction of criticality safety margins.

4.8.3 Lessons learned

Experience with these events confirmed the importance of establishing and implementing a management system process for modifications important to safety. This process has to ensure that modifications important to safety are subjected to adequate safety analysis and to procedures for design, quality assurance, procurement, construction, testing, and documentation that are equivalent to that established for the facility itself. Lessons learned from these events also show the importance of justification of modifications before they are implemented.

4.9 EXPERIENCE WITH RADIATION PROTECTION

4.9.1 Summary of the root causes

Several events were reported to FINAS database, where deficiencies in the operational radiation protection programme was one of the root causes. These events were characterized by unanticipated releases of radioactive material or exposure of personnel, and are described further in this section.

Unanticipated releases of radioactive material

One event reported the dripping of process liquor from a system in a waste treatment and conditioning facility. Subsequent investigations revealed that the liquor was flowing from a vessel and a cell ventilation condensate drain line outside the radiological controlled areas. There was no routine radiological survey or maintenance arrangements for the vessel and drain line. The operating personnel were also unaware of the equipment located in the radiological supervised areas.

Another event occurred at a vitrification facility, where the malfunction of a valve in the process ventilation system induced a pressure increase, resulting in an aerosol release via a vent stack. The fact that a high pressure in the vitrification process equipment could produce gaseous ruthenium was not considered in the design. Further event analysis was conducted, and actions were taken to improve the containment in the process cells as well as the detection of radioactive releases from the vent stack.

An event occurred at a uranium recovery facility, where uranium bearing effluent spread inside and beyond the bounds of the facility. The effluent contaminated a portion of the ground and reached a river via the rainwater drainage system.

Another event occurred during the maintenance of an oxidation furnace in a pressurized water reactor fuel ceramic pellet sintering area of a nuclear fuel fabrication facility. The erroneous opening of the top cover of a cyclone released radioactive aerosols to the workplace.

Exposure of personnel

In one event, a person received a hand injury during decontamination operations in a uranium cell of a facility for separating uranium and plutonium. The injury led to a significant internal plutonium dose above a regulatory limit. The analysis showed that the direct cause of the event was related to a stainless steel wire that fastened a metal identification label on pipework.

In another event, at a MOX fuel fabrication facility, due to loss of leak-tightness in one of the handling gloves, a worker was exposed to radioactive contamination during a routine check of the operating state of a device located inside the glove box.

In another event, two operating personnel were contaminated during facility maintenance operations in a reprocessing facility. The personnel intended to move the new glove box and were exposed to spots of plutonium contamination located on the roof of the new glove box. The contamination originated from the seal of a high efficiency particulate air filter vinyl bag, located above the new glove box. The results of a nose smear examination showed that one person inhaled plutonium.

In another event, a subcontractor's employee was contaminated both internally and externally during a maintenance operation in a glove box at a MOX fuel fabrication facility. The two person maintenance team was preparing to tighten nuts close to a mechanical rotating element designed to feed MOX powder. The motor operating the rotating element inadvertently started up when a person had his arm inside the glove box. The glove of the box was drawn in and pierced and the operator's arm was trapped. The operator was injured and the radiological confinement of the glove box was lost. Investigation showed that prior risk analysis was conducted without preliminary inspection of the glove box. The relevant corrective actions included improving training, re-evaluating of the work permit process and enhancing coordination. The experience feedback from this event was also considered to improve the ergonomics of new equipment and safety procedures for rotating elements.

In one event, inadequate calibration of thermoluminescent dosimeters led to incorrect evaluations of extremity exposures to beta radiation for personnel handling unshielded uranium materials. The evaluation was based on vendor reports and no additional calculations were made to verify the data provided by the vendor. The independent calculations which were required by the regulatory body in conjunction of this event indicated that the minimum dose rate due to exposure to the material exceeded the values derived from the vendor reports by a factor of two.

4.9.2 Safety significance

The events in this category associated with unanticipated releases of radioactive material were among those that resulted in releases on or off the site. However, there were no events reported to FINAS with significant releases of radioactive material into the environment.

Some events involved actual or potential shortcomings in the safety provisions for adequate shielding, some of which led to radiation exposure of personnel.

In a few cases the events led to radiological dose above regulatory limits, although no signs of health effects or radiation injury were reported. However, some events could in more unfavourable circumstances have led to severe health effects, especially in facilities that process nuclides of high radiotoxicity such as plutonium.

Inadequate extremity dose monitoring associated with operating conditions where radioactive materials were handled led to underestimation of the magnitude of the received doses.

4.9.3 Lessons learned

The analysis of the events reported to FINAS indicated the following lessons to be learned:

– An adequate workplace radiation and contamination monitoring programme can help prevent accidents and ensure protection of personnel against internal and external exposure. This programme needs to cover facility's areas that are categorized as supervised areas for radiation protection purposes;

- Radiological protection measures have to be an integral part of the operating and maintenance procedures for the tasks involving radiation or contamination hazards. Training of the operating personnel on radiation protection, adherence to the approved procedures, and proper work planning are essential for protection of personnel and for preventing loss of confinement or significant releases of radioactive material;
- Inadequate consideration of human factors in design of processes and operating procedures can lead to human errors and radiation exposure. Minimization of these vulnerabilities can be achieved through automation of processes and safety systems;
- Small injuries of personnel in nuclear fuel cycle facilities can lead to a significant internal contamination of radioactive material.

4.10 EXPERIENCE WITH CHEMICAL HAZARDS

4.10.1 Summary of the root causes

In addition to radioactive material, nuclear fuel cycle facilities normally process chemically hazardous material. These materials can be found throughout the entire facility (including transfer between vessels) as they are mostly processed through a series of interconnected units, with a potential for events with radiological and non-radiological consequences. FINAS reports include description of a number of these events, as described below. These events are categorized in accordance with events involving releases of hazardous chemicals associated with radiological material, degradation of chemical reactivity control, and degradation of monitoring of process chemistry.

Releases of chemical material involving radioactive material

One event in a uranium enrichment facility involved a flexible metal pipe connecting a tails pump with two valves. The pipe failed, due to ageing degradation, and released about 70 grams of UF_6 into the surrounding area. In addition, six operating personnel ingested small quantities of uranium. The vent investigation also showed that one of the root causes of this event was failure to learn from previous experience from similar events. In another event, hydrogen fluoride was formed in a fuel fabrication facility as a result of UF_6 release which was caused mainly by human error and inadequate maintenance (see also Section 4.5). Analysis of urine samples showed none of the operating personnel was exposed to hydrogen fluoride.

In one event, an overflow of approximately 757 litre of uranium-bearing ammoniated wastewater led to release into a dike outside of the facility.

According to another report, several events associated with improper handling of radioactive and chemically hazardous material resulted in inadvertent introduction of the wrong chemicals into nuclear fuel production processes.

A number of reports recount events involving exposures due to accidental releases of hydrogen fluoride. These events highlight the need for alertness to the dangers of working with hydrogen fluoride, and for offsite medical facilities to be properly equipped and trained to handle emergencies. If improperly treated, the consequences could be fatal.

Two of these events occurred at uranium conversion facilities. In the first event, one person was exposed to UF_6 and hydrogen fluoride due to inadequate use of personal protective equipment. Treatment at the hospital was delayed as the medical staff were unfamiliar with hydrogen fluoride chemical burns and the hospital did not have the required equipment and supplies for this kind of chemical burns. In the second event two persons noted an unusual odour (due to leakage of hydrogen fluoride) and immediately evacuated the process area. The personnel obtained respiratory protection equipment and returned to the process area to determine the source of the leakage. Investigation showed that one of these two persons was exposed to hydrogen fluoride inhalation.

According to another event report, the investigation identified that the event occurred due to inadequate verification of newly procured respirator cartridge filters. Two personnel were exposed to airborne beryllium particulates above the occupational exposure limit.

In another event, that occurred at a facility undergoing commissioning, improper work with a process valve led to a release of 7 m^3 of concentrated nitric acid. Some of the personnel suffered slight acid burns and were affected by the fumes. Event investigation identified deficiencies in the work permit system being used, and the training and experience of personnel.

Degradation of chemical reactivity control

In one event, an uncontrolled exothermic chemical reaction occurred during what was supposed to be a routine operation to dissolve uranium-zirconium alloy swarf, produced as part of the nuclear fuel manufacturing process, in a mixture of hydrofluoric and nitric acids. The ignition of a small quantity of the alloy swarf initiated a heat generating chemical reaction, causing a fire. The fire resulted in a high discharge of hazardous chemical material from a ventilation stack. The cause of the event was determined to be an improper modification to the process which allowed undiluted acid to drip directly onto exposed swarf.

Another event illustrated the risks of unforeseen chemical reactions. The event occurred at a facility where the storage and reprocessing of spent fuel assemblies are conducted. By human error, four drums of tributyl phosphate were discharged into a process system instead of hydrogenated tetra propylene. The unintended chemical configuration could have caused an explosion due to the potential formation of red oils. (Red oils are unstable and potentially explosive and can be formed by uncontrolled reactions between nitrates and organic components.)

In one event, a fire occurred in a uranium enrichment research laboratory during a uranium waste recovery process. The fire was caused by the explosive combustion of flammable gas which was generated by a chemical reaction between water and uranium waste, the latter containing uranium metal carbide, oxide, and hydride. Before the occurrence of this event, there were no approved procedures for handling material with the potential for explosive combustion. The analysis that was performed in conjunction of this event indicated that the combustible gas mixture may have been ignited by the presence of uranium hydride (UH_3) which is pyrophoric in air. There was no radioactivity released to the environment.

Two events indicated that dryness is not a condition for explosions due to ammonium nitrate solutions. A concentrated ammonium nitrate solution, together with activation energy provided by an overheated pump, could be sufficient to cause ignition. In a fuel fabrication facility, a pump servicing a uranyl nitrate system exploded. Another pump that was connected to an ammonium diuranate ($(NH_4)_2U_2O_7$) system also exploded at another fuel fabrication facility.

Degradation of monitoring of process chemistry

In one event a fire broke out in the cell of a bituminization facility. Ten hours after the initiation of the fire, an explosion occurred, and the confinement functions of the cell and building were breached. The amount of released radioactive material was not significant. The event investigation showed that the initiating cause of the event was a low feed rate on an extruder leading to the accumulation and concentration of salt. The proportion of sodium nitrate and nitrite in the bituminized product gradually increased until the salts and the bitumen in the storage drums self-ignited. Water that was sprayed onto the drums caused a release of flammable gases in a low oxygen atmosphere as it came into contact with the heated bituminized product. The gases could not be vented due to clogging of filters in the ventilation system, which was still functioning and continued to supply air until the mixture of gases exploded. The primary cause of this event was inadequate hazards assessment and deficiencies in process design. The operating organization revaluated the design of each relevant process and introduced modifications to ensure safety. The operating procedures were also revised.

Several events involved intense exothermic reactions during the packaging of low temperature or vacuum dried yellowcake. In four events, yellowcake reacted due to the generation of oxygen as a by-product, or due to hydrocarbon contaminants reacting with yellowcake. In the first case corrective actions consisted of taking the lids off the drums for a minimum of 3 hours after filling. In the second case, oil drip pans were installed; and rather than attempting to recover product through recirculation, the oily yellowcake contaminants were transferred into the waste streams.

In two events, radioactive and chemically hazardous gaseous compounds were released due to the following unexpected chemical reactions:

- Iodine compounds reacted with an oxidizing agent in liquid waste, and volatile molecular iodine was generated and released;
- More aluminium than expected was supplied into a dissolving process, generating nitric gas due to the reaction with nitric acid.

4.10.2 Safety significance

Consequences of the events in this category included injuries caused by chemical contamination, inhalation of chemicals, and chronic exposure to beryllium. The most common hazardous chemical compounds were UF_6, hydrogen fluoride and nitrogen oxides. These materials are chemically toxic, and some of them (e.g. hydrogen fluoride) led to severe health consequences in some cases.

Release of chemicals in nuclear fuel cycle facilities can also be associated with the release of radioactive material to the environment.

There were near misses among the events that could have caused fires or explosions as well as events where fires and explosions had already happened.

4.10.3 Lessons learned

The analysis of the events reported to FINAS indicated the following lessons to be learned:

- Careful attention has to be given in design (or modification) and operation of nuclear fuel cycle facilities to process configurations and operations with the potential to cause exothermic chemical reactions, uncontrolled chemical reactions, chemical explosions or flammable gases formation;
- As chemically hazardous materials are found throughout the nuclear fuel cycle facilities, they have a strong interface with nuclear and radiological safety. Such interfaces have to be covered by the facility's safety analysis and have to be subjected to operational limits and conditions that include an adequate monitoring programme of these materials;
- Good system of work permit approval and proper training of personnel already during commissioning of nuclear fuel cycle facilities (including handover procedures and transfer of responsibility) are essential for protection against chemical hazards;
- Approved procedures have to be in place, and strictly followed, for tasks involving chemical reactions. The facility operating personnel, including process operators, maintenance staff and contractors, have to be adequately trained on these procedures. Many events resulted in releases of UF_6 and formation of extremely hazardous hydrogen fluoride. Personnel that could potentially be exposed to these chemicals needs to understand the risks associated with these chemicals;
- It is important to be aware, and take appropriate action concerning the fact that treatment of hydrogen fluoride exposure is complicated and requires more resources compared to the treatment

of other strong acid exposures. Effective coordination with local hospitals as well as developing the capacity for this kind of treatment has to be ensured in accordance with the emergency preparedness measures. Experience with these events also highlights the importance of adequate training of emergency response personnel, and of the regular emergency drills involving release of hazardous chemicals.

4.11 EXPERIENCE WITH DEGRADATION OR LOSS OF MEANS OF CONFINEMENT

4.11.1 Summary of the root causes

In one event, a routine airborne monitoring activity of the ventilation system stack indicated a significant increase in alpha activity. Due to deficiencies in modifications, some parts of the ventilation system were inadvertently left without appropriate filtration as the installation of a newly designed filter was initiated but not completed.

In another event the ventilation system was compromised by runaway reactions in bituminized waste that resulted in a fire.

In some events loss of the dynamic confinement (ventilation system) occurred, resulting in the release of airborne radionuclides. Several cases involved release of radioactive gases (e.g. ruthenium) as the ventilation and scrubber systems were designed to filter only solid particulates. Other events were caused by failures in auxiliary equipment of the ventilation systems such as monitoring equipment. Events occurred also due to failure of the electrical power supply or faults of the instrumentation and control components associated with the ventilation systems.

In another event, a stainless steel dissolver containing uranyl nitrate, plutonium and fission products leaked due to corroded welds on the upper part of the dissolver. There was no dispersal of radioactive products beyond the second containment system.

Another event occurred during the transfer of radioactive waste to a freight container. Part of the load (about 150 kg) slipped and fell 10 m down a hoist-well. No personnel were injured, but there was a spread of contamination as the load’s plastic containment wrapping ruptured. The relevant investigations indicated the following causal factors:

– The extent of migration over time of radioactive material from the hot cells into the adjacent equipment was not considered in the design;
– Lack of a formal process for tracking large radioactive waste items in interim storage.

One event involved a dry storage cask containing a multipurpose canister with spent nuclear fuel assemblies. Vacuum drying of the fuel was initiated with a cooling system connected to circulate water in the annulus between the canister and the cask to keep the fuel cladding temperature within the acceptable limits. The cask was left unattended overnight, and the cooling system was found to be inoperable in the following morning. The fuel cladding temperature was then uncontrolled. However, it did not exceed the limits. The event involved reduction of margins to the integrity of the fuel cladding, which is an important factor for containment of radioactive material and for ensuring criticality safety.

In another event, filters in several containers of high level radioactive waste were inadvertently shipped as low level radioactive waste. The radioactivity concentration in the filters was later estimated to be above the relevant regulatory limit.

4.11.2 Safety significance

The events in this category caused internal and external radiological overexposure to operating personnel, spread of airborne radioactive contamination, or release of radioactive material into the facility or the environment.

4.11.3 Lessons learned

The analysis of the events reported to FINAS indicated the following lessons to be learned:

- The causes of events resulting in degradation (or loss) of means of confinement are diverse. These include inadequate design or quality management, deficiencies in modifications, ageing of SSCs, and human errors. Failure in auxiliary systems can also lead to loss of means of confinement. Adequate consideration of these causes in processes and programmes will help to prevent reoccurrences of these events;
- Degradation (or loss) of dynamic confinement has been more frequent compared to that of static confinement. This calls attention to the importance of maintenance, periodic testing and inspection of SSCs, particularly of the process ventilation systems;
- The quality of the means of confinement in some types of nuclear fuel cycle facilities has a strong interface with the adequacy of heat removal from radioactive decay of material and from chemical reactions. This interface needs to be considered in design, operation and maintenance of cooling systems;
- Several events involving the loss of confinement could have been avoided if adequate administrative control had been included and applied in the operating procedures.

4.12 EXPERIENCE WITH EXTERNAL EVENTS

4.12.1 Summary of the root causes

Several FINAS reports concerned external hazards, which can challenge the safety of the facilities. These hazards included seismic, flood, lightening, heavy rains and snow. These external hazards resulted in deterioration of safety, and extreme conditions might have developed beyond the design basis of the facility.

The serious consequences of the accident at the Fukushima Daiichi nuclear power plant demonstrated the importance of a careful consideration and assessment of external hazards and the potential for their occurrence in combination, either simultaneously or sequentially [14, 19].

In one event, a laboratory undergoing decommissioning was flooded during a rainstorm. Legacy plutonium present in the laboratory was dispersed in the rainwater and spread over the floors. The event caused contamination of the laboratory premises but did not result in radiation doses or release of radioactivity out of the laboratory.

In another event, the site of a nuclear fuel cycle facility was impacted by a flood due to heavy rains. This caused an overflow of a drainage system servicing a fissile material transfer area, allowing ingress of water into a dewatering system. No failure of the structural integrity of the facility or release of fissile material was observed. A moisture detector failed to actuate, delaying operator's action to remove the water. Due to water ingress, the criticality safety margin was deteriorated due to overmoderation, and the double contingency principle for criticality safety was breached. Analysis of the event revealed an incomplete safety analysis and deficiencies in the operational procedures.

In another event, an overcurrent occurred due to the inadvertent supply of electrical power by both the normal operation and emergency power supplies. As a result, the electrical circuit breakers of the safety systems actuated shutdown of the facility. The cause of the event was failure to manually restore access to the offsite electrical power supply following a lightning strike.

In another event severe wind and snow caused a short-circuit in the electrical power transmission line, leading to a voltage drop, which tripped the electrical power supply and caused the loss of steam, water, and compressed air flows to the facility process systems. Emergency response personnel had to restart equipment and restore the supply of water to the facility.

In one event, heavy snow and high winds hit the area around a nuclear fuel cycle facility. Lines of the main electrical grid failed due to ice load, and the breakdown of a ground line of one of the electrical feeders to the site caused voltage dips. This resulted in a trip of the systems important to the safety of the facility, such as ventilation and radiation detection systems. These disturbances led to automatic shutdown of the facility, and its evacuation.

According to another event report, a design deficiency was recognized while performing a post-Fukushima safety assessment of a facility that provides dismantling and radioactive waste handling services of equipment and materials containing ^{235}U (enrichment between 1 and 5%). The safety assessment showed non-adequate measures for maintaining safe storage configuration during postulated flooding and earthquake events. The SSCs that were installed to maintain such a safe configuration were not adequately designed and their ageing degradation were not taken into consideration, leading to a compromise of the criticality safety margins.

4.12.2 Safety significance

The events in this category caused spread of radioactive contamination within the facility, violation of the double contingency principle for criticality safety which jeopardized the availability of safety systems to perform its intended safety functions.

4.12.3 Lessons learned

The analysis of the events reported to FINAS indicated the following lessons to be learned:

- External hazards that are more severe than those considered in the design basis may occur. Therefore, the adequacy of design basis has to be regularly reassessed to ensure continued acceptability of the site and to identify practicable safety upgrades. Additionally, adequate margins need to be provided to protect SSCs important to safety against external hazards more severe than those selected for the design basis as derived from the site hazard evaluation. Furthermore, cliff edge effects have to be identified and adequately addressed;
- Assessments of the robustness of SSCs important to safety in nuclear fuel cycle facilities to withstand extreme external hazards and to ensure that the main safety functions are met for all facility states, to comply with the upgraded safety requirements in SSR-4 [1];
- To ensure safety, it is essential to establish procedures for operating personnel response to design basis accidents and anticipated operational occurrences, including seismic and flooding. These procedures have to be included in the training programme. Emergency preparedness procedures also have to be kept up-to-date and cover all external hazards.

Additionally, most of the lessons learned from the severe accident that had occurred in March 2011 at the Fukushima Daiichi nuclear power plant are also applicable to nuclear fuel cycle facilities. The available experience from this accident is useful for identifying and implementing measures to prevent the occurrence of any accident involving a large or early release of radioactive material at nuclear installations, including at nuclear fuel cycle facilities, in the future.

The lessons learned from the accident justify revisions of the safety analysis for these facilities through the performance of a safety reassessment based on up-to-date IAEA safety standards. Such a reassessment has to take into consideration, among others, the actual status of the facilities, including ageing of SSCs and the quality of means of confinement, the presence of large inventories of nuclear and radioactive material, and the criticality risk and chemical hazards. The IAEA has published a report [14] that provides information relevant for all steps in performing such safety reassessments for nuclear fuel cycle facilities. Although it primarily focuses on operating nuclear fuel cycle facilities, the approaches and methods provided in Ref. [14] also apply to nuclear fuel cycle facilities that are in the stages of planning, design, construction or commissioning, or in long term shutdown.

5 CONCLUSIONS

The conclusions drawn from the analysis of events reported to FINAS can be summarized as follows:

FINAS is an important tool for collecting and sharing the operating experience of nuclear fuel cycle facilities. The analysis of the events reported to FINAS clearly illustrates that there are many reoccuring events, which could have been avoided if the operating experience from similar events had been recognized throughout the nuclear community and utilized properly. The event analysis showed that the lack of sharing of information on operating experience was one of the major contributors to some events at nuclear fuel cycle facilities.

Sharing the operating experience nationally and internationally will help operating organizations in taking preventive measures to reduce the frequencies and consequences of potential events. Regulatory bodies can use operating experience in revising and issuing new requirements and guidelines based on the safety significance of actual events. Operating experience can also be used for the planning and coordination of research and development proposals and other activities aimed at continuous safety improvements.

Publications on operating experience feedback from other types of nuclear installations also contain useful information for nuclear fuel cycle facilities. For example, IAEA-TECDOC-1762 on Operating Experience from Events Reported to the IAEA Incident Reporting System for Research Reactors [20], the latest overview report from the IAEA/NEA International Reporting System for Operating Experience [21], which deals with nuclear power plant events and contains a number of lessons relevant for nuclear fuel cycle facilities, and INSAG-23 on Improving the International System for Operating Experience Feedback [22]. The operating organizations of nuclear fuel cycle facilities can benefit by learning from the lessons that are applicable to their facilities. Information on lessons learned from spent fuel storage operation can be also found in [23].

Despite the variations in type, design and mode of operation of the facilities, many of the events bear similarities in root causes, causal factors and outcomes. The lessons learned from these events, if used appropriately, can help nuclear fuel cycle facilities avoid and handle similar events. The IAEA, together with the OECD/NEA, will continue to collect data on events and disseminate the lessons learned from them through the operation of the FINAS system. Participating Member States are encouraged to continue reporting events of safety significance and to effectively use the operating experience offered by the system to continue enhancing the safety of nuclear fuel cycle facilities worldwide.

Design and quality assurance

The events where design and quality deficiencies were identified as the root cause highlighted the importance of adequate design reviews and quality control, especially in the areas of proper selection of material, identification of proper environmental service conditions and technical specifications of SSCs important to safety, validation and verification of safety analysis computational tools, and effect of auxiliary systems on the performance of the SSCs important to safety. Lack of adequate consideration in the design of accumulation of fissile material in process systems, and of the interaction between the electrical power supply system and instrumentation were identified as causes of some events. The lessons learned from events also showed the importance of periodic review of the facility's design safety features (e.g. in a periodic safety review process) to maintain safety.

Understanding of the design basis and retaining complete and up to date safety and operating documentation, including construction and commissioning documents, is crucial. This is particularly important since most of nuclear fuel cycle facilities were constructed and commissioned many years ago. The documentation from that time is usually limited and the original designers, installation and commissioning engineers and operating personnel may no longer be available. For older nuclear fuel cycle facilities, reconstitution, to the extent practical, of the design basis could significantly enhance safety.

Experience showed some design deficiencies remained hidden for a long period of time before they caused an event. This highlights the need to establish effective monitoring, maintenance, periodic testing, and inspection programmes for the identification of these hidden deficiencies.

Experience also showed the importance of extending quality assurance programmes to cover manufacturing and construction phases (including for modification projects). A number of events could have been avoided if adequate quality control procedures were applied during manufacturing and installation of SSCs, including audits of the suppliers' quality assurance programmes (management systems), verification of the adequacy and validity of specifications of SSCs provided by vendors, and control of the contractors' work.

Human factors and leadership and management for safety

A significant number of events have been reported where human factors, including human errors, and deficiencies in leadership and management for safety were identified as the main root causes. On several occasions, human errors had initiated events or their intervention made event consequences worse. In some other occasions, lack of effective leadership and deficient management, including inadequate communication of expectations for safety, allowed issues to remain hidden or uncorrected until they caused incidents of safety significance. Experience showed effective communication within the organization, through all levels and across organizational boundaries is important for safety. The continuously changing environment in the nuclear fuel cycle facilities industry requires complete, concise and clear communication.

Ineffective use of procedures and improper work planning, lack of questioning attitude, peer reviews, and job briefings also contributed to initiating several events. These highlight the importance, for event prevention, of establishing effective management systems that support developing and maintaining a strong culture for safety. Adequate training of operating personnel on management system processes, including on safety culture, helps prevent reoccurrence of events. This would also help to foster a questioning attitude and learning from experience by the operating personnel.

Lack of adequate consideration of human factors in design of systems and processes as well as in the operating procedures were also identified as root causes of some events. Workplace conditions also provoked human errors. Other error precursors were identified by the analysis including lack of knowledge, over confidence, and inaccurate understanding of risk. Managers and supervisors at all levels need to ensure that personnel performing operations important to safety are aware of the significance of their actions as well as the implications of these actions to safety.

Maintenance and periodic testing

FINAS reports showed that lack of adequate maintenance and periodic testing programmes, or deficient maintenance operations (including erroneous maintenance, ineffective coordination of maintenance work, and inadequate communication during maintenance) can lead to events of significant safety consequences. Several events could have been prevented or their consequences lessened if adequate specialized training was provided to maintenance personnel and post-maintenance checks were included as an integral part of the maintenance procedures. Routine walkdown of the facility, including during shutdown periods, in accordance with approved procedures can help improve the quality of maintenance.

Ageing of structures, systems and components

The majority of nuclear fuel cycle facilities have been operating for several decades and their safety could be challenged by ageing of their SSCs. Some of these challenges can be due to degradation of the SSCs over time, not considered in the design of these facilities. Systematic ageing management during the operation of many of these facilities have not been implemented yet, and most ageing mitigatory actions are limited to periodic replacement of equipment and components, and other maintenance activities. Experience shows that ageing of SSCs could lead to events involving releases of radioactive and chemically hazardous material to the environment. Activities such as maintaining appropriate environmental service conditions, adherence to good engineering practices in operation and maintenance, monitoring and trending ageing degradation of SSCs (through, for example, analysis of results of periodic testing and inspection of physical status), and implementation of modernization and refurbishments help prevent negative impacts of ageing on safety of a facility.

Criticality events

Many events led to inadvertent buildup of fissile material or revealed issues in the handling of fissile material in liquid form, leading to criticality accidents of severe radiological consequences or significant reduction in criticality safety margins. Accumulation of fissile material in process systems handling materials in liquid form needs increased attention. Criticality accidents have to be prevented by design and comprehensive safety analysis and through robust administrative controls. Some events could have been avoided, if criticality safety experts had been involved in the development or review of procedures or modifications of systems or processes involving fissile material. Reduction of criticality safety margins or even criticality accidents also occurred as a result of due to ageing degradation of SSCs, or as a result of inadequate maintenance or periodic testing. Diverse working conditions at nuclear fuel cycle facilities and the complexity of the associated organizational interfaces need to be taken into account in the criticality safety programme during the operation of a facility.

Modifications

Events due to deficiencies in the modification process can lead to events of significant consequences, including exposure to high radiation levels, degradation or loss of means of confinement, or reduction of criticality safety margins. This highlights the need to establish an effective management system process for modifications (or change control). Such a process has to ensure performance of an adequate safety analysis of proposed modifications, and application of adequate quality management procedures to all phases and activities of a modification project, including construction, commissioning and operation.

When SSCs important to safety are to be replaced by equivalent ones, careful attention needs be paid to ensure that at least the same level of safety is achieved. In many cases identical components may not be available and therefore modification to the design may be necessary.

Degradation (or loss) of means of confinement, Radiation protection and chemical hazards

Degradation or loss of means of confinement that occurred at nuclear fuel cycle facilities were mainly caused by inadequate design or quality management, deficiencies in modifications, ageing of SSCs, or human errors. Particular attention has to be paid to the design and maintenance of process ventilation systems, as operating experience has shown that degradation or loss of dynamic confinement has been more frequent compared to that for static confinement.

Degradation or loss of means of confinement has led to the release of radioactive and chemically hazardous materials to the workplace and to the environment, resulting in severe health consequences to operating personnel or members of the public. Exposure of personnel to high radiation levels was also due to the lack of adequate workplace mentoring programmes, management supervision, coordination of maintenance activities involving exposure to radiation, or procedures. Experience also showed that minor personnel injuries led to significant contamination in nuclear fuel cycle facilities. All these aspects, including the training of personnel, need to be covered by the operational radiation protection programme of the facility.

Experience also showed that events involving chemically hazardous material have occurred more frequently than those involving radiation hazards. The events reported to FINAS also highlighted the importance of an adequate training of emergency response personnel (including medical specialists), and of the regular emergency drills whose scope needs to cover the release of chemically hazardous material.

External events

Experience with FINAS reports showed that external events that are more severe than those that were considered in the design basis may occur. This has been also showed in the accident at the Fukushima-Daiichi nuclear power plant. Therefore, the adequacy of design basis has to be regularly reassessed to ensure continued acceptability of the site and to identify practicable safety upgrades. Additionally, safety margins need to be provided for beyond design basis events, with special attention given to the potential for cliff edge effects. The robustness of the SSCs of the nuclear fuel cycle facilities to withstand external events and to ensure main safety functions of the facilities need to be assessed for their compliance with up-to-date safety requirements, including the IAEA safety standards.

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ANNEX: OPERATING EXPERIENCE PROGRAMME DESCRIPTION

A-1. GENERAL

Requirement 73 of SSR-4 [A–1] states:

"The operating organization shall establish a programme to learn from events at the facility and events at other nuclear fuel cycle facilities and in the nuclear industry worldwide."

Further requirements on operating experience are established by

- Para. 9.136 of SSR-4 [A–1]:
  "Information on operating experience shall be examined for any precursors to, or trends in, adverse conditions for safety, so that any necessary corrective actions can be taken before serious conditions arise."; and
- Para. 4.26 of SSR-4 [A–1]:
  "In accordance with national regulatory requirements, the operating organization shall carry out systematic periodic safety reviews of the nuclear fuel cycle facility throughout its lifetime, with account taken of ageing, modifications, human and organizational factors, operating experience, technical developments, new information on site evaluation and other information relating to safety from other sources."

In addition, para. 9.133 of SSR-4 [A–1] requires that the operating organization

"… shall also encourage the exchange of experience within national and international systems for the feedback of operating experience. These activities shall be performed in accordance with the management system."

SSG-50 [A–2] provides recommendations on the implementation of the operating experience programme.

Annex III of IAEA-TECDOC-1762 [A–3] provides a detailed description of the objectives and key features of an operating experience programme in the context of research reactors. This is also applicable to nuclear fuel cycle facilities and is as follows:

> "The primary objectives of a system for the feedback of operational experience are that no safety related event remains undetected and that corrections are made to prevent the recurrence of safety related events by improving the design and/or the operation of the installation. This criterion reflects the notion that an accident of any severity would most probably have been marked by precursor events, and to this extent would have been predictable and, therefore, avoidable. Feedback of experience also increases knowledge of the operating characteristics of equipment and performance trends, and provides data for quantitative and qualitative safety analysis.

The operating organization has a responsibility to ensure that operating experience is used effectively within the organization to promote safety. Therefore it is important for the operating organization to have an effective programme for identifying, analysing and reporting events in order to feedback the lessons learned.

An effective operating experience programme relies on certain essential characteristics including that:

- Policies are established by management to align the organization to effectively implement the operating experience programme. These policies include established thresholds and set criteria for expectations and priorities;
- Event identification and reporting is strongly encouraged at all levels in the organization;
- Timely identification and reporting of events are undertaken to ensure that the facts are communicated and recorded properly so that learning opportunities can be extracted and followed through;
- Collection of information is timely and sufficiently comprehensive so that no relevant data is lost;
- The information collected is screened effectively by knowledgeable persons, to ensure that all important safety related issues that have to be reported and analysed with priority, are identified;
- Employees who identify problems receive feedback on problem resolution;
- Appropriate resources (personnel, equipment, funds) are allocated by the management to support the operating experience programme;
- Management of the operating experience programme is focused on improvement of safety;
- Facility personnel at all levels of the organization demonstrate ownership for identifying, reporting and screening of events by directing, promoting, prioritizing, and sufficiently staffing programme activities;
- Failures and near misses are considered opportunities to learn and are used to avoid more serious events;
- Management provides continuous direction and oversight."

A-2. EVENT IDENTIFICATION

Annex III of IAEA-TECDOC-1762 [A-3] describes the identification of events in the context of research reactors. This is also applicable to nuclear fuel cycle facilities and is as follows:

"The first key activity of the operating experience programme is to identify events or good practices. The purpose of identifying events is to feed the operating experience programme with information for further evaluation, and corrective actions to reduce potential for event recurrence, and the applicability of good practices.

In the context of the operating experience programme, an event is any occurrence unintended by the operator, including operating error, equipment failure or other mishap, and deliberate action on the part of others, the consequences or potential consequences of which are not negligible from the point of view of protection or safety.

Identifying events have to include the capability of personnel to recognize deficiencies or potential/actual adverse conditions and provide suggestions for improvements, as well as the capability to recognize good practices.

Management has to establish and communicate the expectations on the threshold for identifying events. Experience has shown that causes of low level events and near misses can be similar as causes of significant events.

All events, however minor, present learning opportunities to improve safety and performance, reduce errors and avoid repeat issues. Good practices, either external or internal, are also opportunities to emulate for improving safety and performance. Identifying activities are focussed on what is wrong (the gap or deviation between 'what is' and 'what should be') and what needs to be improved."

A-3. MAIN ELEMENTS OF AN OPERATING EXPERIENCE PROGRAMME

Annex III of IAEA-TECDOC-1762 [A-3] sets out the main elements of an effective operating experience programme for research reactors. The corresponding elements for nuclear fuel cycle facilities are similar and are as follows:

- Identification and reporting of events;
- Screening of events based on safety significance;
- Investigation of events;
- Causal analysis;
- Recommended actions resulting from the assessment, including approval, implementation, tracking and evaluation;
- Trend evaluation;
- Dissemination and exchange of information including by the use of international systems such as FINAS;
- Continuous monitoring and improvement of programmes for the feedback of operating experience;
- Documentation.

A detailed procedure has to be developed by the operating organization on the basis of the requirements for a national system established by the regulatory body. This procedure has to define the process for dealing with all internal and external information on events at nuclear fuel cycle facilities. The procedure has to define the structure of the system for the feedback of operational experience, the types of information, the channels of communication, the responsibilities of the groups and organizations involved, and the purpose of the documentation produced.

Screening of event information is undertaken to ensure that all significant matters relevant to safety are considered and that all applicable lessons learned are taken into account. The screening process has to be used to select events for detailed investigation and analysis. This includes prioritization according to safety significance and the identification of adverse trends.

The use of external operating experience can have the benefit of discovering latent potential failures that could pose concerns for safety. Such information has to be reviewed to determine whether it is applicable to the facility and if any actions are warranted.

The level and scope of the investigation to be carried out has to be commensurate with the consequences of an event and the frequency of reoccurring events using a graded approach.

Event analysis has to be conducted on a timescale consistent with the safety significance of the event. The main phases of event analysis can be summarized as follows:

- Establishment of the complete event sequence (what happened);
- Determination of the deviations (how it happened);
- Cause analysis;
- Direct cause (why it happened);
- Root cause (why it was possible);
- Assessment of the safety significance (what could have happened);
- Identification of corrective actions.

Actions taken in response to events constitute the main basis of the process of feedback of operational experience to enhance safety at nuclear fuel cycle facilities. Such actions are aimed generally at correcting a situation, preventing a reoccurence or enhancing safety.

The development of recommended corrective actions following an event investigation has to be directed towards the root causes and the contributory causes and has to be aimed at strengthening the weakened or breached barriers that failed to prevent the event.

A tracking process has to be implemented to ensure that all approved corrective actions are completed in a timely manner and that those actions with long lead times to completion remain valid at the time of their implementation in the light of later experience or more recent developments.

The purpose of an event trending process has to be to determine the frequency of occurrence of certain conditions that have been gathered from reports on minor and major problems and event investigations. These data include information about equipment failures and shortfalls in human performance, and situational data that describe conditions at the times of the events.

Once an abnormal trend has been identified it has to be treated as an event, and the established deficiency reporting programme is used to initiate an appropriate analysis and to determine whether the trend is identifying adverse performance.

For maximum impact and benefit, appropriate information relating to the feedback of operational experience has to be disseminated to relevant bodies. A list of possible recipients for different types of information has to be prepared. A periodic review has to be undertaken of all stages of the process for the feedback of operational experience to ensure that all of its elements are performed effectively. Continuous improvement of the process for the feedback of experience is an objective of the review.

The operating organization or licensee has to be responsible for integrating operational experience feedback into its management system in accordance with national and international standards.

The event reporting has to be established in accordance with the licensing conditions and operational limits and conditions of the facility. The event reporting system includes the reporting criteria, format of the report, timeline for reporting and the individuals and/or organization(s) to which the report is submitted. The FINAS guidelines [A-4] represent a useful publication in developing the event reporting system.

Generally, the event report includes:

- Basic information;
- Narrative description;
- Safety assessment (consequences and implications);
- Causes and corrective actions (taken and/or planned);
- Lessons learned;
- Graphical information (e.g. drawings, sketches, photos, process and instrumentation diagrams) for a better understanding of the event (if necessary).

Basic information includes items such as:

- Title of the event;
- Date and time of occurrence;
- Facility name and site;
- Facility type and throughput;
- Facility status at the time of event (e.g. commissioning, operation, maintenance, start-up, shutdown, decommissioning);
- An abstract containing a brief statement describing the major occurrences during the event, including all actual system or component faults and/or failures that contributed to it, all relevant personnel actions or violations of procedures, and any significant corrective action taken or planned as a result of the event.

The narrative description explains exactly what has happened and what has been discovered in the event. Emphasis is put on how the facility responded and how SSCs and operating personnel performed. A description of what the operator observed, did, understood or misunderstood is important, including how the event was discovered. Unique characteristics of the facility which influenced the event (favorably or unfavorably) are described. The following specific information is included:

- Facility status prior to and following the event;
- Event sequence in chronological order;
- System and component faults and/or failures;
- Operator actions and/or procedural controls;
- Events that have reoccurred.

The safety assessment has to be focused on the safety consequences and implications of the event. The primary aim of this review is to ascertain why the event occurred and whether it would have been more severe under reasonable and credible alternative conditions, such as in changed modes of operation, equipment and processes. The safety significance of the event has to be indicated.

The direct causes, root causes and causal factors of the event have to be clearly described. The causes have to include reasons for equipment malfunctions, human performance problems, organizational difficulties, design and manufacturing deficiencies and other facts. The cause analysis has to be conducted by the trained personnel.

All corrective actions taken or planned have to be listed and described in sufficient detail. In case of a number of planned corrective actions, they have to be clearly prioritized. For follow-up purpose, the individuals, group or department responsible for authorizing or implementing corrective action may be identified.

The event report has to clearly identify lessons learned. The communication of lessons learned can lead to enhanced safety, positive changes in working practices, increased reliability of equipment and improvements in procedures. Sharing of lessons learned from operational experience is one of the most valuable parts of the process of feedback of operational experience.

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