Nuclear Regulation
NEA/CNRA/R(2015)4
September 2015

www.oecd-nea.org

Second Construction Experience Synthesis Report 2011–2014

Working Group on the Regulation of New Reactors (WGRNR)

OECD
BETTER POLICIES FOR BETTER LIVES

NEA
NUCLEAR ENERGY AGENCY

Unclassified **NEA/CNRA/R(2015)4**

Organisation de Coopération et de Développement Économiques
Organisation for Economic Co-operation and Development **28-Sep-2015**

English text only

NUCLEAR ENERGY AGENCY
COMMITTEE ON NUCLEAR REGULATORY ACTIVITIES

NEA/CNRA/R(2015)4
Unclassified

Working Group on the Regulation of New Reactors

**Second Construction Experience Synthesis Report
2011-2014**

JT03382550

Complete document available on OLIS in its original format

English text only

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

The OECD is a unique forum where the governments of 34 democracies work together to address the economic, social and environmental challenges of globalisation. The OECD is also at the forefront of efforts to understand and to help governments respond to new developments and concerns, such as corporate governance, the information economy and the challenges of an ageing population. The Organisation provides a setting where governments can compare policy experiences, seek answers to common problems, identify good practice and work to co-ordinate domestic and international policies.

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

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

This work is published on the responsibility of the OECD Secretary-General.
The opinions expressed and arguments employed herein do not necessarily reflect the official views of the Organisation or of the governments of its member countries.

NUCLEAR ENERGY AGENCY

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

The mission of the NEA is:

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

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

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

COMMITTEE ON NUCLEAR REGULATORY ACTIVITIES

The Committee on Nuclear Regulatory Activities (CNRA) shall be responsible for the programme of the Agency concerning the regulation, licensing and inspection of nuclear installations with regard to safety. The Committee shall constitute a forum for the effective exchange of safety-relevant information and experience among regulatory organisations. To the extent appropriate, the Committee shall review developments which could affect regulatory requirements with the objective of providing members with an understanding of the motivation for new regulatory requirements under consideration and an opportunity to offer suggestions that might improve them and assist in the development of a common understanding among member countries. In particular it shall review current management strategies and safety management practices and operating experiences at nuclear facilities with a view to disseminating lessons learnt. In accordance with the NEA Strategic Plan for 2011-2016 and the Joint CSNI/CNRA Strategic Plan and Mandates for 2011-2016, the Committee shall promote co-operation among member countries to use the feedback from experience to develop measures to ensure high standards of safety, to further enhance efficiency and effectiveness in the regulatory process and to maintain adequate infrastructure and competence in the nuclear safety field.

The Committee shall promote transparency of nuclear safety work and open public communication. The Committee shall maintain an oversight of all NEA work that may impinge on the development of effective and efficient regulation.

The Committee shall focus primarily on the regulatory aspects of existing power reactors, other nuclear installations and the construction of new power reactors; it may also consider the regulatory implications of new designs of power reactors and other types of nuclear installations. Furthermore it shall examine any other matters referred to it by the Steering Committee. The Committee shall collaborate with, and assist, as appropriate, other international organisations for co-operation among regulators and consider, upon request, issues raised by these organisations. The Committee shall organise its own activities. It may sponsor specialist meetings and working groups to further its objectives.

In implementing its programme the Committee shall establish co-operative mechanisms with the Committee on the Safety of Nuclear Installations in order to work with that Committee on matters of common interest, avoiding unnecessary duplications. The Committee shall also co-operate with the Committee on Radiation Protection and Public Health and the Radioactive Waste Management Committee on matters of common interest.

.

FOREWORD

Laurence J. Peter once said: "There is only one thing more painful than learning from experience, and that is not learning from experience". Many of the events reviewed in the Second Construction Experience Synthesis Report presented here stem from causes that are well-known to the nuclear industry. Therefore, these events could have been prevented had the lessons gained from previous experience been better communicated and effectively applied by the nuclear industry. The Second Construction Experience Synthesis Report presented here aims to change that. It was developed by a subgroup of the Working Group on the Regulation of New Reactors (WGRNR) with the goal of improving the quality of the various technical disciplines within design, fabrication, construction and testing of new nuclear reactor builds. This should help eliminate latent defects that may result in future unexpected failures. This second report continues the path initiated by the *First Construction Experience Synthesis Report* NEA/CNRA/R(2012)2[1] issued in May 2012. However, it is organised differently because the Construction Experience (ConEx) database (available to WGRNR members only) now includes significantly more events than it did at the time the first report was issued. This better allows for the grouping of events by the various technical disciplines within design, fabrication, construction and testing activities, and the identification of cross-cutting lessons learnt associated with management system processes, safety culture, supply chain and human and organisational issues.

This report is intended to be used by nuclear new build designers, fabricators, installers, licensees and regulators. WGRNR hopes that you find the information it presents useful and ask that you contact neapub@oecd-nea.org should you require more information or desire to provide constructive feedback to help improve future reports.

[1] Follow this link to download the report http://www.oecd-nea.org/nsd/docs/2012/cnra-r2012-2.pdf.

ACKOWLEDGEMENTS

This report was prepared by a subgroup of the WGRNR on the basis of input provided by the member countries of the WGRNR. This subgroup was composed of:

Janne NEVALAINEN	(STUK, Finland), WGRNR Chair,
Philippe JOYER	(ASN, France), ConEx task leader,
Aurélien PRÉVOST	(ASN, France),
Walter KIM	(KINS, Republic of Korea),
Marcin ZAGRAJEK	(PAA, Poland), WGRNR Vice-Chair,
Pablo ABBATE	(FANR, United Arab Emirates),
Alfred ISSA	(NRC, United States of America),
John MONNINGER	(NRC, United States of America),
Andrea VALENTIN	(NRC, United States of America),
Craig REIERSEN	(ONR, United Kingdom),
Miguel PEINADOR-VEIRA	(European Commission).

Aurélie Lorin and Takayoshi Nezuka (NEA Secretariat) skilfully supported the meetings and editing of this report.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The purpose of the WGRNR construction experience (ConEx) programme is to learn from past construction related experience by collecting, analysing, reporting and sharing related information to help avoid recurrence during all stages of new reactor construction. This ConEx Second Synthesis Report summarises 63 events reported to the WGRNR ConEx database by the NEA member countries regulatory bodies between 2011 and 2014.

The reported events are discussed in seven chapters, each oriented around a technical discipline. An overview is included at the beginning of each chapter to summarise the lessons learnt in that section. The main findings of the report are drawn together in the form of a set of cross-cutting conclusions.

Some of the notable events discussed in this report include a catastrophic pipe failure during pre-operational testing caused by inadequate overpressure protection; significant and complicated problems with the supply of emergency and station blackout diesel generators caused by, among other things, inadequate design inputs, the lack of interdisciplinary involvement and poor supplier oversight; and a significant problem with cable installation caused by a poor design that did not take into account cable separation requirements and underestimated the volume of cables needed.

Many of the reported events were caused by a failure to apply well-known and well-established industry standards and guidelines. They illustrate the importance of instituting and implementing a rigorous design control process. Deficiencies caused by an inadequate design control process may be latent and therefore difficult to detect by normal inspection and surveillance processes. Thus, these defects may only become evident when they cause unexpected failures that result in significant problems during testing and operations.

The report reinforces the need to create, maintain and enhance a robust management system for new reactor construction which integrates all relevant processes, including engineering and design management, requirements management, configuration management including change management, and quality management programme including corrective actions and non-conformances. All processes should be well-defined through clear procedures, which are applied consistently and met throughout the supply chain.

Several events illustrate the importance of having a robust safety culture. Some events provide examples where management pressure to meet programme schedules resulted in errors or omissions; others highlight the importance of having a conservative decision making process that prioritises nuclear safety; while another event shows the importance of having robust risk assessment processes for high risk maintenance, repair or testing works. The need for a questioning attitude and a rigorous and prudent approach is a common theme in the events reported here. Several emphasise the importance of individuals understanding work procedures, being alert for the unexpected and forgoing shortcuts. These behaviours should be reinforced by front line control and supervision to be sure that nuclear safety requirements are understood, prioritised and met.

Underpinning this front line focus on supporting the right behaviours to prioritise safety should be a senior management commitment to put in place the infrastructure that addresses aspects such as safety policies and processes, and provides for independent challenge and advice functions that support effective self-regulation. The events described in this report have illustrated the contribution to safety that can be made by, for instance, open and effective communication and the feedback of operating experience; and good control of design changes, plant modifications and operating procedures. All organisations should arrange for regular review of those of their practices that contribute to nuclear plant safety culture. Independent reviewers can sometimes more clearly notice the need for improvements and suitable provision for this should be considered by both licensee and regulator.

A number of events highlight weaknesses in supply chain management and oversight. Quality assurance and control of material and component procurement need continuous and proactive oversight from the vendor and licensee. Particular attention must be dedicated to situations where small or new subcontractors are in charge of safety related components manufacturing, because they often provide services to other organisations outside the nuclear sector and may not understand, or wish to adhere to, nuclear-specific standards and processes. For this reason, regulatory oversight of the way in which the licensee ensures that its expectations are met at all levels in the supply chain is advisable.

INTRODUCTION

In December 2007, the OECD Nuclear Energy Agency's Committee on Nuclear Regulatory Activities (CNRA) decided to establish the Working Group on the Regulation of New Reactors (WGRNR) which is responsible for the scope of work dealing with regulatory activities in the primary programme areas of siting, licensing and oversight of construction for new commercial nuclear power reactors.

In order to support the implementation of these new build programme areas, WGRNR established an international construction experience (ConEx) programme to exchange construction experience including the impact of construction activities on the safe operation and decommissioning of existing plants (at new construction sites where such older plants exist). In order to support their nuclear safety mission, the nuclear regulatory organisations involved in new build activities incorporate the applicable lessons learnt from this programme into their regulatory oversight programmes.

The ConEx programme includes a database which contains events that have causes and/or lessons learnt related to problems introduced before the commercial operation of nuclear power plants and detected at any stage of the plant life (during design, fabrication, testing, operation and inspection). As such, this database includes many events at operating nuclear power plants caused by latent design and construction activities as well as events revealed during the construction and commissioning of new plants. In addition, the database may include events caused by the implementation of major design modifications at operating facilities if they result in lessons learnt for new builds.

Although the ConEx database is intended for use solely by participating nuclear regulatory organisations, this report was developed with the aim of serving all designers, vendors, licensees and regulators alike with the objective of maximise improvements to nuclear safety by helping to avoid recurrence.

This second report continues the path initiated by the *First Construction Experience Synthesis Report* NEA/CNRA/R(2012)2[1] issued in May 2012 that provided a summary and brief on events and lessons derived from the first entries that were loaded in the ConEx database.

At the time this report was issued, the ConEx database contained 92 events that were discovered between 1985 and 2014 and have been reported between 2010 and 2015, of which 63[2] events are analysed in this report and 7[3] in the first report. The 63 events covered in this report were loaded in the ConEx database between 2011 and 2014 and have been quality checked. A further 22 events were either entered into the database after the preparation of the report started or had not been quality checked to include in this issue. The quality of the ConEx event entries and the ensuing synthesis reports is still improving. Therefore, constructive feedback in this regard is welcome.

To enhance the usability of the report, events have been grouped in 7 technical chapters. When events are related to several categories, they have been classified in the most relevant one. Each chapter includes an overview section with key recommendations along with a list of related events. The list provides a summarised description of each event, its causes, resulting lessons learnt and available references. The

[1] Follow this link to download the report http://www.oecd-nea.org/nsd/docs/2012/cnra-r2012-2.pdf.
[2] Please consult Appendix 1 for the list of ConEx database entries analysed in the second synthesis report.
[3] Please consult Appendix 2 for the list of ConEx database entries analysed in the first synthesis report.

report is concluded with a discussion of the cross-cutting issues of safety culture, human and organisational factors and supply chain management as applicable.

Acronyms used throughout this report are presented in Appendix 3.

Given the summary nature of the information presented in this report, readers interested in more details about a specific event should contact neapub@oecd-nea.org.

1. DESIGN

Overview

Most of the events reported in this chapter were caused by a failure to apply well-known and well-established industry standards and guidelines. They illustrate the importance of instituting and implementing a rigorous design control process (such as that described by US Nuclear Regulatory Commission (NRC) Regulations, Title 10, Code of Federal Regulations, Part 50, Appendix B, Criterion III). Deficiencies caused by an inadequate design control process may be latent and therefore difficult to detect by normal inspection and surveillance processes. Thus, these defects may only become evident when they cause unexpected failures that result in significant problems during testing and operation or, worse, complicate the response to certain transients or accidents. One reported event emphasises the importance of establishing and maintaining adequate interfaces among the various design disciplines in order to account for human factors requirements and another event discusses problems with innovative digital Instrumentation and Control (I&C) system design. Finally, general quality assurance problems associated with commercial grade dedication (supply chain) have the potential to cause common cause failures and result in latent defects during accident conditions. The following constitute illustrative examples:

- Event 71 describes a pipe failure during pre-operational testing caused by inadequate overpressure protection, a well-established requirement.
- Event 48 describes a single point vulnerability that caused an unplanned shutdown. Designing for single failure is a known regulatory requirement (for example in the NRC Regulations, Title 10, Code of Federal Regulations, Part 50, Appendix A General Design Criteria for Nuclear Power Plants).
- Event 63 describes concerns with tanks that had the potential to complicate the response of certain plants to seismic events. Again, the protection of safety related plant equipment and features during seismic events during all testing and operating conditions is a well-known requirement.
- Event 107 describes a design interface problem that affected the readability of alarm messages displayed in the control room, a human factors problem. Establishing and implementing adequate design control interfaces is required by regulations. Accounting for human factors specifically is also a well-known requirement.
- Event 68 included in chapter 5 describes multiple significant problems associated with the design of safety related digital I&C systems. The use of safety related digital I&C in the nuclear industry is fairly new and, therefore, is considered innovative. It has specific and unique requirements that were not very well-understood and implemented according to the inspection report referenced in event 68. It is essential to understand and correctly implement the unique requirements of the design of digital I&C systems, to comply with applicable codes and standards that require among other things, a defence-in-depth approach such as the conduct of a fully independent software verification and validation process.
- Event 47 describes several cases of inadequate commercial-grade dedication procedures. These deficiencies, if not corrected, may become latent vulnerabilities which might be revealed only much later, during the operation of the plant. It is thus essential not to overlook the significance of this kind of event.

Event 47. Commercial-grade dedication issues identified during inspections

United States of America – All Nuclear Power Plants (NPPs) – 2011/02/15

Description	Cause(s)	Lesson(s) learnt
Commercial grade dedication (CGD) problems identified in four main areas of concern: (1) lack of engineering justification during the CGD process, (2) documentation, (3) vendor audits versus commercial-grade surveys and (4) sampling plans.	Some procedures did not provide adequate guidance; lack of safety significance determination; lack of appreciation of the complexity of the item being dedicated; inadequate selection, documentation and implementation of sampling plans; and misunderstanding of Nuclear Regulatory Commission (NRC)'s expectations.	Regulators may want to verify the following related to commercial grade dedication: – Complete documentation and auditable records of the rationale, justifications and engineering analyses are available as part of the dedication package for the item or service being dedicated; – Dedicators are properly implementing related NRC and industry guidance such as Electric Power Research Institute (EPRI) NP-5652.
References: NRC Information Notice (IN) 2011-01, "Commercial-Grade Dedication Issues Identified During NRC Inspections"		

Event 48. Spurious shutdown system 2 trip

Canada – Darlington 4 – 2010/04/10

Description	Cause(s)	Lesson(s) learnt
A spurious signal from two instrumentation channels caused the shutdown of the unit. NB: A unit trips when two out of the three instrumentation channels send trip signals on any parameter.	Both channels share the same instrument tap line to the Calandria. Hydraulic interaction occurs when the manual isolation valve is opened after backfill activities, resulting in signal spikes. The opening speed determines the magnitude of the spike, which explains why this this phenomenon had not been observed earlier.	The design of the instrumentation tubing in new plants should carefully consider the operability and testability of systems. Hydraulic interaction between instrumentation impulse lines belonging to redundant channels should be avoided for all system configurations. More generally, new builds need to maintain independence between redundant systems in order to avoid single point vulnerabilities.

Event 63. Seismic considerations – Principally issues involving tanks

United States of America – LaSalle, River Bend, Shearon Harris – 2012/01/26

Description	Cause(s)	Lesson(s) learnt
NRC inspectors have identified multiple seismic concerns with tanks at US nuclear facilities. In two instances, the seismic II/I analyses for non-safety related test tanks assumed the tanks to be empty when they could have significant water under some conditions. In another instance, the seismically supported refuelling water storage tank was aligned to the non-seismic fuel pool purification system, making the tank inoperable.	The impacted licensees failed to recognise various seismic considerations and system alignment issues that could negatively impact nuclear safety by invalidating the related seismic analyses.	Lessons learnt stemming from these events as they apply to new build design and construction include: – Seismic analyses must be based on correct design inputs and meet engineering rigor; – Assumptions must be validated and maintained by instituting proper controls, e.g. test tanks should be drained after testing if the seismic calculation is based on an empty tank; – Design control measures must be instituted at all times and not just during initial design in order to ensure that design and procedure changes do not result in unanalysed conditions. For example, a procedure change to align non-seismic piping to seismic piping could result in draining an associated tank during or following a seismic event and therefore, invalidating its seismic qualification.
References: NRC IN 2012-01, "Seismic Considerations – Principally Issues Involving Tanks"		

Event 71. Rupture of a feedwater pipe

Germany – Muelheim-Kaerlich – 1985/06/27

Description	Cause(s)	Lesson(s) learnt
During pre-operational tests, a pressure increase in one of the four main feedwater pumps discharge lines caused the rupture of the pipe (440 mm nominal diameter) and damaged two valves.	A volume of cold water had been trapped in the discharge line of one of the pumps, between a check valve and the isolation gate valve. Heat conduction through the closed valves from the hot feedwater flowing in recirculation mode caused the temperature of the trapped water to rise producing a pressure increase high enough to burst the pipe.	Prior to pre-operational testing, new plants should analyse whether any of their systems could experience operating conditions causing the heating of an enclosed volume of water up to an unacceptable pressure. New build regulators may want to verify that their licensees either design fluid systems for overpressure protection per applicable boiler and pressure vessel codes, or include protected procedural steps to avoid over-pressurisation under all testing and operating conditions.

Event 90. Receipt inspection issues

United States of America – Vogtle -3 & 4 and V.C. Summer-2 & 3 – 2012/11/30

Description	Cause(s)	Lesson(s) learnt
NRC inspections revealed several failures of the licensee to adequately inspect safety-related materials (embedded plates or nuclear island basemat reinforcing steel among others) at supplier facilities and upon receipt. If undetected, this event would have caused the auxiliary building and containment internal structures not to meet their design basis requirements.	The quality oversight and inspection programme put in place by the plant contractor did not use a strategic, integrated and graded approach.	In light of this event, regulators may want to verify that licensees and their contractors have established and adequately implemented a robust quality oversight and inspection programme that provides reasonable assurance that constructed structures, systems and components, meet their design specifications.

References:

1. Southern Nuclear Operating Company Vogtle Electric Generating Plant Units 3 And 4 – NRC Integrated Inspection Reports 05200025/2012-004, 05200026/2012-004 and Notice Of Violation
2. South Carolina Electric And Gas V.C. Summer Nuclear Station Units 2 And 3 – NRC Inspection Report 05200027/2012004, 05200028/2012004 and Notice Of Violation

Event 107. Design mismatch of control room display windows of plant monitoring and alarm system

Republic of Korea – Shinwolsung 2 – 2011/05/19

Description	Cause(s)	Lesson(s) learnt
During regulatory inspection of the plant monitoring and alarm system, some control room display windows did not display the whole alarm messages when the length of the message exceeded certain length. In all, 203 out of 1 042 windows were affected. This would have degraded human factors of control room operators.	Lack of co-ordination between teams designing the window pixel size and the alarm messages.	– Human factor requirements need to be emphasised when designing plant monitoring and alarm system. – Co-ordination and co-operation efforts are recommended between relevant groups when designing plant monitoring and alarm system. – New build regulators may want to verify that measures are "established for the identification and control of design interfaces and for co-ordination among participating design organisations. These measures shall include the establishment of procedures among participating design organisations for the review, approval, release, distribution and revision of documents involving design interfaces" (from NRC Regulations, Title 10, Code of Federal Regulations, Part 50, Appendix B, Criterion III).

Event 113. Improperly sloped instrument sensing lines

United States of America – Watts Bar-2 – 2013/04/29

Description	Cause(s)	Lesson(s) learnt
Watts Bar Unit 2 issued an interim construction deficiency report regarding a condition that had the potential to be a significant programmatic breakdown in the instrument sensing line installation programme.	The instrument line sloping problems described in IN 2013-12 were caused by either misinterpreting the related construction procedure, which lacked proper detail, or failing to install the lines per the appropriate design and installation criteria.	New build regulators may want to verify that: – installed instrument sensing lines for liquid measurements slope continuously downward from the process connection to the instrument to help prevent air entrapment in the lines that could impact the function of the instrument and lead to false indications; – installed sensing lines for gas measurements slope continuously upward from the process connection to the instrument to ensure water entrained in the gas does not impair the function of the instrument.
References: NRC IN 2013-12, "Improperly Sloped Instrument Sensing Lines"		

2. CIVIL CONSTRUCTION

Overview

The events reported in this chapter highlight the importance of adhering to the applicable design and licensing bases including the industry codes and standards that they invoke. In addition, they show that use of the defence-in-depth concept during all design and installation phases can prevent significant latent problems. Good housekeeping and avoiding water intrusion into the concrete is another factor to be managed during concrete work. A positive safety culture, good organisational management, and effective and efficient inspection programmes established and performed by the licensee and regulatory body are also necessary.

- Events 44 and 115 illustrate the importance of the application of the defence-in-depth concept during the design and installation phases. In the first event, the licensee correctly followed alkali-silica reaction ASR testing specifications acceptable at the time of construction but later proved to be deficient in detecting ASR prone conditions in all cases. The resulting problems would have been avoided had the waterproof membrane not been damaged and had the dewatering channels not been abandoned. The second event describes laminar subsurface cracks in a building exposed to the elements. It was determined that the cracks were caused by moisture intrusion and freezing. Although the building was designed in accordance with applicable codes and standards, the problem could have been avoided by the application of waterproofing material (e.g. sealant or coating) on the outer surface of the containment shield building.
- Event 116 highlights the importance of implementing a solid foreign material exclusion (FME) and good housekeeping programmes during design and construction. Containment liner corrosion problems occurred because organic foreign materials were either deliberately introduced by designers or left behind by construction workers between the liner or penetration sleeve and concrete. It is recommended that designers avoid the introduction of organic material at concrete and steel interfaces. In addition, good housekeeping should be implemented throughout all phases of new build construction.
- Event 57 reports that some subcontractors did not follow some ETC-C rules (European Pressurized Reactor Technical Code for Civil works) in their concrete work such as lack of joint treatment for the concrete pouring activities, use of concrete rake which is not allowed, use of surface solvent for joint treatment for which justification is not made and poor joint treatment quality. Regulators need to focus on how well licensee, contractors and subcontractors meet the code requirements while performing onsite inspection. A high standard of safety culture and adherence to well-established management system also need to be emphasised.
- Event 67 reports that a licensee did not get prior approval through the licence amendment process when it modified a certified design control document. This is considered to be an example of lack of safety culture and illustrates concerns with human and organisational issues.
- Event 100 reports that some safety-related anchors designed by several anchor manufactures were found to have not been properly installed and had to be replaced. Construction personnel training, quality checking and recording on each installation step, plus sufficient co-operation between system personnel and construction personnel was found to be necessary to prevent the event from recurring.
- Event 101 reports that high rebar density areas and high pouring lift issues caused a problem which exceeded the criteria for flatness of walls. The lesson learnt from this event is that when a new approach is introduced which is not specified in the relevant design code, the approach should be justified through mock up to prove the appropriateness of the new method. This event illustrates concerns with human and organisational issues.

Event 44. Adverse concrete conditions due to distress from alkali-silica reaction

United States of America – Seabrook – 2009/06/01

Description	Cause(s)	Lesson(s) learnt
Alkali-silica reaction (ASR) is a slow chemical process in which alkalis, usually predominantly from the cement, react with certain reactive types of silica (e.g. chert, quartzite, opal and strained quartz crystals) in the aggregate, when moisture is present. This reaction produces an alkali-silica gel that can absorb water and expand to cause micro-cracking of the concrete. Excessive expansion of the gel can lead to significant cracking which can significantly degrade the concrete by changing its mechanical properties. This reaction took place at a US NPP resulting in a substantial reduction in compressive strength and modulus of elasticity.	The licensee believes that the waterproof membrane was damaged during original installation or backfill activities and the damaged membrane caused the water intrusion problem. Water intrusion was exacerbated by the fact that dewatering channels were abandoned.	Although the final root cause analysis has not been determined by the licensee yet, some of the lessons learnt for new reactor construction as of this time may include: – Utilise the latest techniques to check concrete constituents susceptibility to ASR; – Minimise water intrusion by eliminating such causes as damage to waterproofing membrane during installation and post installation activities. Note that besides contributing to ASR, water intrusion can also cause general corrosion to below grade steel, piping and pipe supports etc.; – Mitigate the consequences of water intrusion such as by using dewatering channels.
References: NRC IN 2011-20, “Concrete Degradation by Alkali-Silica Reaction”		

Event 57. Defects in joint treatments between two concreted parts

France – Flamanville 3 – 2009/02/11

Description	Cause(s)	Lesson(s) learnt
The EPR Technical Code for Construction (ETC-C) requires a defined pressurised air and water technique for the realisation of joint treatments between two concreted parts and any other techniques must be fully justified. There have been found some non-compliances such as: – lack of joint treatment for the concrete pouring activities of the gusset area; – the use of concrete rake on the aircraft shell concrete walls; – the use of surface solvents on several buildings; – poor joint treatment quality (lack of roughness) and applying joint treatments techniques without justification for the techniques different from the one (pressurised air and water) required by the ETC-C requirements; – use of a solvent (the deactivator) that is not allowed for construction joint in nuclear plant civil works.	– Not fully justified joint treatment techniques were implemented between the two concrete parts; – Misunderstanding of ETC-C code requirements for the use of deactivator in joint treatment; – Inappropriate application of surface solvents for joint treatments.	Based on the French Nuclear Safety Authority (ASN)'s regulatory inspection results, the following lessons have been learnt: – Joint treatment techniques need to be verified to ensure concrete construction is proceeded in accordance with the construction code requirements; – Caution should be given to operator and subcontractors to see if they address the derogations to the construction code appropriately.

Event 67. Rebar design change

United States of America – Vogtle-3 – 2012/05/07

Description	Cause(s)	Lesson(s) learnt
During a NRC inspection completed on 7 May 2012, two violations of NRC requirements were identified: 1) The nuclear island basemat bottom flexural reinforcement did not comply with the provisions of ACI 349-01; 2) The licensee departed from the certified design control document without NRC approval. This violation impacts the ability of the NRC to perform its regulatory oversight function.	The causes of these violations are human performance related. The licensee failed to assure that regulatory requirements and the design basis for systems, structures and components were correctly translated into specifications and instructions associated with the nuclear island basemat reinforcement. In addition, the licensee failed to request a licence amendment from the NRC prior to deviating from the certified design control document.	Regulatory requirements and the design basis for systems, structures and components must be correctly translated into specifications and instructions. In addition, licensees must comply with the requirements of the certified design control document or request a licence amendment.
References: Southern Nuclear Operating Company Vogtle Electric Generating Plant Units 3 – NRC Inspections, Tests, Analyses and Acceptance Criteria (ITAAC) Inspection Report No. 05200025/2012-008 and Notice of Violation		

Event 100. Incorrectly installed anchors in German nuclear plants

Germany – All NPPs – 2006/09/15

Description	Cause(s)	Lesson(s) learnt
During a plant walk-down after refuelling outage of a German NPP, 3 self-undercutting anchors of the design HDA-T (heavy-duty mechanical anchor through set-style) had been found to be loosened from their correct positions. A check of other upgraded anchorages showed that some of these had also not been mounted correctly. Similar anomalies were also found in the several NPPs and the affected anchors were manufactured by several anchor manufactures. The wrongly installed anchor designs were undercut anchors, self-undercut anchors and expansion anchors. The further inspections revealed: – too few anchors installed; – missing washers and; – the use of wrong anchor types. In the case of rear bar hits new holes had to be drilled. In some cases the unused holes were not correctly backfilled.	The direct causes seem to be: – too deep bore holes; – bore holes drilled not deep enough; – anchors not in the correct position; – undercutting not correctly performed. The main root causes are: – insufficient training of the installation personal including work sample; – insufficient written instructions for planning and installation; – lack of detailed check lists; – final checks of installed anchors (before mounting the anchor plate); – missing coordination and unclear responsibilities between the plant departments for system design and departments for buildings; – use of improper tools.	Before the installation of safety-related anchors: – the function of the anchors should be explained to the personnel in detail; – the personnel must be trained; – installation instructions must be available and understood; – specified tools must be used (drill bits and drilling machine); – every step of installation must be checked and documented by competent personnel; – sufficient co-operation and co-ordination methods must be established between the systems and construction departments as well as between the licensee and the relevant organisations.

Event 101. Pouring activities of pools or tanks – high rebar density areas and high pouring lift issues

France – Flamanville 3 – 2010/12/01

Description	Cause(s)	Lesson(s) learnt
The ETC-C specifies the flatness tolerances for the wall of the pools is important to reduce the mechanical loading resulted from temperature increase due to an accident. The unproven new approach of the following caused the flatness problem: – Use high pouring lifts (up to 6 metres); – Fix the steel framework to the reinforcement steel and/or to the formwork and pour directly the concrete; – Fix the steel structures receiving removable steel gates and use it as formwork for pouring; – When the formworks were removed, numerous areas of the walls were found full of stones and/or without cement; – Due to the height of the lift, it was not possible to perform adequate join treatments between 2 lifts. – Acoustic method was used to check whether concrete was correctly poured behind the steel structures.	– An unproven way of pouring concrete was introduced. – Analysis was not performed for the new approach of high pouring lift up to 6 meters in concrete pouring against the ETC-C code. – Flat tolerances for the wall of pools were not considered satisfactorily while performing the concrete pouring work.	– When a new way of concrete pouring method is introduced, the operator should require a mock up to prove the appropriateness of the new way with the safety criteria. – Operator has to perform risk analysis of the new method to implement preventive actions and avoid defects. – Acoustic method was proven to be efficient and effective to check whether concrete was correctly poured behind the steel structures when rework was performed. – Cautions need to be paid in flatness check for the wall of the pools while performing the concrete pouring work.

Event 115. Shield building concrete subsurface lamina cracking caused by moisture intrusion and freezing

United States of America – Davis-Besse – 2011/10/10

Description	Cause(s)	Lesson(s) learnt
Laminar subsurface cracks were discovered in the Davis-Besse reinforced concrete containment shield building (SB) caused by moisture intrusion and freezing.	The SB concrete laminar cracking was caused by the integrated effect of moisture content, wind speed, temperature and the duration of these conditions during a snow blizzard.	For new build, preventative measures can be taken in the design and construction phase to ensure the effect of moisture intrusion in concrete will be mitigated. For example, the application of waterproofing material (e.g. sealant or coating) on the outer surface of the containment shield building combined with an effective maintenance programme for the waterproofing material should preclude moisture induced subsurface laminar cracking.
References: NRC IN 2013-04, "Shield Building Concrete Subsurface Laminar Cracking Caused by Moisture Intrusion and Freezing"		

Event 116. Containment liner corrosion

United States of America – Beaver Valley-1 – 2009/04/23

Description	Cause(s)	Lesson(s) learnt
Many instances of concrete containment liner corrosion caused by latent design and construction problems.	Moisture contacting the steel liner through construction practices, water leaks or organic material left in place due to inadequate housekeeping and quality assurance practices during construction.	The objects and materials that caused liner corrosion that licensees have found lodged between or embedded in the containment concrete include both foreign material (e.g. wooden pieces, workers' gloves, wire brush handles) and material that was deliberately installed as part of the design. Designers should avoid the deliberate installation of organic material between the liner or penetration sleeve and concrete; and construction should adhere to good housekeeping practices that prevent the introduction of foreign organic material between the steel liner and the concrete.
References: NRC IN 2010-12, "Containment Liner Corrosion"		

3. MECHANICAL

Overview

The events reported in this chapter highlight the importance of adhering to applicable mechanical and manufacturing codes, standards and procedures. In addition, they emphasise the need for adequate welding procedures, personnel training and quality oversight. An effective corrective action programme by the licensees and their nuclear safety related suppliers should include a thorough failure mode analysis to determine the correct causes of significant conditions adverse to quality and implement preventive actions to preclude recurrence. Finally, regulators should verify that licensees are applying adequate oversight of their nuclear safety related suppliers to insure a high quality supply chain.

- Event 71, discussed in Chapter 1 above, describes a catastrophic pipe failure during pre-operational testing caused by inadequate overpressure protection, a well-established requirement by boiler and pressure vessel codes.
- Event 114 covers significant large component fabrication welding issues that provide important lessons learnt in the areas of adequate procedures, training and quality oversight.
- Event 112 illustrates that control over all aspects of welding American Society of Mechanical Engineers (ASME) Code Class 1, 2 and 3 components can prevent similar welding defects from occurring.
- Event 40 emphasises the need to determine the root cause of the event. It also highlights the importance of oversight activities of manufacturing first of a kind components even when applying qualified and long established manufacturing processes.
- Event 65 reflects the importance of following the applicable manufacturing codes. In this case, shot blasting after casting hid surface indications formed during the casting process. Material surface inspections, such as Penetrant Test (PT) examinations, should be performed as soon as possible after the forming process. In addition, when grinding austenitic steel, visual examination of internal and external surfaces are required to detect non-conformities. Event 62 shows that compliance with the radiation protection requirements of the relevant RCC-M code and the licensee's guidelines were not sufficient to insure cleanliness requirements following the grinding of austenitic steel. This resulted in the supplier producing tubes that contained loose particles that were not detected by the quality control processes used. Purchase specifications should supplement manufacturing codes to insure the required surface finish cleanliness of manufactured parts;

- Many events discuss issues with the quality of the supply chain. Event 103 and event 99 represent significant supply chain management problems. These problems include among other things: outdated/inaccurate design inputs by the purchaser; lack of engineering interdisciplinary involvement (only electrical engineers were initially involved in the design); using unqualified/unaudited sub-suppliers; and lack of adequate oversight. Finally, fraud and human performance problems in the manufacturing supply chain caused mistakes to occur as indicated in event 97. The events discussed above stress the importance of preparing accurate and detailed purchase specifications and keeping them up to date. The requirements in these specifications must be imposed on all suppliers and sub-suppliers. The licensees and their contractors should utilise qualified and audited suppliers to supply their safety related structures, systems and components, and exercise adequate quality control oversight of the supply chain at all levels. Safety culture and the potential for fraud should be closely monitored and problems should be dealt with immediately and effectively.

Event 9. Heavy component manufacturing – Pressuriser

France – Flamanville 3 – 2008/07/10

Description	Cause(s)	Lesson(s) learnt
In 2008, an approved organisation was appointed by ASN to perform the conformity assessment of a shell of the pressuriser at a subcontractor factory. On 10 July 2008, during an inspection, the approved organisation detected a non-conformity during mechanical tests (drop-weight test) done at the end of one of the shell manufacturing.	The drop-weight test is used to determine the nil-ductility transition temperature. This test employs simple beam specimens specially prepared to create a material crack. It employs a small weld bead deposited on the specimen surface and is performed in accordance with the ASTM (American Society for Testing and Materials) E208 standard. The procedure used by the supplier met the American standard; however the test was not performed according to this procedure. In fact, the welding electrodes were not qualified. This was detected by the approved organisation after the test was done because the results were incorrect. The use of non-qualified welding electrodes is the direct cause of the event. As no qualified electrodes were available, the subcontractor chose to use other electrodes without checking their conformity.	The manufacturer must improve its agreement and subcontractors surveillance system by using an appropriate analysis of non-conformities and difficulties encountered during inspections and manufacturing.

Event 10. Heavy component manufacturing – Steam generator misdrilling

France – Flamanville 3 – 2008/11/19

Description	Cause(s)	Lesson(s) learnt
On 19 November 2008, the manufacturer detected a manufacturing anomaly on the conical shell of steam generator for the European Pressurized Reactor (EPR) at Flamanville 3. The manufacturer discovered that the hole for the tubular feed-water nozzle was vertically misaligned by 453 mm. The hole had been bored in the wrong position due to a marking error. This anomaly was not consistent with the design of the steam generator internals or with the installation of the steam generator into the primary cooling system. The drilling non-conformance occurred following incorrect marking. It is believed that there was insufficient independence of the operator and verifier for the marking.	Management related causal factors and root causes : the consequence of the drilling of a hole misaligned by 453 mm was the rendering a conical shell unusable for the Flamanville 3 steam generator. This has entailed a considerable additional amount of test, analyses and ultimately time and money for the fabrication of the Flamanville 3 EPR components.	As a preventive action, the manufacturer performed a root cause analysis which was reviewed by ASN as part of its review inspection held on 14 to 18 September 2009. ASN found the preventative actions taken by the manufacturer to be sufficient to prevent recurrence. ASN has been monitoring the situation closely. The manufacturer is required to obtain ASN approval for certain activities, and ASN maintains hold points at various stages of pressure boundary equipment, such as the steam generators. As such, the manufacturer has kept ASN informed of its planned actions and sought approval when necessary.

Event 40. Main coolant lines (hot and cold legs) manufacturing – Heat-affected zone micro-cracking

Finland – Olkiluoto 3 – 2009/02/10

Description	Cause(s)	Lesson(s) learnt
Main coolant line (MCL) girth welds are made using narrow-gap Gas Tungsten Arc Welding (GTAW) – or Tungsten Inert Gas (TIG) – process. In two hot legs, weld intermediate PT showed indications in the heat-affected zone (HAZ) at the pipe external surfaces. Indications were formed at cracked grain boundaries. They were removed by grinding before continuing to the final weld surfacing passes. A metallographic replica study, scanning electron microscope (SEM) examinations and weld thermal cycle modelling were conducted. Proof of an exact root cause for the cracking was not found out, but ductility dip cracking (DDC) was seen the most relevant mechanism. The phenomenon was occurring at thick section outer surface. Since no effect deeper on the wall thickness was seen possible, the case was considered to have minor safety significance.	The micro-cracking was located at the component outer surface. It was concluded that cracking depth was shallow and it would not be likely to occur as buried under-surface defects. In case this type of defects would remain in the component unfound, they would still not have a major effect on the pipe strength due to the small depth and due to the fact that the cracked positions will be covered by a weld surfacing overlay when welding the final passes. Grinding and extra PT and Ultrasonic Test (UT) were conducted by the vendor to repair the defects. According to reports to the Finnish regulatory body STUK, vendor did not make corrective actions. However, the defects were only reported in two of the first welds. A total of 36 of this type of welds were made including both shop and onsite welds. Extra PT and UT were required. A thermo-mechanical weld modelling was required and reported for a clearer picture on the strain-temperature-deformation history of the weld area.	During manufacturing first of a kind evolutionary components, even qualified and long used manufacturing processes may produce surprises. Following of welding and materials technology research is essential in order to understand possible component failure mechanisms.

Event 41. Main coolant lines (hot and cold legs) manufacturing – Non-documented weld repairs

Finland – Olkiluoto 3 – 2009/10/06

Description	Cause(s)	Lesson(s) learnt
Visual testing (VT) after pipe pickling revealed small non-documented welds on MCL inner and outer surfaces at an offsite manufacturer. Welds were found on 10 out of 12 pipes. Weld depths were 0-5 mm. The reason for making the welds had been a habit to finalise small scratches and dents by welding and to re-melt manual metal arc (MMA) weld toes using TIG process. TIG welding and the filler metals used were qualified for nozzles welding, but the repair welding was done without documentation (violation of Design and Construction Rules for mechanical components of pressurized water reactor (PWR) nuclear islands (RCC–M) S 7120 and S 7600) and without Non-Conformance Report (NCR) handling. Technical NCR's were opened and welds' properties were evaluated using VT, PT, UT, radiographic test (RT), positive material identification (PMI) – chemical analysis – and metallographic replicas. Some welds were removed using smooth grinding while the majority was left in the products as is. New repairs were not needed. The manufacturer's quality management system for the supply was based on ISO 9001 and Olkiluoto 3 specific quality plan only. Audit conducted by the licensee revealed deficiencies including failure of not implementing RCC-M A 5200 as a reference for the quality management system. Also Finnish regulatory guide YVL 1.4 (Management systems for nuclear facilities) and IAEA requirements were not followed. The manufacturer started a programme to update the quality management system to fulfil the nuclear quality standards.	Causes for the deficiencies were lack of communication between fabrication and design departments, inadequate education of welders (welding without specification and without documentation) and failures in the implementation of quality management system. These causes reflect lack of nuclear safety culture implementation: – human performance related causal factors and root causes; – management related causal factors and root causes; – repair welds are not located at highly stressed areas. Pipe internal repair welds are not considered likely to have an effect on the component ageing. Pipe external repair welds are considered non-significant.	– Licensee: Manufacturer audits should be capable of setting requirements for the implementation of required quality management systems and quality assurance (QA) requirements, especially nuclear standards. This is specially the case if the manufacturer has not been involved in nuclear fabrication for years. More intense presence in the early manufacturing stages should be considered. – Vendor, manufacturer, contractor: Open and continuous communication between manufacturing and design department is necessary. Presence, support and good example given by the fabrication foremen is needed at fabrication. – Regulator: Regulator should ensure that licensee's supervision of manufacture meets the requirements. The supervision should reveal deficiencies in the manufacturer's quality activities in an early stage of the procurement process. The manufacturer launched the implementation of nuclear specific quality management system and nuclear safety culture enhancement and education programmes. Manufacturer's approval for welding fabrication was suspended.

Event 42. Main coolant lines (hot and cold legs) manufacturing – Internal indications in bended areas

Finland – Olkiluoto 3 – 2010/07/27

Description	Cause(s)	Lesson(s) learnt
Inside surfaces of induction bent main coolant line areas showed circumferential VT and PT indications after pickling right before delivery to site. The majority of the indications were found more than a year after the induction bending, where they originated from. Qualification of the induction bending process had not been completely successful and the quality of the following PT tests had been poor in revealing material discontinuities. Contrary to the RCC-M code, sand blasting had been used directly before PT and it obviously smeared the metal surface and ruined the PT performance. Majority of the indications had successfully gone through two previous VT and PT associated to the bending process. Possibility for common cause not having been properly evaluated as some of these material discontinuities had been found soon after bending.	Direct causes are not yet properly evaluated by the vendor/subcontractor. Material discontinuities have obviously formed in elevated temperature during induction bending. The two possible theories for the formation mechanism are: 1) metal folding or 2) grain boundary cracking. Indirect cause was that 1) the qualification of the induction bending process failed. Preparation for PT was unacceptably done using sand blasting, which resulted in the indications hiding and improper evaluation of the qualification pieces. 2) Even if some indications were found soon after bending, an enhanced test programme was not started by the manufacturer and the common cause was not properly evaluated.	– Licensee: PT should be done as soon as possible after the forming process; – Manufacturing code should be followed during component non-destructive testing. Sand blasting before PT should not be permitted. Root cause and common cause analyses should be raised by default when non-acceptable indications are found during manufacturing. – Vendor, manufacturer, contractor: Forming processes qualification and work test pieces need to be better evaluated before full production. In addition to immediate repair action, common causes have to be properly evaluated; Manufacturing code should be followed during component non-destructive testing; As commonly known, surface preparation may ruin PT reliability by hiding indications under plastic lip (metal smear). – Regulator: Root cause and common cause analyses should be required by default when non-acceptable indications are found during manufacturing.

Event 60. Heavy component manufacturing: vessel closure head buttering thickness

France – Flamanville 3 – 2011/06/01

Description	Cause(s)	Lesson(s) learnt
During the repair work of the adapters' welds of the vessel closure head, manufacturer discovered a second defect concerning the buttering thickness on about 50 welds. Even though it was only evidenced at the time of repair, this defect also concerns grinding operations carried out during the initial fabrication of the closure head before welding. When a grinding operation is carried out on the buttering itself or on an adapter weld, manufacturer uses a template to ensure that the remaining buttering thickness is compliant. Manufacturer has used this template in different configurations: – In the buttering application and machining phases, manufacturer observed areas lacking buttering. Manufacturer therefore performed build-up operations before heat treating the closure head, operations that were followed simply by grinding, not machining. The lack of machining resulted in an excessively thick buttering layer that hampered welder access to the chamfer for the welding operation. Manufacturer therefore reduced the excess thickness of certain buttering layers using guiding templates; – During elimination and repair of the adapter welds, manufacturer used a template to inspect the chamfer depth while grinding the welds; – During the fabrication operations, and notably welding of the dome onto the flange and the stress-relief heat treatment, the closure head dome sags slightly.	Human performance related causal factors and root causes: Manufacturer indicates that 50 adapters were ground before or after welding, sometimes both. Of the 50 adapters subjected to expert operations, the residual buttering thickness of 49 of them cannot be proved satisfactory. The nominal buttering thickness is 8 mm and the minimum thickness required for welding qualification is 5 mm. The lowest residual buttering thickness is to be less than 1 mm. Of the 50 adapters concerned, 35 – corresponding to buttering layers eliminated prior to adapter welding – were welded on insufficiently thick buttering. In such cases it is possible that the closure head base metal was damaged, or even that defects were initiated in the base metal under the buttering. Corrective actions: Manufacture proposed a large-scale repair solution to ASN, involving going back over many of the closure head fabrication steps. This repair process comprises removal of the adapter, all the welds and buttering layers in the heat affected zone on those adapters concerned, reconstruction of the buttering, preventive build-up of the keyways, heat treatment, final machining of the closure head and shrink-fitting of the adapters as well as welding of the adapters onto the closure head.	Risk analysis is necessary when important deviation treatment operations are performed to ensure that all relevant important risks are identified and that preventive actions are defined. ASN has asked the manufacturer to demonstrate that all the risks associated with the repair have been identified, appropriate preventive measures have been implemented and the corresponding procedures are available. Appropriate inspections have been defined in order to detect any drift in the repair process, no operation is likely to call into question the essential safety or radiation protection requirements defined by the regulation, that could not be detected with certainty. The reparation is performed under extra surveillance by ASN and a third party inspection body. Particular vigilance must be applied when implementing the repairing operations to ensure that the critical steps are clearly identified and the associated risks are known and controlled. Manufacturer must demonstrate these elements prior to each step of closure head repair. For the buttering and welding operations, tests must be carried out on a mock-up to allow for the geometry encountered in the buttering repair.

Event 61. Heavy component manufacturing: reactor pressure vessel closure head

France – Flamanville 3 – 2010/11/01

Description	Cause(s)	Lesson(s) learnt
During ultrasonic testing, the manufacturer detected some 6 400 defect indications on the reactor pressure vessel (RPV) closure head penetration welds, at the interface between the adapters and their welds. 93 adapters displayed indications outside the acceptance criteria, while for 13 adapters, the preliminary calculations showed there was no guarantee of their stability if subjected to hydrostatic testing. For the adapter welds, manufacturer used the RCC-M code and considered that the requirement to inspect the entire volume could be replaced by penetrant testing every three weld layer. Manufacturer supplemented this penetrant testing with ultrasonic inspection from the interior of the adapter. The area thus inspected by ultrasounds is restricted to the weld/adapter interface for reasons associated with the weld geometry and the structure of the deposited metal. These indications were detected during an ultrasonic testing; penetrant testings performed during welding had given compliant results. Manufacturer decided to repair all the adapter welds.	Indications were due to change in welding procedures. The cavity repairs carried out led manufacturer to conclude that the observed indications were due to oxide and slag inclusions at the interface between the adapter and the weld on the closure head. There were several welders worked on the same welds. Also there were misinterpretation of an instruction and instead of grinding the angle between the weld and the adapter, the operators almost always belt brushed it, which is less effective. More complex spotfacing geometry: in addition to the higher density of adapters in the EPR reactor closure heads than in the former ones, the spotfacings are particularly narrow and deep. Manufacturer performed an analysis of the consequences of these changes but did not take into account all the potential consequences.	Manufacturer modified its procedures and decided to perform an examination of any change of manufacturing procedures in the future and changes were made in welding practices. Internationally, several closure heads and several manufacturers are concerned by defect indications in the adapter welds. Therefore, further studies should be carried out by the different manufacturers to examine the possibility of improving the conditions for producing these welds. Particular vigilance must be applied when implementing the repairing operations to ensure that the critical steps are clearly identified and the associated risks are known and controlled. Manufacturer must demonstrate these elements prior to each step of closure head repair. Inspection provisions must be supplemented to guarantee the quality of the adapter welds.

Event 62. Non-conformity concerning the surface finish of pipes

France – Flamanville 3 – 2012/03/01

Description	Cause(s)	Lesson(s) learnt
A non-conformity concerning the surface finish of pipes from the EPR safety injection system was detected by the manufacturer during an onsite inspection of those pipes, just before welding. The surface finish presented small particles stuck inside the straight section of the pipes. The tubes used for manufacturing the pipes came from different supplier. A survey has been carried out by the manufacturer in order to check the surface state of every supplied pipe. This survey concludes that only austenitic stainless steel hot extruded pipes are concerned by the non-conformity. Some particles was longer than 1.5 mm (concerned pipes total length: 1 800 m). Some small ripples were also found on these pipes. No issue related to those particles inside the pipes was identified in risk analysis. The radiation protection requirements during manufacturing were not well-identified.	The process of extrusion does not allow the required surface roughness for the austenitic stainless steel. The particles inside the pipes can be activated by the radiation inside the reactor and then cause occupational exposure. A grinding operation has been performed on the pipe by their suppliers in order to satisfy that requirement. This operation is the cause of the particles stuck on the pipes surface. Corrective actions: Manufacturer proposed complementary manufacturing operations to get an acceptable surface finish inside the pipes in non-conformance (by polishing) and decrease the required roughness to ensure the result. Preventive actions: Manufacturer will specify to all their suppliers and subcontractors concerned by austenitic steel the requirement of a surface finish without particles. Manufacturer will decrease the required roughness of austenitic steel equipment in order to avoid grinding. Manufacturer will specify to their subcontractors a visual inspection inside the pipes.	Radiation protection requirements of RCC-M code and the French licensee Electricité De France (EDF) guideline were not sufficient in the case of austenitic steel grinding. Thus, the suppliers produced tubes with removable particles inside and those particles have not been detected by the different tests related to this risk (A23 RCC-M A, B and D tests). EDF proposed to modify its guide about radiation protection requirements during manufacturing to include new requirements concerning surface finish. Visual examination of internal and external surface from the equipment, required by the final verification according to French regulation, is necessary to detect such non-conformities. The manufacturer organisation for risk analysis has to ensure that operations managed by their suppliers or subcontractors do not cause risks not identified in the risk analysis written at an earlier stage. ASN inspected the manufacturing operations to get an acceptable surface finish of the pipes.

Event 64. Ineffective use of vendor technical recommendations

United States of America – All NPPs – 2012/04/24

Description	Cause(s)	Lesson(s) learnt
The NRC issued an IN to inform addressees of recent operating experience regarding the ineffective use of vendor technical recommendations at US nuclear power plants. The resulting events related to construction activities include: the separation of an emergency diesel generator (EDG) exhaust header elbow caused by the failure of temporary welds that should have been replaced by permanent welds as recommended by the vendor; and a significant lubricating oil leak on another EDG caused by inadequate bolt torqueing procedure that did not conform to vendor and industry recommendations.	The causes of these events are human performance related. The impacted licensees did not follow applicable vendor recommendations resulting in significant failures.	In the absence of an engineering evaluation, licensees must follow applicable vendor recommendations to prevent similar failures at their plants. See Generic Letters 83-28 and 90-03 for additional recommendations.

References:

1. NRC IN 2012-06, "Ineffective Use of Vendor Technical Recommendations"
2. Generic Letters 83-28, "Required Actions Based on Generic Implications of Salem ATWS Events"
3. Generic Letter 90-03, "Relaxation of Staff Position in Generic Letter 83-28, Item 2.2 Part 2 "Vendor Interface for Safety-Related Components"

Event 65. Non-conformities on valve body surface

Finland – Olkiluoto 3 – 2010/06/23

Description	Cause(s)	Lesson(s) learnt
Inspection of some valves performed at Olkiluoto unit 3 (OL3) site before delivery to installation found that the valve bodies made of cast austenitic stainless steel showed a number of surface indications. Due to this finding, installation of similar valves already accepted for installation was stopped. The valves installed and delivered from the manufacturer were inspected visually. All valves with surface defects were transported back to manufacturer for corrective actions. The valve bodies are subjected to surface PT after casting and subsequent shot blasting. The shot blasting deforms the cast metal surfaces which may hide surface indications formed in casting. This is why the indications were not detectable in the PT. In the subsequent pickling the acid etching opens the indications again making them visible, which was detected in the receiving inspection. The detected defects are caused by the casting process. Steel casting can cause some surface defects such as small pores. Subsequent shot blasting, however, hides the indications from PT.	Direct cause: – Detected surface defects can cause cracks. These causes a possibility for corrosion and fatigue issues in a long term period; – The manufacturing process and related inspections have been updated so that an extra PT examination (100%) is done after pickling; – Non-conformance report was asked to be sent to STUK for approval. NCR included corrective actions for the valves. Also a root-cause analysis of the event was presented.	Shot blasting after casting can hide surface indications formed during casting process. The surface inspection (in this case PT) should be done so that shot blasting will not disturb inspectability of the components. In this case, an additional PT was scheduled after final pickling where surface indications are detectable.

Event 72. Missing counter-boring in butt weld of safety injection pipes

Republic of Korea – Shin-Kori 3 & 4 – 2011/11/23

Description	Cause(s)	Lesson(s) learnt
Class 2 pipes (4") in the safety injection system had been fabricated without counter-bore, and UT and PT had not been performed after field welding, because requirements of in-service inspection (ISI) was omitted from isometric drawing. One of the purposes of counter-boring is to ensure accurate fit-up prior to welding by machining both pipe ends to the same dimensions, removing any dimensional inconsistencies. Other one is to minimise geometric signals as much as possible on the UT. All butt weld areas in outlet lines of the safety injection pump in the safety injection system should be examined by radiographic test (RT) as non-destructive test in accordance with MNC 5222 of Korea Electrical Power Industry (KEPIC) Code 2000 edition (similar to ASME Code Sect. III. Subsect. NC), and should be performed UT and PT in accordance with Technical Specification for safety related shop fabricated piping for Shin-Kori Units 3 & 4.	Human error: – inattention about exception conditions for ISI requirement of safety injection (SI) system; – lack of supervision of checker and approver system; – absence of previous orientation for ISI requirements; – lack of experienced human resources for design of SI system; – insufficient delivery of experience and information from previous plant design. – Design process: – lack of upgrading effort to computer program. The licensee had issued non-conformance report (NCR) and investigated to establish countermeasures by comparing UT results of Class 1 pipes with counter-bore against UT results of Class 2 pipes without counter-bore. Adequacy of countermeasures and repair process is reviewed as regard to misapplication of ISI requirement in the SI system of Shin-Kori Units 3 & 4. Revisiting to the design system check.	Correction system for human error about major design variables should be established. The licensee and regulator should be well-acquainted with the exception conditions for ISI requirements. The length of counter-bore and the minimum wall thickness of component should be as specified in the applicable standard or specification for the component.

Event 73. Missing of shot peening work process to high pressure turbine rotor

Republic of Korea – Shin-Kori 3 – 2012/03/15

Description	Cause(s)	Lesson(s) learnt
After the delivery of turbine assembly to the NPP construction site, manufacturer's inspector found that there was no shot peening on the turbine rotor. Afterwards the turbine assembly was taken back to the factory and the missing shot peening was performed at the shop. Turbine rotor was shipped to the NPP construction site and reassembled. This kind of event could be hardly detected during manufacturing.	– Missing of description of the shot peening on the fabrication drawing; – Lack of supervising process; – Improper implementation of QA system. The licensee issued the NCR and investigated the cause of the event by checking the fabrication process and the QA system.	Manufacturer should operate the system to prepare the cross-check sheet and distribution, logging system of the design change to prevent the omission of the design change items on the drawing. The licensee should establish the plan to strengthen and implement the fabrication and testing system of the mechanical / electrical / instrumental components. The licensee should also promote the computerised supplier's real-name system about the fabrication and quality control process. In addition to this, the licensee should extend the computerised system to include the contractor's career control and all concerned areas. Finally, the licensee should establish the methods of securing the quality function development of major components.

Event 94. Damage to the moderator inlet nozzles of calandria

India – Kaiga 3 & 4 – 2002/04/30

Description	Cause(s)	Lesson(s) learnt
In pressurised heavy water reactor (PHWR), calandria is a horizontal cylindrical shell which holds low temperature and low pressure heavy water moderator. During transportation of two calandrias for Kaiga 3 & 4 project on two separate tractor-trailers by road, the shipping frame was hit by tree branches while taking some sharp turn. The shipping frame got locally damaged and in process it hit the wooden covers of the nozzles and damaged the nozzles at the free end. In the first calandria six nozzles got damaged where four out of these six had flat spot (60 mm max.) from outside and other two had dents (approx. 1.5 mm depth) from inside. In the second calandria there was one nozzle damaged which had a dent from inside. Corrective actions: non-destructive testing (NDT) was carried out on the inner and outer surfaces of the damaged nozzles including weld areas. No unacceptable indication was found. The main shell around the damaged nozzle was checked and no damage was noticed. A detailed procedure was prepared for smooth grinding and filling of the dents and removal of the flat spots by cutting.	Flat spots on the outer face of the nozzles were due to hit by the angles of shipping frame located near the nozzle. The dents on the inner face were due to the hit by the bolts supporting the wooden covers, for the nozzles. These wooden covers were hit by the angles of the shipping frame and got broken; resulting in hit on the inner face of the nozzle by the supporting bolts. The event was due to inadequate supervision and deficiency in adherence to transport procedure for over designed consignment (ODC) by the transporter. Calandria is an irreplaceable component during the operating life time of PHWRs. During the course of plant operation, any repair or modification job on calandria is highly dose intensive and should be avoided.	Enhanced supervision and strict adherence to transport procedure for transportation of ODC should be ensured.

Event 95. Guillotine rupture of fire water line to a steam generator in reactor building

India – Rajasthan-5 – 2009/12/23

Description	Cause(s)	Lesson(s) learnt
On 23 December 2009, Rajasthan-5 was under start-up and operating at a power level of 0.09% full power (FP). "Leak detection system" for pump room indicated external leak in the area. Field operators observed water pouring from pump room to the south fuelling vault machine through a viewing window provided in the normal accessible area of the reactor building. At 10:49, reactor tripped automatically on pump room pressure increasing beyond 18 $g.cm^{-2}$. During the event, primary heat transport (PHT) system pressure could be maintained and there was no change in radiological status in the reactor building. These observations ruled out the possibility of leak from PHT system i.e. loss of coolant accident (LOCA). However, as a precautionary measure, plant emergency was declared at 11:27 due to appearance of one of the LOCA signal i.e. "pump room pressure high". By following a special procedure, a search team including health physics person was sent to the pump room and the area was found to be full of steam. Subsequently, it was observed that the fire water line to SG (steam generator)-4 had got sheared off and a nearby anchor support had uprooted from the wall. Steam/hot water was coming out from the ruptured end of the fire water line towards SG-4 side. Some of the pipe supports provided far away from the ruptured location of fire water line was also found damaged.	After the event, check valves provided in all three lines to SG-1 and SG-4 were inspected and the following observations were made. – Flapper anchor bolts of the check valves V1and V2 in 10% feed water line and fire water line to SG-1 respectively had dislodged and the flappers were resting on valve seats. A welding electrode piece was found between the seat and flapper of the check valve V1. – Valve seat of the check valve V5 in fire water line to SG-4 was found dislodged from its position and lying inside the valve body. The event initiated due to presence of a piece of welding electrode between the seat and flapper of the check valve V1 in 10% feed water line to SG-1 and caused it to stuck open during reactor operation. The event was attributed to deficient QA practices during construction of Rajasthan-5. During the event, failure in the flexible impulse tubing of flow element occurred due to severe vibrations which occurred during pressure transients. Utility took immediate corrective actions/measures in Rajasthan-5 to avoid recurrence of such events.	Since Rajasthan-5 is a newly constructed reactor, the presence of foreign material in the check valve indicated deficiencies in QA and implementation of foreign material exclusion policy. Following the event, utility strengthen the QA practices in all NPPs.

Event 96. Indications in small bore fittings

Finland – Olkiluoto 3 – 2013/03/18

Description	Cause(s)	Lesson(s) learnt
In 2010 a number of surface indications were detected from small bore (< 50 mm) pipe fittings at Olkiluoto 3 pipe preassembly works. These indications were longitudinal and located in stainless steel small bore (< 50 mm) pipe fittings (elbows, reducers and tees) procured by a subcontractor. Defective fittings were sent back to the subcontractor for repair. A part of the defective fittings were already installed to the preassembly lines (isometrics) or pipelines. The non-conformance was thought to be under control and installations continued. In 2011 a much larger number of similarly defective fittings were, however, found and the plant vendor decided to stop installation work of small bore pipelines. Thorough investigations reaching up to about 10 600 fittings were started, about 7 400 of these were already installed. The pipelines were from safety class 2 and 3 as well as from non-safety classified systems. A large amount of defective fittings (not yet installed) were delivered to the vendor's materials laboratory for detailed material and non-destructive investigations. It was realised that the indications were always in longitudinal direction and located at outer and/or inner surfaces of the fittings. In the great majority of cases the indications were superficial. The material was Nb-stabilised stainless steel. Sulphuric acid was one pickling agent component, even if it was forbidden in vendor specification.	– Direct cause: The fittings concerned are manufactured by a specific mould guided cold forming process with subsequent solution annealing. The forming reductions are relatively high and may cause surface ruptures especially in a steel including more non-metallic inclusions that more easily initiate local material breaking. – Underlying causes: The follow-up and control of the pipe material delivered for fitting manufacturing has been insufficient. The forming process used is very popular and the risk of flaw formation was not fully understood with the materials and fittings of question. The visual and penetrant tests carried out by the fitting manufacturer did not indicate any non-conformances. These were found at a later stage and the scope of the event was not understood even then. First NCRs were opened and handled slowly and not proactively.	Quality assurance and control on material and component procurement need continuous and proactive touch from the vendor and licensee.

Event 97. Undocumented heat treatment and interchanging of main steam line pipe forgings during manufacturing

Finland – Olkiluoto 3 – 2008/10/11

Description	Cause(s)	Lesson(s) learnt
The penetration pipes (leading the main steam line through the containment) were manufactured by a subcontractor that applied heat treatment improperly and interchanged two heats with each other, which led to deviations described in the following. The end of manufacturing report of the main steam line forged P355NH-type steel penetrations stated that the material is in normalised condition as required in the manufacturing specification. Lower than reported strength values were found on specimens tested two years after end of factory manufacturing. The plant vendor made an investigation and found that the material microstructure deviated essentially from the specified normalised condition. It was revealed that the forging company had made an undocumented heat treatment in order to obtain the strength values specified in the manufacturing specification. This treatment was austenitising followed by accelerated cooling, using large air blowers with water spray. The issue was originally found during tearing resistance testing of cut-out test pieces. These tests were required by STUK because the penetration pipes are manufactured along with the break preclusion (BP) requirements. At that time, the penetration pipes were already under installation work on site.	Direct causes: – Forging company made an undocumented heat treatment in order to obtain the strength values specified in the manufacturing specification. Machining shop changed two pipes with each other. Underlying causes: – After the 1st manufacturing trial, the production pieces (2nd set) were made and delivered in 2008 despite the fact that an undocumented heat treatment had been done to gain the specified strength. After the undocumented treatment was revealed, a 3rd set was manufactured and delivered successfully. The economic pressure for delivering the 2nd set has obviously been too high. Infringing the rules and agreements has been too attractive and the work ethic too low; – Potential consequences would have been the use of not-known material in safety critical (SC 2) large piping. This steel in quenched (but not tempered) condition could have suffered from unknown damage mechanisms due to e.g. high residual stresses and bainitic microstructures involved. Corrective actions: pipes were removed, construction plans revised and pipes remanufactured.	Normal quality control processes may be inefficient if fraud and human mistakes occur in the manufacturing chain. STUK has developed new requirements for supply chain management in new YVL-guide A.5, chapter 3.4, requirements #342-353.

Event 99. Procurement of the emergency diesel generators and their auxiliary systems

Finland – Olkiluoto 3 – 2010/11/26

Description	Cause(s)	Lesson(s) learnt
In its inspections carried out in 2009-2010, STUK had repeatedly noted the poor quality of the design documents of the auxiliary systems and equipment of Olkiluoto 3's EDGs. On the basis of these observations, STUK suspected that there were deficiencies in the quality management of the licensee, the plant supplier and the supplier of auxiliary equipment, and required the licensee (Teollisuuden Voima Oy, TVO) to carry out follow-up inspections (audits) at the main supplier of auxiliary equipment for the EDGs and its main subcontractors. An emergency diesel generator is by itself a power plant which comprises auxiliary systems composed of different types of mechanical and electrical equipment (e.g. fuel feed and cooling systems). The procurement is characterised by long supply chains. The supplier of diesel generator auxiliary systems has purchased equipment from almost 30 subcontractors. The equipment contains parts and components manufactured by several subcontractors. The audit performed in the autumn 2010 at the supplier of auxiliary equipment revealed that the plant supplier had not provided it with up-to-date design criteria that should have been used as the basis for designing and manufacturing.	– The procurement for emergency diesel generators was the second subcontract procurement carried out by the plant supplier. The complex contractual arrangements hampered the supply management. The procurement was characterised by long supply chains. The supplier of diesel generator auxiliary systems had almost 30 subcontractors of which around ten belonged to a lower tier of suppliers who, in turn, relied on further subcontractors for component deliveries; – Control of the long procurement chains and quality control of components was a demanding task for all parties involved. Basic design was initially guided by incomplete definition of requirements, their management in the course of the supply project and differing ideas of the standard of requirements. Inaccurate definition of requirements led to shortcomings in quality assurance; – The licensee had interpreted STUK's standpoint to be that it had approved the use of serially produced parts without supplementary quality assurance.	STUK took the lessons learnt in this case very widely into account in its new YVL guidance but also in the guides for management systems of a nuclear facility and regulatory control of the safe use of nuclear energy, as well as technical specific guides. In the revised YVL guidance there are certain requirements for a supply chain. It is emphasised that there must be a good set of contracts, first between the licensee and a vendor about how the management of supply chain should be organised, and then the vendor must have full responsibility to look at its contractors and subcontractors. Each manufacturer of any item must have a quality plan to meet the standards specified by the vendor. Basic design and engineering stages must be carried out with care and enough time reserved for it. Basic design should generate comprehensive technical specifications, quality control specifications, specifications for the documents required for regulatory oversight and specifications to demonstrate conformance.
References: STUK investigation report 27 May 2011		

Event 103.Manufacturing of the engines for station black-out diesels

France – Flamanville 3 – 2012/03/22

Description	Cause(s)	Lesson(s) learnt
The EPR being built on the site of Flamanville is expected to be equipped with four main diesels and two station black-out (SBO) diesels in case the main ones would fail. The holder of the main contract for the supply of SBO diesels put a contract to different subcontractors for each component of the SBO diesels. The holder of the main contract is mainly in charge of the assembly of the different parts. During an inspection performed on 22 March 2012 in the workshops of the SBO diesels supplier, ASN observed that manufacturing of the engines of the SBO diesels had been launched on the basis of a set of requirements of the manufacturer different from the frame of reference specified by the licensee. The manufacturer's requirements did not take into account all the requirements specified by the licensee. This difference in the frame of reference was identified and notified to the manufacturer by the licensee as soon as 2009. But discussions between the contractors and the licensee failed to converge on the principles of solving of the gap, which led to a deadlock. This situation did not allow the licensee to start the supervision process of the engines' manufacturing that requires first a specification and a provider quality plan approved by the licensee. Therefore, the operator did not implement any supervision on the manufacturing of the engines.	This situation lead the licensee to report to ASN an event relevant to safety, based on the following deviances: – Manufacturing was initiated on the basis of a list of quality relevant activities and of specification of equipment not approved by the licensee and not taking into account all the requirements specified by the licensee; – The licensee did not carry out any supervision during the manufacturing of the engines. These deviances constitute breaches of the ministerial order relating to the quality of design and construction and operation of nuclear installations. Although these deviances were detected and reported to the manufacturer as soon as 2009, the records of non-compliances were only made in November 2011 after an agreement was reached between the operator and its contractor on a programme of conciliation of both frame of reference and of solving of the non-compliances.	The monitoring of the contracts implemented by the licensee was judged poor and inefficient. No monitoring performed in the manufacturer factory by the licensee because of disputes between the operator and its contractors due to procedures probably unsuitable. A particular attention must be dedicated to situations where "small" subcontractors are in charge of safety related components manufacturing, because they often contract with other subcontractors that are more important and do not want to take into account their requirements.

Event 110. Potential for Teflon® material degradation in containment penetrations, mechanical seals and other components

United States of America – Fort Calhoun – 2012/05/12

Description	Cause(s)	Lesson(s) learnt
Teflon was used in applications where the expected radiation levels under accident conditions exceed its qualification limits. Teflon material may be used in containment penetrations, containment personnel airlocks, pump seals and other components.	– Ineffective corrective action programme; the licensee had previously identified this problem but their extent of condition failed to identify all impacted applications. – Inadequate safety classification; the non-Class 1E seals were classified incorrectly as non-safety-related based solely on their electrical function. These seals have a safety function to maintain containment integrity. – Other impacted licensees were either unaware that Teflon was present in their equipment or did not realise its limited capacity to handle the expected radiation levels at their location.	– Improper classification of structures, systems and components at original design and construction can cause significant latent problems. – NRC Regulations, Title 10, Code of Federal Regulations, Part 50.49 provides the requirements for environmental qualification of electric equipment important to safety. – ASME QME-1-2007 provides guidance for the qualification of non-metallic parts used in nuclear safety-related active mechanical equipment. – Adequate oversight must be exercised during all phases of design, procurement, testing, receipt inspection and installation, in order to ensure that all piece part materials are compatible with the expected environmental conditions including those experienced under postulated accidents.
References: NRC IN 2014-04, "Potential for Teflon® Material Degradation in Containment Penetrations, Mechanical Seals and Other Components"		

Event 112. Welding defects in replacement steam generators

United States of America – San Onofre-3 – 2010/04/05

Description	Cause(s)	Lesson(s) learnt
A 5-inch long surface flaw was discovered in the replacement steam generators (RSGs) for San Onofre Nuclear Generating Station Unit 3. This crack is of concern because it is unlike the weldability issues that are typically observed in the welding of nickel-based alloys.	The weld joint was prepared by removing the stainless steel cladding from the RSG surface using air carbon-arc gouging (ACAG) which resulted in higher carbon content and areas of higher hardness in the vicinity of the fusion line. Subsequent surface preparation by grinding did not ensure that all of the surface carbonised material was removed.	Although all specific requirements or standards were met, this event illustrates that control over all aspects of welding ASME Code Class 1, 2 and 3 components can prevent similar welding defects from occurring.
References: NRC IN 2010-07, "Welding Defects In Replacement Steam Generators"		

Event 114.Welding problems during fabrication of reactor plant components

United States of America – Vogtle-3 – 2012/10/04

Description	Cause(s)	Lesson(s) learnt
Significant welding problems occurred during the fabrication of large reactor plant components which required significant repair. Problems include defects of the Alloy 52M inlet nozzle-to-safe end welds of the reactor vessel and cracks in four welds in the lower ring of the containment vessel. Both vessels belong to the Vogtle Unit 3 plant currently under construction.	– Inadequate procedures to control critical welding parameters; – Inadequate quality checks; – Inadequate technical evaluation of welding conditions; – Loss of weld shielding gas during welding operations due to the ventilation configuration in the vicinity of welding; – A combination of fit-up problems and inadequate post weld heat treatment that did not take into account the unusually thick plates being welded.	The implementation of adequate procedures, training and quality oversight is necessary to avoid these types of welding issues as required by 10 CFR Part 50, Appendix B, Criteria VII and IX.
References: NRC IN 2013-21, "Welding Problems During Fabrication of Reactor Plant Components"		

Event 117. Motor-operated valve inoperable due to stem-disc separation

United States of America – Browns Ferry-1 – 2010/10/23

Description	Cause(s)	Lesson(s) learnt
The 24-inch motor operated valve (MOV) for the low pressure coolant injection outboard injection valve failed to open due to stem disc separation.	– Tack welds between the disc and skirt failed; – Threads on the upper disc skirt were undersized; – MOV test programme weaknesses significantly delayed detecting the problem.	New build regulators may want to verify that: – licensees identify all of a valve's safety related functions during design to ensure that it is appropriately included in the MOV programme; – licensees supplement position indicating lights by other indications such as the use of flow meters, to verify valve position during testing; – licensees' MOV testing procedures assure proper valve operations.
References: NRC IN 2012-14, "Motor-Operated Valve Inoperable Due To Stem-Disc Separation"		

4. ELECTRICAL

Overview

The events presented in this chapter show how important it is to assure comprehensive and timely communication between all parties involved in the construction of nuclear power plants (designer, vendor, subcontractor and operator).

Also, adequate attention should be paid to the control of design changes and their impact on system interfaces. Due consideration should be given to the analysis of temporary modifications.

- Event 22, which discusses multi-unit trip, highlights the importance of thorough independent design verification, the adequacy of installation procedures and the independent as-built (switch setting) verification.

- Event 77 describes loss of offsite power initiated by a malfunction of the interim step-down transformer followed by jamming of power transfer from the auxiliary transformer due to deficiencies in the power transfer logic. Adequate design change control and the performance and proper communication of a failure mode and effect analysis (FMEA) could prevent similar problems.

- Event 104 is a very good illustration of problems that can arise when installation starts before the design is complete and adequately verified. In the initial EPR design, cables volume as well as distances between power and instrumentation and control cable trays were underestimated. Solving this problem in the advanced construction stage was complicated due to lack of available space and other engineering concepts had to be introduced.

- Event 110 discussed in Chapter 3 above shows environmental qualification problems with the use of Teflon in electrical penetrations where the expected radiation levels under accident conditions exceed its qualification limits. The event highlights the importance of implementing an effective corrective action programme and the proper safety classification of structures, systems and components.

Event 22. Switchyard transient leads to dual unit trip

United States of America – Oconee-1 – 2007/02/1

Description	Cause(s)	Lesson(s) learnt
Grid disturbance (external reasons) caused trip of two units at Oconee NPP. Unit 1 recovery was complicated by incorrect setting on the auxiliary switch systems. 30 hours into the event, motor driven emergency feed water pump (MDEFWP) of unit 1 was lost due to high bearing temperature. Also water hammers throughout secondary side of unit 1 occurred. Unit 2 recovery was uncomplicated. Unit 3 was unaffected by grid disturbance.	Latent wiring design error in the loss-of-excitation relays caused those relays to trip units 1 & 2. Incorrect settings of the fast contacts located on the auxiliary switches on the main feeder bus normal breakers resulted in unit 1 slow bus transfer. Improper installation of pump oil slinger ring caused by a procedure deficiency resulted in MDEFWP loss.	A better control of new build design and installation activities would likely help avoid similar latent problems including: – Verifying that licensees employ a rigorous design verification process; – Performing a careful review of installation procedures; – Independently verifying switch settings. Multi-unit tripping should be taken into consideration during design and safety analysis since it poses additional challenges to the grid stability and the operators' response.
References: Licensee Event Report 269/2007-01, Revision 1, "Dual Unit Trip from Jocassee Breaker Failure"		

Event 77. Loss of offsite power due to incomplete logic for interim transformer

Republic of Korea – Shin-Kori 1 – 2010/07/06

Description	Cause(s)	Lesson(s) learnt
Malfunction of the oil pressure relay for the high voltage bushing of the interim step-down transformer caused opening of the 756 kV switchyard circuit breakers which resulted in the offsite power supply from the unit auxiliary transformer (UAT) unavailable for the plant. Additionally, due to deficiency in power transfer logic opening of the above mentioned breakers jammed power transfer from UAT to standby auxiliary transformer (SAT). Two emergency diesel generators were actuated automatically and supplied power for safety bus and its related equipment as designed.	Direct cause of the transient was an invalid actuation of the oil pressure relay which indicated erroneous measurement result. Furthermore deficiency of the power transfer logic was a root cause of the loss of offsite power. Entire interim step-down transformer was installed temporarily because grid operating company failed to build 756 kV transmission line. However, at the time of its installation, opening of the power circuit breakers was not considered in the design. Another identified root cause was insufficient communication on the failure mode and effect analysis (FMEA) between designer and operator.	Poor engineering change control and insufficient understating of influence of the introduced change on the design led to the interim transformer being installed without due consideration of its impact on the functioning of the plant. As a result, this transient was not anticipated, due in part to the FMEA not having been communicated from the designer to the operator.

Event 104. Cabling non-conformances

Finland – Olkiluoto 3 – 2010/12/31

Description	Cause(s)	Lesson(s) learnt
During OL3-electrical system installation phase in 2010 and 2011, it was noted that separation distances between safety and non-safety cables did not fulfil OL3-cabling concept. It was also noted that separation distances between power and I&C cables did not fulfil OL3-cabling concept. In 2012 it was also noted that some of Level 3 (U < 1 kV, P < 15 kW) cable trays were overfilled. These cable trays were mainly in cable rooms under switchgears.	Separation of safety and non-safety cables was originally not used in EPR concept but this requirement was communicated by STUK to vendor prior to construction licence phase. However vendor was not able to fulfil the requirement mainly because of a lack of space. Overfilling of cable trays was caused by 20% increase of final cable volume in comparison to initial calculations in EPR design.	The amount of cables should be known before layout planning. Also, main cable routes should be clear before layout planning. In new nuclear power plant concepts, it should be taken into account that more cables might be needed than originally planned. Installation procedures should force subcontractor to suspend installation when cable trays are obviously going to be overfilled. Lesser separation between cables – where electromagnetic compatibility (EMC) disturbances are risk factor – can be accepted when metal separation sheets are used.

5. INSTRUMENTATION AND CONTROL

Overview

The events described in this chapter (as in chapter 4) illustrate the importance of implementing an adequate design change control process and communication between parties responsible for design of changes and their implementation. Comprehensive analysis is needed to assure a shared understanding of the significance, influence and interdependencies of introduced changes on other systems and components.

For reactor designs in which digital Instrumentation and Control (I&C) must provide reasonable assurance that important systems and components can perform their intended safety related functions as designed, it is extremely important to introduce a comprehensive and systematic process for software validation and verification. Safety related digital I&C is used extensively in new reactor designs and has unique requirements. Licensees and their contractors may not have enough experience complying with these requirements. New build regulators should pay special attention to overseeing digital I&C work to help ensure that licensees and their contractors understand the unique requirements and are taking appropriate steps to implement them.

- Event 50 describes a plant shutdown caused by the wrong design of control rod system hardware (unsafe failure mode) and poor workmanship and materials (supply chain problems). It highlights the need to maintain an adequate knowledge of original specifications and to impose a tight control of the supply chain.
- Event 68 describes the need to set up and implement a comprehensive digital I&C software validation and verification programme.
- Event 79 highlights the important of design control and as-built verification.

Event 50. Adjuster rod electronics issue

Canada – Darlington 4 – 2010/04/21

Description	Cause(s)	Lesson(s) learnt
An adjuster rod assembly (AA) 18 spuriously drove out-of-core even though the handswitch was in "Manual" (rather than "Auto"). Main control room (MCR) indications and parameters were monitored to be consistent with an adjuster rod out of core. Unit was shut down by setting the alternate power mode setpoint to -3 decades, consistent with station procedures. The unit was placed in the "low power hot" state. A simulation of the event with AA18 out of core demonstrated that the highest fuel bundle power was in the operating bundle range and below licensing limits. Furthermore, the highest channel power observed was within normal operating range and well below licencing limits. AA rods are used to flatten the flux shape in the core, which is why the handswitches are in "Manual", in order to prevent the Reactor Regulating System from moving them.	Wrong design of control rod system hardware (unsafe failure mode) resulted in adjuster rod assembly spuriously drove out – of-core when its power supply voltage drifted low. Poor workmanship and materials used in power supply led to internal shorting and thermal breakdown of insulation material.	Control of the supply chain is an important function throughout the life of the station. Also maintaining corporate knowledge of the original specifications of components proved to be important as short/medium term mitigation strategy consisted of replacing specific modules with previous model of power supplies.

Event 68. Digital instrumentation and control violation

United States of America – Vogtle Electric Generating Plant (VEGP)-3 & 4 – 2012/06/19

Description	Cause(s)	Lesson(s) learnt
The licensee failed to conduct software validation and verification (V&V) according to regulatory requirements described in Inspections, Tests, Analyses and Acceptance Criteria (ITAAC), combined construction operation licence (COL) and other NRC rules and regulations. Insufficiencies contained following issues: – software requirements evaluation, interface analysis, criticality analysis, hazard analysis and risk analysis were not conducted according to minimum required V&V scope; – V&V activities were not performed independently (individuals from the design team were included in V&V team); – software requirements specification was ambiguous, not complete and was not ranked for importance.	The licensee failed to assure that applicable regulatory requirements and the design basis were correctly translated into specifications, drawings, procedures and instructions. No process was in place to review procedures and guidelines from regulatory compliance standpoint. Corrective action programme was not properly utilised for digital I&C projects due to gaps in training programmes and lack of management enforcement. Process requirements such as the V&V activities must be performed independently from the design team, were not included and verified in supporting documents. See the licensee response referenced below for more information.	Design and construction activities associated with ITAAC must comply with all applicable design and licensing bases as delineated in the COL. This includes the implementation of design control measures such as complying with applicable codes and standards and performing independent software verification and validation. The licensee (and their contractors as appropriate) should develop a process for project licensing plans or incorporate licensing into the main project plan to ensure that regulatory requirements and commitments are addressed by each project. The licensee training oversight and procedures review processes should include regulatory compliance issues: – implement a training oversight process to ensure that all groups performing digital I&C work have adequate training encompassing both the work functions, the regulatory requirements and the corrective action program; – implement a process for the review of procedures, guidelines, work instructions and work products with respect to regulatory compliance. The process should include mapping the procedure to the codes and standards, identifying any gaps and determining exceptions.

References:

1. NRC inspections reports and notice of violation
2. Licensee response

Event 79. Manual reactor shutdown to examine measuring error of ex-core detectors

Republic of Korea – Shin-Kori 1 – 2010/09/14

Description	Cause(s)	Lesson(s) learnt
Reactor was manually shut down to investigate causes of incorrect indications of ex-core neutron flux detector. The licensee re-adjusted the installation location of detector as well as evaluated and updated shape annealing function (SAF) calculation code.	Ex-core neutron flux detector was installed differently compared to the base line. The designer had changed the configuration of the detectors from two tubes to a single tube but the detectors were not installed correctly (according to changed design).	Poor engineering change control. Failure to understand the significance of the design change on the installed positions and results of measurements.

6. SITE CONSTRUCTION, ERECTION AND INSTALLATION

Overview

This chapter deals with events that occurred during the construction on site of new nuclear power plants. The causes of the events are very diverse and concern topics related to design, quality assurance controls at the manufacturers' facilities as well as at the construction site and non-compliance with procedures. They show the need to develop a strong safety culture, and to provide oversight of manufacturing of equipment by vendors and design control of equipment. This overview is divided in three main areas: safety culture, human and organisational factors, and design and technical issues.

Safety culture weaknesses have been identified as one of the causes of major accidents and incidents such as the Fukushima Daiichi nuclear power plant accident in 2011, the Davis-Besse reactor vessel head degradation near-miss incident discovered in 2002, the Chernobyl nuclear power plant accident in 1986, and the Three Mile Island Unit 2 accident in 1979. Construction activities present unique challenges as new employees who lack familiarity with the nuclear safety culture expectations join the nuclear workforce for the first time. New build regulators may want to verify that their applicants, licensees and contractors have established, implemented and maintained an effective safety culture and are continuously ensuring that expectations and consequences are clearly stated and understood. Several events in this report illustrate the need and the importance to develop a strong safety culture during the construction phase. The causes of these events range from a lack of questioning attitude to a total disregard of nuclear safety by willful misconduct. A prudent approach to safety culture comprises understanding of work procedures, being alert for unexpected situations and forgoing shortcuts by the licensee and the construction staff. The following events give some illustrations:

- Event 18 discusses the failure of staff to identify that auxiliary feed-water pumps were vulnerable to external flooding due to floor drains without flow restricting orifices being installed. The requirement for the orifice plates was not clearly specified in the design basis document but staff did not question this.
- Event 43 describes damage to the closing gate of the spent fuel interim storage pumping station. The cause was a lack of reporting of the event by the crane driver who could not reach his supervisor and then forgot to report. This event also reveals a problem of co-ordinating activities by the site contractor.
- Event 111 describes many incidents of willful misconduct and record falsification that took place at a variety of nuclear facilities, both operating and under construction, by multiple organisations.

Causes of some events are linked to the lack or inadequate management oversight required to ensure the rigorous implementation of nuclear safety related activities. This can be improved by better management's commitment to nuclear safety oversight, the use of operating and construction experience, pre-job briefing and the control of design changes and operating procedures. Illustrative examples include:

- Event 26 demonstrates that an independent verification should be performed for safety related design and procedural changes to account for all the potential interactions these changes can have. Commitment to conduct such verification should be set out in the policy defined by the managers and by the safety policy statements.
- Event 51 shows that attention should be paid to ensuring that work practices are up to date. In addition to internal procedural controls, independent supervisors can sometimes more clearly notice the need for improvements in the practices. It is also worth noting that, as the problem dealt with subcontractors, sharing information can help to improve the performance in the future.
- Event 106 describes the mis-installation of containment vertical tendon sheaths in a plant due partly to lack of pre-job instruction before starting the activity that could have highlighted the potential for error. This event is also partly due to lack of quality control oversight.

Some events are due to equipment design problems and risk management. Other events are caused by inadequate supplier oversight that ensures compliance to purchase specifications.

Illustrative events are:

- Event 84 describes a seawater flooding at a plant caused by collapse of a bulk head that was not designed to withstand the expected static pressure.
- Event 34 describes the failure observed on an instrument air header. Contrary to the requirements of the purchase specifications to supply annealed red brass, the supplier started providing un-annealed red brass without notifying the licensee. In addition, it should be noted that annealed and un-annealed red brass look the same.

Event 18. Floor drain flow pump inoperability due to flooding potential

United States of America – Catawba-1 – 2008/01/30

Description	Cause(s)	Lesson(s) learnt
The floor drains of the interior "doghouse" did not have flow restricting orifices as required by design. The floor drains were instead covered with a grate similar to those used in a shower drain. The floor drains in the interior doghouse structures flow into a sump located in the auxiliary feed water (AFW) pump room. The floor drain flow restrictors are designed to prevent the flow rate from exceeding the capacity of the AFW room sump pump in the event of a Main Feedwater Line Break. Exceeding the capacity of this sump pump would allow water to spill over and out of the sump, onto the AFW pump room floor and into the AFW pump pits, potentially rendering all AFW pumps inoperable. This problem existed since initial plant construction.	The identified internal flood protection deficiencies were caused by inadequate design and configuration control (inadequate as-built verification) during original plant design. See section III of the licensee event report referenced below for more details.	Assumptions used in calculations should be verified. In addition, as-built verification during the construction phase of nuclear power plants is an extremely important step required to insure design compliance. Regulators may want to inspect the processes used for design control and as-built verification used by their licensees especially in areas prone to common cause failures during flooding.
References: Licensee Event Report 413/2008-001, "Auxiliary Feedwater Pumps Declared Inoperable Due to Inadequate Design and Configuration of Floor Drain Flow Restrictor Cover Plates"		

Event 26. Service water inoperable due to valve modification

United States of America – McGuire-1 & 2 – 2007/08/06

Description	Cause(s)	Lesson(s) learnt
The seasonal run of "alewife fish" causes macro-fouling of the service water (SW) strainers at McGuire-1 and -2, requiring backwashing of the strainers. Backwash valves (originally manually operated) were replaced in 2000 with air-operated, fail-closed, valves, so that backwashing now requires instrument air. Instrument air at McGuire is a non-seismic system and hence, may be unavailable during post-accident conditions. SW strainer fouling concurrent with loss of backwash capability due to loss of instrument air could render SW inoperable. By replacing the manual valves with air-operated valves and downgrading of the SW strainers and the backwash system to non-safety-related made the post-accident procedures inadequate.	Inadequate design change process. Modifications to the SW strainers were completed without an adequate evaluation of the safety-related to non-safety-related system interactions. In addition, the impact on the post-accident operating procedures was not properly assessed.	Regulators may want to inspect design modifications to insure that their impact on original specifications, drawings, procedures and instructions is properly assessed.
References: Licensee Event Report 369/2007-004, "Procedure Deficiency identified for Performing a Manual Backwash of Nuclear Service Water (RN) Strainers due to reliance on Non-Safety Instrument Air"		

Event 34. Instrument air header failure

United States of America – Nine Mile Point-2 – 2008/03/26

Description	Cause(s)	Lesson(s) learnt
On 26 March 2008, Nine Mile Point Unit 2 experienced an axial split in a two inch instrument air system supply header. The split was ¼ inch wide and 41 inches long and caused instrument air header pressure to drop from 110 psig to 80 psig. The licensee had previously identified that un-annealed red brass was used in the instrument air system which was not an acceptable material per the final safety analysis report (FSAR). Specifically, the FSAR required material to be fabricated and installed according to ANSI B31.1, which un-annealed red brass did not meet.	The cause of the failure was determined to be stress corrosion cracking of the un-annealed red brass header. The licensee failed to verify that the material used met the requirements of ANSI B31.1 as required by the FSAR.	New build regulators may want to verify that their licensees are performing adequate vendor oversight, receipt inspection and material verification commensurate with the safety significance of purchased components. Deviations from codes, standards and other purchase specifications must be adequately dispositioned.
References: Nine Mile Point Nuclear Station - NRC Problem Identification And Resolution Inspection Report 05000220/2008007 and 05000410/2008007		

Event 43. Closing gate damage of the spent fuel interim storage pumping station

Finland – Olkiluoto 3 – 2009/03/02

Description	Cause(s)	Lesson(s) learnt
A maintenance-man of Olkiluoto operating plant units 1 and 2 noticed that the closing gate (500 kg) of the spent fuel interim storage seawater pumping station had shifted from its storage position and it was found lying on the ground. Some damages were found also on the corner of the pumping station. The incident happened between the previous checking round done on 26 February 2009 and the date of observation, 2 March 2009). The gate and the building were hit by the near-by crane (C8) of Olkiluoto 3 construction site while lifting a load. The crane driver noticed the risk of collision but did not manage to stop due to the inertia of the crane. He was turning this direction due to interface with crane C4 operating in the area too. The crane driver said he tried to report the incident to the supervisor but did not reach him and later forgot reporting. The licensee only received on 25 May 2009 the vendor's event report in which the vendor clarified the circumstances of the incident.	– Direct cause: The lifting route over the construction site could not be used because of another crane and thus the route which ranged inside the fence of the spent fuel interim storage pumping station and the cooling water tunnel from the pumping station was preferred. The operating area of the crane C8 was drawn on the crane route map. There were not identified areas or building outside the fence of OL3 construction site. – Lack of communication between subcontractor-contractor-vendor-licensee: • The crane route map was sent to the licensee for information – not for approval. The opinion of the main contractor of construction was that no official notice was needed because the issues presented in the crane route map are part of contractor's normal work planning; • The influence of cranes or lifting heavy loads over the areas ranging outside the fence of OL3 construction site were not considered by the licensee to assess the risks of construction on operating plant units and the interim storage of spent fuel. At the construction site there were not made risk lists where the interfaces of operating plant units and construction and interrelated risks would have been taken into consideration.	– For licensee: An important factor of safety culture is open disclosure and handling of near-misses, non-conformances and other problems. The licensee has to emphasise the principle of openness outside its own organisation to promote open communication of events to itself and further to the regulatory body. The means for recording and reporting near-misses and non-conformances should be available and easy to use by all employees (anonymously) at the construction site. – For vendor, contractor: Same as for the licensee. Event investigations should not be blaiming. Event investigation practices should be part of vendors' and contractors' training. – For regulator: Regulator should ensure that licensee's supervision of construction is performed according to the requirements. Regulator should require comprehensive risk assessments and risk lists on the interfaces between operating plant units and construction site and interrelated risks.

Event 51. Deficient hydrostatic pressure test arrangement of valves

Finland – Olkiluoto 3 – 2009/04/12

Description	Cause(s)	Lesson(s) learnt
During a construction inspection of the manufacturer, it was noticed that pressure test arrangement of certain valves did not correspond to real loading situation. Pressure test rig did not allow pressure induced loading in vertical direction as in real circumstances, i.e. did not correctly load the valve cover boltings. The valves in question included 3-way and angle control valves. For example with 3-way control valve the test bench construction included two side blind covers and one lower blind cover. Lower blind cover and lower test bench plate were connected to the upper test bench plate in the upper part of valve with rods. The pressure load of the lower blind flange area was collected at the upper test bench plate and therefore reduced the load at the valve bolting. Because of this, the test bench construction was modified. The lower blind flange is directly from now on mounted (fixed) at the valve housing (body) itself and not supported as before. The valve housing has been modified with additional threaded holes in each corner of the valve housing. New lower test bench plate is to be fixed directly into the housing.	According to the subcontractor, similar pressure test arrangement have been used for a long time without noticing any deficiencies in this arrangement. Therefore, it can probably also be concluded that there has been no negative consequences or feedback because of this test arrangement. Work practices can be performed out of old habit without any further analysing of the requirements and fundamentals if no immediate need to reconsider these practices appears. In some cases an independent supervisor can more clearly notice the need for improvements in work practices, as was the case here.	Attention should be paid to ensure that work practices are up to date. In some cases, independent supervisors can more clearly notice the need for improvements. Discovered deficiencies should be analysed and taken into account. Sharing of information and experiences can help to improve performance in future.

Event 53. General corrosion of pressuriser and steam generators during transportation and storage prior to installation

Finland – Olkiluoto 3 – 2009/12/15

Description	Cause(s)	Lesson(s) learnt
After manufacturing and final inspections the pressuriser and all four steam generators were corrosion protected. The protection consisted of 2 layers: (1) "Cortec VpCI-377" [1] compound and (2) wrapping to "Cortec VpCI-Milcorr" [2] which is a shrinkable plastic film covering the vessel. After that, the components were stored outside the manufacturing hall before shipping to Olkiluoto. After shipping, the components were shifted to temporary storage hall waiting for installation that took place approximately one year later. During, the storage period it was detected that large areas of the component surfaces were corroded. It became evident that a substantial amount of water had penetrated through the plastic cover, probably during storage and transportation out of doors.	It is obvious that the corrosion protection has not been sufficient for outside storage period and transportation to site. The plastic film Cortec VpCI-Milcorr and its sealings may have been untight e.g. from the sealings, making water penetration under the film possible. The next protective layer Cortec VpCI-377 seems not to be protective enough under these circumstances. According to the film manufacturer, it is intended mainly for indoor storage purposes (see [1]).	Careful attention should be paid to packing and corrosion protection when heavy components need to be transported and stored outdoor.
[1] http://www.cortecvci.com/Publications/PDS/377.pdf [2] http://www.cortecvci.com/Publications/PDS/MilCorr.pdf		

Event 56. Damage of the 400 kV Power cable of an operating unit during construction of a new unit

France – Flamanville 3 – 2010/06/08

Description	Cause(s)	Lesson(s) learnt
Digging activities were carried out on Flamanville 3 site to realise a gutter near the frontier between the construction EPR site and the adjacent operating reactor Flamanville 2 (1300 MWe PWR). Next to this working zone is located a concrete electrical block containing three 400 kV cables. Those cables provide power to the auxiliary voltage transformer of the adjacent operating reactor. On 8 June 2010, before pouring concrete in the preformed gutter, a civil work contractor had to fix a form panel against the concrete electrical block, maintained by a prop. While using a drilling machine to make a hole in the block in order to fix the prop, the contractor damaged one of the 400 kV power cables. As soon as detected by an operator's supervisor, the activity was immediately stopped. Usually, the concrete block is supposed to be covered but due to the gutter activities in progress, it was exceptionally uncovered.	– Lack of preparation concerning the subcontractor's activity in the area of the power cable. The subcontractor did not know the risks (worker security and safety) related to the electrical cables in the concrete block. – Lack of questioning attitude before starting the activity. – Lack of communication on site. – Lack of warning mean (for example warning panel) on site to warn of the electrical danger in the concrete electrical block. – Beginning of the subcontractor's activities on the gutter without the licensee's approval.	This event shows the importance of communication between the potential operating units and the construction site concerning the hazards that construction activities may induce on the adjacent operating reactors.

Event 84. Seawater flooding of construction field

Republic of Korea – Shin-Wolsong 1&2 – 2009/04/29

Description	Cause(s)	Lesson(s) learnt
An event of inflow of seawater into the construction field occurred due to the collapse of bulk head for protection against inflow of seawater at the Shin-Wolsong Unit 1&2 seawater discharge construction site on 29 April 2009 around 16:50. The lower part of Unit 1 condenser and a part of the turbine building and intake structure of Unit 1&2 were over-flooded with seawater due to inflow of seawater. Construction process was carried out after appropriate corrective actions were taken through applicant's safety evaluation, regulatory body special inspection etc.	The bulk head did not withstand seawater static pressure.	Design basis for the dam was inadequate (did not handle the rainfall).

Event 98. Flooding at the construction site during heavy rain

Finland – Olkiluoto 3 – 2011/07/03

Description	Cause(s)	Lesson(s) learnt
Temporary sump pumps were installed on the OL3 construction site's major draining pits according to site plan. This installation was due to a previous heavy rain storm which caused accumulation of rainwater on Sunday morning 3 July 2011. Later on that day, access to the site was restricted due to radiographic test. No check of temporary sump pumps at draining pits was performed. Therefore, it was not observed that some pumps in a draining pit at the northern part of the site were not functioning properly during the heavy rain. Further on it was not seen that the water was flooding though unfinished open construction joint and inspection well of draining to bottom floor of essential service water pump building and rock channel. Water was flooding in electric motor room, which resulted to short circuit, disabling the rest of the temporary pumps in the northern part drainage pit. Finally, water was flooding in electric motor room 92 cm above the floor and in rock tunnels between 20 and 85 cm above the inclined floor.	– Direct causes: Temporary sump pumps in the major draining pits on OL3 construction site were not verified according to site plan and partial disabling of drainage pumping during heavy rain was unnoticed. Unfinished construction details caused more rainwater to the drainage pit and an open way for flooding in essential service water pump building and rock tunnels. – Underlying causes: Prolonged construction projects with unfinished construction details are more exposed to different combinations of exceptional circumstances and non-conformances in site plan compared to shorter period construction sites with faster finishing works. Further requirements due to prolonged construction time and unfinished structures for site planning and quality control were not considered enough.	Preparedness for prolonging of construction works with considerably high degree of unfinished construction details is challenging work. Finalising of the roofing, courtyard and drainage systems should be clearly scheduled without any unnecessary delays. STUK resident inspectors should take these flooding risks into account when conducting the overall oversight at construction site.

Event 106. Mis-installation of containment vertical tendon sheaths

Republic of Korea – All PWRs – 2010/04/12

Description	Cause(s)	Lesson(s) learnt
During the reactor containment structure installation, four out of 96 vertical containment tendon sheaths for post tensioning use were found to have been mis-installed. V108 and V109 sheaths were installed at each other's place and V110 and V111 were also installed at each other's place. The mis-installation problem started at the 8th stage (near to equipment airlock) and the construction work continued up to the 15th stage without being noticed until the problem was identified during utility's quality control (QC) inspection activity.	– Complex layout around the equipment airlock may have led workers to make a mistake. – Lack of the pre-job instruction before work regarding the possibility of mis-installation. – Lack of QA and QC activities.	– Special attention is needed when tendon sheath work is performed around the equipment airlock because of the complexity arrangement of the sheaths passing around the equipment airlock; – Strengthening of inspection is needed when tendon sheath work is involved.

Event 111. Willful misconduct/record falsification and nuclear safety culture

United States of America – Vogtle-3 – 2011/09/01

Description	Cause(s)	Lesson(s) learnt
IN 2013-15 discusses many incidents of willful misconduct and record falsification that took place by multiple organisations at a variety of nuclear facilities both operating and under construction.	The incidents discussed in IN 2013-15 can all be traced to an ineffective safety culture that did not prevent willful misconduct by ensuring expectations and consequences are clearly stated and understood.	Safety culture weaknesses have been identified as one of the causes of major accidents and incidents such as the Fukushima Daiichi nuclear power plant accident in Japan in 2011, the Davis-Besse reactor vessel head degradation near-miss incident discovered in 2002, the Chernobyl nuclear power plant accident in the former Soviet Union in 1986, and the Three Mile Island Unit 2 accident in 1979. Construction activities present unique challenges as new employees who lack familiarity with the nuclear safety culture expectations join the nuclear workforce for the first time. New build regulators may want to verify that their applicants, licensees and their contractors have established, implemented and maintained an effective safety culture and are continuously ensuring that expectations and consequences are clearly stated and understood.
References: NRC IN 2013-15, “Willful misconduct/record falsification and Nuclear Safety Culture”		

7. COMMISSIONING, PRESSURE TESTING

Overview

The following recommendations flow from the commissioning and testing events discussed in this chapter. The recommendations are grouped in four main areas: safety culture, human and organisational factors, use of operating and construction experience, and design and technical.

Several events illustrate the importance of having a robust safety culture. Some events were caused by schedule pressure resulting in errors or omissions; other events highlight the importance of having a conservative decision making process that prioritises nuclear safety; while another event shows the importance of having robust risk assessment processes for high risk maintenance, repair or testing activities. Illustrative examples are:

- Event 82 describes a reactor trip during Commissioning Physics Tests caused by schedule pressure to complete the test on time.
- Event 49 describes a manual reactor shutdown in response to anomalies that arose during the maintenance of a clutch relay card in a shutoff rod assembly due to a latent installation error. The causes included an ineffective corrective action programme and lack of adherence to the risk assessment process for high risk work.

Some events illustrate deficiencies of a human and/or organisational nature. One event illustrates the importance of applying good standards of cleanliness during construction and another event highlights the importance of as-built verification. A couple events emphasise the importance of having a robust process for the production of testing and operation procedures to ensure potential implications of testing and maintenance sequences are properly addressed. Finally, a couple of events reinforce the need for a training programme that prepares qualified personnel to test, commission, maintain and operate the facility in a safe manner. Some examples of these events are:

- Event 76 describes a bulging of a stainless steel liner plate in the inside-containment refueling water storage tank during pressure testing caused by an inadequate testing procedure. This event highlights the need for the adequate review and approval of testing procedures.
- Event 91 describes a manual scram due to the detection of unidentified drywell leakage during power ascension resulting from the lack of full tensioning of the reactor vessel head studs. Among the causes was a failure to provide proper training and procedure guidance to maintenance staff.

An important causal factor of some events was the lack of timely and effective collection, assessment and use of experience from the licensee's own facility or other facilities. Much can be learnt and applied from past construction and operating experience in order to identify and implement improvements which may avoid the occurrence of problems similar to those reported. An illustrative example is:

- Event 93 describes a series of water leaks from the primary cooling system at several plants due to pin holes in connected tubing. The leaks, of identical nature, happened at different times in four nuclear power plants, and no proactive preventive measures were implemented at the other similar plants due to inadequate sharing of experience between them.

From a design and technical point of view, one of the events highlights the importance of having in place robust design procedures for ensuring that new build projects which reuse or adapt structures, systems and components from another nuclear power plant design properly assess these in the context of the new design. Another event reinforces the importance of proper filling and venting of fluid systems in order to avoid malfunction or damage caused by gas ingress.

- Event 74 describes damage to anchor bolts and anchor chairs of a reactor makeup water tank during a hydraulic pressure test. The event happened due to the reuse of the tank design from the OPR1000 reactor in the APR1400 reactor model without appropriate design verifications.

- Event 45 describes several events associated with the operability of the component cooling water system at a number of plants, due to inadequate design and fill and vent procedures that caused gas to accumulate in the system jeopardising its function.

Event 45. Component cooling water system gas accumulation and other performance issues

United States of America – All NPPs – 2011/07/18

Description	Cause(s)	Lesson(s) learnt
There have been many recent events in the United States associated with the operability of the component cooling water (CCW) system caused by gas accumulation and the failure to account for the effects of high energy line breaks (HELB), seismic events and tornados.	– Latent design issues, – Inadequate design and fill and vent procedures.	Gas accumulation in nuclear power plant systems can cause water hammer, gas binding of pumps, and inadvertent relief valve actuation that may damage pumps, valves, piping and supports, and may render the CCW system inoperable. The CCW system is a safety-related system that provides cooling to components in other safety-related systems and in non-safety-related systems. Malfunctions of non-safety-related components could render the safety-related CCW system inoperable. New build regulators may want to verify that their licensees are accounting for the effects of gas accumulation, HELB, seismic events and tornados on fluid systems during the design phase. In addition, the design should provide adequate means to vent fluid systems prone to gas accumulation and specify fill and vent requirements under all operating conditions. Commissioning activities should include providing adequate procedures for filling and venting and implementing these procedures in accordance with design.
References: NRC IN 2011-14, "Component Cooling Water System Gas Accumulation And Other Performance Issues"		

Event 49. Transient due to odd shutoff rods drop in core

Canada – Darlington 3 – 2011/07/28

Description	Cause(s)	Lesson(s) learnt
The odd back of shutoff rods fell in core during maintenance of the shutoff rod assembly (SA) 15 clutch relay card (CRC). A jumper was connected to the positive side of the clutch coil prior to CRC swap, as per procedure. A spark was observed and the odd power supply failed (blown fuses). As a result, the odd bank of shutoff rods dropped in core. A shut down system (SDS) 1 was manually actuated and the unit was shut down as per station procedure. This was the first time that this activity had been performed with the unit at power; all previous ones had been done while the unit was shut down, which would not have revealed the problem.	Wiring to SA15 CRC was installed in reverse. Error went undetected during commissioning wire-to-wire checks. Ineffective processes used to evaluate and correct deficiencies to ensure scope or potential impact of problem was fully addressed. Potential for wiring reversals within CRC panels and consequential challenge to technicians was not thoroughly evaluated even when a potential error precursor was identified informally earlier. Lack of detailed extent-of-condition review was identified to the station condition record (SCR) evaluators, but expectations and standards of this aspect of the SCR evaluation were foreign to personnel involved. The effectiveness of the corrective actions was not reviewed within Engineering or Maintenance, despite the fact that the standing SA26 wiring/labelling discrepancy was noted in the system health report. Although the task of replacing the CRC was recognised as high-risk work, not all aspects of the risk assessment process were met.	This event highlights several matters for the attention of new built regulators. Licensees shall have robust and thorough planning and commissioning checks, to verify that the as-installed is as-designed. Licensees should have procedures in place that call for addressing all aspects of risk assessment processes for high risk works. Licensees should put in place appropriate procedures for evaluation of extent of condition when analysing deficiencies and/or malfunctions. Licensees should have in place appropriate procedures to evaluate and correct deficiencies to ensure scope or potential impact of problem is fully addressed.

Event 74. Deformation of anchor bolts during hydrostatic test of reactor makeup water tank

Republic of Korea – Shin-Kori 3 – 2011/10/24

Description	Cause(s)	Lesson(s) learnt
While undertaking a hydraulic pressure test of the reactor makeup water tank 3, test engineer filled the tank with water up to the design level and pressurised the tank up to the design pressure. While pressurising the tank, the grout around the anchor bolt was damaged with the extension and bending of anchor bolt and the anchor chair was deformed.	Use of components designed for the OPR1000 in the APR1400 design without appropriate verifications. Anchor bolt design mistake: calculation of the anchor bolt load for test did not consider the load caused by the inner side tank pressure.	Appropriate practices shall be implemented by licensees and designers to ensure that in reusing or adapting structures, systems and components (SSCs) from one NPP design for its use in another NPP design a robust design procedure is applied to ensure all design requirements and loads conditions for the new plant have been properly been accounted for.

Event 76. Bulge of steel liner plate of in-containment refueling water storage tank during hydrostatic test

Republic of Korea – Shin-Kori 3 – 2012/07/31

Description	Cause(s)	Lesson(s) learnt
During a pneumatic test of the drain piping for tracing leakage installed directly under the inside-containment refueling water storage tank (IRWST), some parts of the bottom plate of the IRWST stainless steel liner plate (SSLP) bulged upwards.	During the pressurisation process, a wrongly specified valve alignment resulting in air injected into the space between the outer bottom wall of the IRWST and the concrete structure under the IRWST caused upper direction bulge of the IRWST SSLP.	This event highlights the importance that the licensee has in place a thorough process for the review and approval of tests specifications as to ensure that tests do not result in conditions that may jeopardise components integrity.

Event 81. Reactor trip due to core protection calculator low departure from nucleate boiling ratio during 80% load rejection test

Republic of Korea – Shin-Kori 1 – 2010/11/17

Description	Cause(s)	Lesson(s) learnt
During commissioning, while the plant was performing a 80% load rejection test, the switch yard breaker was opened, the turbine generator tripped due to the turbine high acceleration rate signal and the reactor tripped automatically according to the reactor coolant system trip in the process of the power transfer. This was only one of several reactor trips that occurred during commissioning and performing load rejection tests, reported previously and affecting similar reactor units.	Reactor tripped due to inadvertent turbine trip during the load rejection test. The turbine trip on the high rate signal. Incorrect setpoint was loaded in the turbine protective circuit. Management pressure on operators to complete the commissioning tests, may have led them to cut corners.	Licensees should effectively use internal and external operating experience and carry out appropriate corrective action investigations to avoid the occurrence of similar problems reported in other facilities. Licensees should follow appropriate procedures to ensure that correct setpoints are loaded on systems. Licensees should have a robust safety culture in place to prevent management pressure on operators to comply with schedule from resulting in errors or omissions.

Event 82. Reactor trip due to core protection calculator low departure from nucleate boiling ratio during 0% reactor core physics test

Republic of Korea – Shin-Kori 1 – 2011/01/25

Description	Cause(s)	Lesson(s) learnt
During commissioning, a reactor trip was triggered by the departure from nucleate boiling ratio low (DNBR-Low) signal of the core protection calculator (CPC) during the reactor core physics test.	While the control element assembly (CEA) worth measurement test was being performed, the control rod #1 group was inserted and the reactor trip signal occurred because the CPC trip bypass was omitted due to the human error of the test operator. Inappropriate conforming to procedure (omission of step) due to decision error of test operator and supervisor. Human error related to lack of attention to conform to the initial condition indicated in the procedure and mistake in the implementation of the procedure during the CEA Worth Measurement Test.	The licensee should have appropriate arrangements in place for suitable operator checks to ensure quality of procedure and operator actions during tests. Licensees should have a robust safety culture in place to prevent management pressure on operators to complete commissioning tests as per schedule from leading to cutting corners.

Event 83. Reactor trip due to steam generator low level caused by main feed water pump trip

Republic of Korea – Shin-Kori 1 – 2011/02/18

Description	Cause(s)	Lesson(s) learnt
During commissioning at 100% power operation, the main feed water pump (MFWP) stopped due to the close of demineralizer gate valve, resulting in a reactor trip by SG Level Low signal. The regeneration pump in operation stopped, 16 gate valves in the condensate polishing plant (CPP) demineralizer tower closed simultaneously due to instrument air pressure low, and then the condensate regeneration valve opened due to low flow in the post-condensate pump. Pressure difference alarm inlet and outlet of CPP occurred and CPP bypass valve opened automatically. Then the condensate and the deaerator water level were recovered. Later the main feedwater booster pump and the main feedwater pump were stopped by net positive suction head (NPSH) low-low signal. The reactor tripped automatically by the SG level low signal.	Initial transient was due to the simultaneous closure of 16 gate valves in demineralized tower. The delay of valve open was caused by the inner debris in the quick exhaust valve. It was found that loss of the NPSH occurred due to decreasing of the water level in demineralizer.	Licensees should implement proper commissioning tests to verify that systems are able to operate as designed and their reaction when confronted with anticipated events conforms to design requirements. Licensees should have proper foreign material exclusion (FME) arrangements in place and ensure appropriate construction/ commissioning debris control. Licensees should have a robust safety culture in place to prevent management pressure on operators to comply with schedule from resulting in errors or omissions.

Event 91 Reactor vessel closure head studs remain detensioned during plant startup

United States of America – Brunswick-2 – 2012/04/11

Description	Cause(s)	Lesson(s) learnt
The Brunswick 2 licensee declared an Unusual Event during power ascension as a result of unidentified drywell leakage exceeding 10 gallons per minute (gpm). The operators initiated a manual reactor scram due to the continued increase in unidentified drywell leakage. Investigation revealed that the reactor vessel head studs were not fully tensioned during startup operations.	– The licensee failed to provide the necessary training and procedure guidance to correctly interpret critical indications on the stud tensioning and stud elongation measurement equipment; – A non-conservative decision was made that a post maintenance reactor vessel pressure test was not necessary.	New build regulators may want to verify that vessel head closure head studs are properly tensioned during commissioning activities and thereafter, including, that related procedures include appropriate quantitative or qualitative acceptance criteria; the assigned personnel is properly qualified; and that licensees are utilising a conservative decision process that ensures nuclear safety.
References: NRC IN 2012-21, "Reactor Vessel Closure Head Studs Remain Detensioned During Plant Startup"		

Event 92. Presence of foreign material in the primary heat transport system

India – Rajasthan-3 – 2002/05/15

Description	Cause(s)	Lesson(s) learnt
The presence of foreign material in south reactor inlet header (SRIH) resulted in partial flow blockage on three occasions. On each occasion the flow blockage occurred in different channels, due to shift of the material within the inlet header. The reactor is a horizontal pressure tube type using heavy water (D_2O) as coolant. D_2O flows through pressure tubes to remove heat from fuel bundles located in these channels. Each coolant channel is connected through a feeder pipe to inlet and outlet headers at both ends of the reactor. Coolant flow through channels is adjusted by orifices installed at channel inlet to obtain near uniform coolant temperatures at channel outlets. Channel temperature monitoring (CTM) instrumentation is provided for measuring coolant outlet temperature at each channel. Flow reduction in any channel can be detected by increase in channel outlet temperature.	Presence of foreign material was due to inadequate quality assurance during construction. Any disturbance in coolant flow rate is reflected in change in CTM outlet temperature. Presence of foreign material in the south reactor inlet header resulted in partial channel flow blockage. This event took place on three occasions with a different channel getting affected each time, possibly due to shift of the foreign material within the inlet header. Careful investigation of the abnormalities in CTM readings at different power level could have helped in detecting the foreign material at first occurrence.	The licensee should maintain appropriate standards of construction cleanliness, especially for safety related components; and implement timely and detailed investigation of events happening at the plant, to avoid escalation and/or recurrence.

Event 93. Events of pin-hole leaks of heavy water from primary heat transport system tubing due to fretting damage

India – Madras-1 and Tarapur-3 & 4 – 2009/03/11

Description	Cause(s)	Lesson(s) learnt
Similar events of leaks of heavy water from the PHT system occurred during operation at NPPs Madras-1, Tarapur-3 and Tarapur-4: – Madras-1: fretting damage to Delayed Neutron Monitoring (DNM) tube of coolant channel due to interference with Mineral Insulated (MI) cable of Resistance Temperature Detector (RTD); – Tarapur-3: fretting damage to impulse tube of venturi on feeder pipe of coolant channel due to interference with adjacent feeder; – Tarapur-3: fretting damage to impulse tube of venturi on feeder pipe of coolant channel due to interference with adjacent impulse tube; – Tarapur-4; fretting damage to impulse tube of header level transmitter due to interference with feeder of coolant channel. All these events resulted in occurrence of pin-hole leaks from small bore tubings of PHT system. Following the leaks of heavy water, tritium activity in fuelling machine (FM) vaults and the area dryer's collection showed increasing trend. It was not possible to find the location of the leaks in PHT system during unit operation either by survey with closed-circuit television (CCTV) cameras or through viewing windows of FM vaults. Leaky PHT system tubings were identified only during field inspections that were carried out after the reactor was brought to cold shutdown state. All leaky impulse/DNM tubings of PHT system showed tell-tale signs of fretting wear on outside surface near the leaky location.	All damaged impulse/DNM tubings were touching adjacent PHT system components (such as feeders, MI cable of RTD and impulse tubings of various instrumentation) in the feeder cabinet and were having tell-tale signs of fretting wear near the leaky locations. Therefore, it was concluded that the inferences between PHT system components during unit operation led to fretting damage of the impulse/DNM tubings in due course. Deficient design/installation procedures, and/or lack of consideration of aging and/or operation environment conditions. Unsuitable operating experience feedback (OPEX) programme implementation and sharing of experiences between units.	The licensee should have in place appropriate design and installation procedures that address the screening, identification and analysis of potential interactions and interphases between systems both during normal and abnormal plant conditions. The licensee in-service inspection plan should cater for inspection of activities in vulnerable areas on routine basis. The licensee should implement an appropriate and timely OPEX programme that allows to share and provide warnings to similar units of detected problems and/or anomalies.

CONCLUSION

An analysis of the events reported in each technical area of this Second Construction Experience Synthesis Report enables a number of general cross-cutting observations to be drawn. These are presented below as high level lessons learnt against four broad themes.

Management system processes

A number of events reinforce the need for the licensee to define and maintain a robust management system throughout all stages of new reactor construction (including engineering, construction, installation and commissioning). The management system should integrate all relevant processes, including engineering and design management; requirements management; configuration management including change management; quality management; corrective action management; and management of non-conformances. For change management, comprehensive analysis is needed to ensure that there is an understanding of the significance and influence of a proposed change and that its potential interdependencies with other systems and components are assessed. Engineering processes should ensure that design codes used in the nuclear power plant project are justified and followed. Benchmarking the engineering management processes with those used successfully in other nuclear construction projects as well as other safety significant industries could help to further enhance construction management system processes. It is important to establish and maintain adequate interfaces among the various design disciplines in order to ensure that inter-dependencies are identified and managed.

Safety culture

Several events collected in the ConEx data base illustrate the importance of having a robust safety culture. There are examples where management pressure on operators to meet project schedules has resulted in errors or omissions; other events highlight the importance of having a conservative decision making process that prioritises nuclear safety; while another event shows the importance of having robust risk assessment processes for high risk maintenance, repair or testing works.

The need for a questioning attitude and a rigorous and prudent approach is a common theme in the events reported here. Several emphasise the importance of individuals understanding work procedures, being alert for the unexpected and forgoing shortcuts. These behaviours should be reinforced by front line control and supervision to be sure that nuclear safety requirements are understood, prioritised and met.

Underpinning this front line focus on supporting the right behaviours to prioritise safety is a senior management commitment to put in place the infrastructure that addresses aspects such as safety policies and processes, and independent challenge and advice functions that support effective self-regulation. The events described in this report have illustrated the contribution to safety that can be made by, for instance, open and effective communication and the feedback of operating experience; and good control of design changes, plant modifications and operating procedures. All organisations should arrange for regular review of those of their practices that contribute to nuclear plant safety culture. In some cases independent reviewers can more clearly notice the need for improvements and suitable provision should be considered by both licensee and regulator.

Some of the reported events indicating shortcomings in safety culture involved failure to comply with requirements stated in procedures. New nuclear reactor construction activities present unique challenges as new vendors and their employees who lack familiarity with nuclear industry standards and expectations join the nuclear workforce for the first time. New build regulators may want to verify that applicants, licensees and their contractors have established, implemented and maintained an effective safety culture and are continuously ensuring that expectations and consequences are clearly stated and understood.

Human and organisational issues

The civil construction related events reported show that successful application of the construction specifications during construction work is a key factor in assuring that the safety of the structures can be maintained during the design life. Good housekeeping as well as avoiding water intrusion into the concrete is another factor to be kept during concrete work. High levels of organisational management including the establishment by the licensee and regulatory body of an effective and efficient inspection programme are also necessary. A graded approach should be used in defining the inspection programme.

Especially the electrical and I&C related events show that it is extremely important to ensure comprehensive and timely communication between all parties involved in the construction of an NPP (designer, vendor, subcontractor, operator). In particular, these events illustrate the importance of communication between parties responsible for design of changes and their implementation.

Some events related to commissioning tests, in service inspections or maintenance activities have human and/or organisational factors as root causes. One of the events illustrates the importance of applying good standards of housekeeping during construction; another event highlights the need for proper planning and commissioning checks to verify that as-installed structures, systems and components are as-designed. A couple of events emphasise the importance of having a robust process for the production of testing and operation procedures to ensure potential implications of testing and maintenance sequences are properly addressed. One of the events reinforces the need for an appropriate corrective action programme, with procedures to evaluate the impact of, and to correct, deficiencies or malfunctions. Finally, a couple of events remind us about the attention that should be given to implementing a training programme that provides qualified personnel to test, commission, maintain and operate the facility in a safe manner.

An important causal factor underlying some events was the lack of timely and effective collection, access and use of experience from the licensee's own facility or other facilities. Much can be learnt and applied from past construction and operating experience in order to identify and implement improvements which may avoid the occurrence of problems similar to those reported.

We can go further and note that the majority of events, if not all of them, have their origins in human and organisational factor-related root causes. Further analysis of events is needed to highlight this issue and the way in which the ConEx database captures these factors is an area for improvement. Organisational issues are also considered as a topic for future work within the ConEx group.

Supply chain management

Many of the events reported here were caused by the failure to apply well-known and well-established industry standards and guidelines. They illustrate the importance of instituting and implementing a rigorous design control process. Deficiencies caused by an inadequate design control process may be latent and therefore difficult to detect by normal inspection and surveillance processes. Thus, these defects may only become evident when they cause unexpected failures that result in significant problems during testing and operation or worse, complicate the response to certain accidents. One reported event emphasises the importance of establishing and maintaining adequate interfaces among the various design disciplines in order to account for human factors requirements and another event discusses problems with innovative digital I&C system design.

One event showed the absence of an appreciation of the requirements for in service inspection (ISI) requirements, reinforcing the need for the licensee and regulator to have competent staff well-acquainted with ISI requirements.

Adequate oversight by the licensee is recommended during all phases of design, procurement, testing, receipt inspection and installation to avoid events where wrong material is used, as occurred in one case where Teflon® material was used in safety-related systems without being properly qualified in accordance with environmental requirements.

At the end of manufacturing, the need for proper design, management and control of component packaging and shipment should not be underestimated.

Root cause and common cause analyses should be raised by default when significant conditions adverse to quality are found during manufacturing. If a requirement additional to the original supplier's quality control plan is to be presented by the regulator, it should monitor the delivery of that plan.

It is extremely important to assure comprehensive and timely communication between all parties involved in the construction of an NPP (designer, vendor, subcontractor, operator) to ensure that the nuclear and radiation safety requirements are understood by all actors within the supply chain. Quality assurance and control on material and component procurement need continuous and proactive oversight from the vendor and the licensee. Particular attention must be dedicated to situations where "small or new" subcontractors are in charge of safety related components manufacturing, because they often provide services to other organisations outside the nuclear sector and may not understand, or wish to adhere to, nuclear-specific standards and processes. For this reason, regulatory oversight of the way in which the licensee ensures that its expectations are met at all levels in the supply chain is advisable.

APPENDIX 1
CONEX DATABASE ENTRIES ANALYSED IN THE SECOND SYNTHESIS REPORT

Identification number in ConEx database	Title	Reporting country	Plant	Date of the discovery of the event
1. Design and miscellaneous				
Event 47	Commercial-grade dedication issues identified during inspections	USA	All NPPs	2011/02/15
Event 48.	Spurious shutdown system 2 trip	Canada	Darlington 4	2010/04/10
Event 63.	Seismic considerations – Principally issues involving tanks	USA	LaSalle, River Bend, Shearon Harris	2012/01/26
Event 71.	Rupture of a feedwater pipe	Germany	Muelheim-Kaerlich	1985/06/27
Event 90.	Receipt inspection issues	USA	Vogtle-3 & 4 and V.C. Summer-2 & 3	2012/11/30
Event 107.	Design mismatch of control room display windows of plant monitoring and alarm	R. of Korea	Shinwolsung 2	2011/05/19
Event 113.	Improperly sloped instrument sensing lines	USA	Watts Bar-2	2013/04/29
2. Civil construction				
Event 44.	Adverse concrete conditions due to distress from alkali-silica reaction	USA	Seabrook	2009/06/01
Event 57.	Defects in joint treatments between two concreted parts	France	Flamanville 3	2009/02/11
Event 67.	Rebar design change	USA	Vogtle -3	2012/05/07
Event 100.	Incorrectly installed anchors in German nuclear plants	Germany	All NPPs	2006/09/15
Event 101.	Pouring activities of pools or tanks – high rebar density areas and high pouring	France	Flamanville 3	2010/12/01

	lift issues			
Event 115.	Shield building concrete subsurface lamina cracking caused by moisture intrusion and freezing	USA	Davis-Besse	2011/10/10
Event 116.	Containment liner corrosion	USA	Beaver Valley-1	2009/04/23
3. Mechanical, manufacturing within the supply chain				
Event 9.	Heavy component manufacturing – Pressuriser	France	Flamanville 3	2008/07/10
Event 10.	Heavy component manufacturing – Steam generator misdrilling	France	Flamanville 3	2008/11/19
Event 40.	Main coolant lines (hot and cold legs) manufacturing – Heat-affected zone micro-cracking	Finland	Olkiluoto 3	2009/02/10
Event 41.	Main coolant lines (hot and cold legs) manufacturing – Non-documented weld repairs	Finland	Olkiluoto 3	2009/10/06
Event 42.	Main coolant lines (hot and cold legs) manufacturing – Internal indications in bended areas	Finland	Olkiluoto 3	2010/07/27
Event 60.	Heavy component manufacturing: vessel closure head buttering thickness	France	Flamanville 3	2011/06/01
Event 61.	Heavy component manufacturing: reactor pressure vessel closure head	France	Flamanville 3	2010/11/01
Event 62.	Non-conformity concerning the surface finish of pipes	France	Flamanville 3	2012/03/01
Event 64.	Ineffective use of vendor technical recommendations	USA	All NPPs	2012/04/24
Event 65.	Non-conformities on valve body surface	Finland	Olkiluoto 3	2010/06/23
Event 72.	Missing counter-boring in butt weld of safety injection pipes	R. of Korea	Shin-Kori 3 & 4	2011/11/23
Event 73.	Missing of shot peening work process to high pressure turbine rotor	R. of Korea	Shin-Kori 3	2012/03/15
Event 94.	Damage to the moderator inlet nozzles of calandria	India	Kaiga 3 & 4	2002/04/30
Event 95	Guillotine rupture of fire water line to a steam generator in reactor building	India	Rajasthan-5	2009/12/23
Event 96.	Indications in small bore fittings	Finland	Olkiluoto 3	2013/03/18
Event 97.	Undocumented heat treatment and interchanging of main steam line pipe forgings during manufacturing	Finland	Olkiluoto 3	2008/10/11
Event 99.	Procurement of the emergency diesel generators and their auxiliary systems	Finland	Olkiluoto 3	2010/11/26
Event 103.	Manufacturing of the engines for station black-out diesels	France	Flamanville 3	2012/03/22
Event 110.	Potential for Teflon® material degradation in containment penetrations, mechanical seals and other components	USA	Fort Calhoun	2012/05/12
Event 112.	Welding defects in replacement steam generators	USA	San Onofre-3	2010/04/05
Event 114.	Welding problems during fabrication of reactor plant components	USA	Vogtle-3	2012/10/04
Event 117.	Motor-operated valve inoperable due to stem-disc separation	USA	Browns Ferry-1	2010/10/23

4. Electrical				
Event 22.	Switchyard transient leads to dual unit trip	USA	Oconee-1	2007/02/1
Event 77.	Loss of offsite power due to incomplete logic for interim transformer	R. of Korea	Shin-Kori 1	2010/07/06
Event 104.	Cabling non-conformances	Finland	Olkiluoto 3	2010/12/31
5. Instrumentation and control				
Event 50.	Adjuster rod electronics issue	Canada	Darlington 4	2010/04/21
Event 68.	Digital instrumentation and control violation	USA	Vogtle-3 & 4	2012/06/19
Event 79.	Manual reactor shutdown to examine measuring error of ex-core detectors	R. of Korea	Shin-Kori 1	2010/09/14
6. Site construction, erection and installation				
Event 18.	Floor drain flow pump inoperability due to flooding potential	USA	Catawba-1	2008/01/30
Event 26.	Service water inoperable due to valve modification	USA	McGuire-1 & 2	2007/08/06
Event 34.	Instrument air header failure	USA	Nine Mile Point-2	2008/03/26
Event 43.	Closing gate damage of the spent fuel interim storage pumping station	Finland	Olkiluoto 3	2009/03/02
Event 51.	Deficient hydrostatic pressure test arrangement of valves	Finland	Olkiluoto 3	2009/04/12
Event 53.	General corrosion of pressuriser and steam generators during transportation and storage prior to installation	Finland	Olkiluoto 3	2009/12/15
Event 56.	Damage of the 400 kV Power cable of an operating unit during construction of a new unit	France	Flamanville 3	2010/06/08
Event 84.	Seawater flooding of construction field	R. of Korea	Shin-Wolsong 1&2	2009/04/29
Event 98.	Flooding at the construction site during heavy rain	Finland	Olkiluoto 3	2011/07/03
Event 106.	Mis-installation of containment vertical tendon sheaths	R. of Korea	All PWRs	2010/04/12
Event 111.	Willful misconduct/record falsification and nuclear safety culture	USA	Vogtle-3	2011/09/01
7. Commissioning, pressure testing				
Event 45.	Component cooling water system gas accumulation and other performance issues	USA	All NPPs	2011/07/18
Event 49.	Transient due to odd shutoff rods drop in core	Canada	Darlington 3	2011/07/28
Event 74.	Deformation of anchor bolts during hydrostatic test of reactor makeup water tank	R. of Korea	Shin-Kori 3	2011/10/24
Event 76.	Bulge of steel liner plate of in-containment refueling water storage tank during hydrostatic test	R. of Korea	Shin-Kori 3	2012/07/31
Event 81.	Reactor trip due to core protection calculator low departure from nucleate boiling ratio during 80% load rejection test	R. of Korea	Shin-Kori 1	2010/11/17
Event 82.	Reactor trip due to core protection calculator low departure from nucleate boiling ratio during 0% reactor core physics test	R. of Korea	Shin-Kori 1	2011/01/25

Event 83.	Reactor trip due to steam generator low level caused by main feed water pump trip	R. of Korea	Shin-Kori 1	2011/02/18
Event 91	Reactor vessel closure head studs remain detensioned during plant startup	USA	Brunswick-2	2012/04/11
Event 92.	Presence of foreign material in the primary heat transport system	India	Rajasthan-3	2002/05/15
Event 93.	Events of pin-hole leaks of heavy water from primary heat transport system tubing due to fretting damage	India	Madras-1 and Tarapur-3 & 4	2009/03/11

APPENDIX 2
CONEX DATABASE ENTRIES ANALYSED IN THE FIRST SYNTHESIS REPORT

Identification number in ConEx database	Title	Reporting country	Plant	Date of the discovery of the event
Event 2	Steel reinforcement arrays for the reactor fuel building and safeguard auxilliary building basemat	France	Flamanville 3	2008/03/01
Event 4	Liner welding activities – Reactor building basemat	France	Flamanville 3	2008/02/01
Event 6	Service lifetime and strength of the base slab concrete for reactor building	Finland	Olkiluoto 3	2005/10/01
Event 7	Main coolant lines (hot and cold legs) manufacturing – Inhomogenous grain size	Finland	Olkiluoto 3	2008/01/01
Event 8	Containment steel liner welding	Finland	Olkiluoto 3	2007/06/01
Event 54	Appearance of cracks in the concrete basemat of the reactor building of Flamanville 3	France	Flamanville 3	2008/01/01
Event 55	Absence of joint treatment between two concreting lifts in the gousset area	France	Flamanville 3	2008/10/01

APPENDIX 3
LIST OF ACRONYMS

A

AA: Adjuster rod Assembly
ACAG: Air Carbon-Arc Gouging
AFW: Auxiliary Feed Water
ASME: American Society of Mechanical Engineers
ASN: Autorité de Sûreté Nucléaire (French Nuclear Safety Authority)
ASR: Alkali-Silica Reaction
ASTM: American Society for Testing and Materials

B

BP: Break Preclusion

C

CCTV: Closed-Circuit TeleVision
CCW: Component Cooling Water
CEA: Control Element Assembly
CGD: Commercial Grade Dedication
COL: Combined Construction Operation Licence
ConEx: Construction Experience
CPC: Core Protection Calculator
CPP: Condensate Polishing Plant
CRC: Clutch Relay Card
CTM: Channel temperature monitoring

D

DDC: Ductility Dip Cracking
DNBR-Low: Departure from Nucleate Boiling Ratio Low
DNM: Delayed Neutron Monitoring

E

EDF: Electricité De France, French electricity supplier
EDG: Emergency Diesel Generator
EMC: ElectroMagnetic Compatibility
EPR: European Pressurized Reactor

EPRI: Electric Power Research Institute
ETC-C: European Pressurized Reactor Technical Code for Construction

F

FM: Fuelling Machine
FME: Foreign Material Exclusion
FMEA: Failure Mode and Effect Analysis
FP: Full Power
FSAR: Final Safety Analysis Report

G

GPM: Gallons Per Minute
GTAW process: Gas Tungsten Arc Welding process

H

HAZ: Heat-Affected Zone
HDA-T: Heavy-Duty mechanical Anchor-Through set-style
HELB: High Energy Line Breaks

I

I&C: Instrumentation and Control
IN: Information Notice
IRWST: Inside-containment Refueling Water Storage Tank
ISI: In Service Inspection
ITAAC: Inspections, Tests, Analyses and Acceptance Criteria

L

LOCA: Loss of Coolant Accident

M

MCL: Main Coolant Line
MCR: Main Control Room
MDEFWP: Motor Driven Emergency Feed Water Pump
MFWP: Main Feed Water Pump
MI: Mineral Insulated
MMA: Manual Metal Arc
MOV: Motor Operated Valve

N

NCR: Non-Conformance Report
NDT: Non-Destructive Testing
NEA: Nuclear Energy Agency
NPP: Nuclear Power Plant

NPSH: Net Positive Suction Head
NRC: Nuclear Regulatory Commission (USA)

O

ODC: Over Designed Consignment
OECD: Organisation for Economic Co-operation and Development
OL3: Olkiluoto unit 3
OPEX: Operating Experience feedback

P

PHT: Primary Heat Transport
PHWR: Pressurised Heavy Water Reactor
PMI: Positive Material Identification
PT: Penetrant Test
PWR: Pressurized Water Reactor

Q

QA: Quality Assurance
QC: Quality Control

R

RCC-M: Règles de Conception et de Construction des équipements électriques et de contrôle commande des îlots nucléaires des REP – Matériels (Design and Construction Rules for mechanical components of PWR nuclear islands – Materials)
RPV: Reactor Pressure Vessel
RSG: Replacement Steam Generator
RT: Radiographic Test
RTD: Resistance Temperature Detector

S

SA: Shutoff rod Assembly
SAF: Shape Annealing Function
SAT: Standby Auxiliary Transformer
SB: Shield Building
SBO: Station Black-Out
SCR: Station Condition Record
SDS: ShutDown System
SEM: Scanning Electron Microscope
SG: Steam Generator
SI: Safety Injection
SRIH: South Reactor Inlet Header
SSCs: Structures, Systems and Components
SSLP: Stainless Steel Liner Plate

STUK: Säteilyturvakeskus (Finnish regulatory body)
SW: Service Water

T

TIG: Tungsten Inert Gas
TVO: Teollisuuden Voima Oy, Finnish electricity supplier

U

UAT: Unit Auxiliary Transformer
UT: Ultrasonic Test

V

VT: Visual Testing
V&V: Validation and Verification

W

WGRNR: Working Group on the Regulation of New Reactors (reports to the Committee on Nuclear Regulatory Activities of the Nuclear Energy Agency)