

# **F**irst Construction Experience **Synthesis Report** **2008–2011**

Working Group on the Regulation  
of New Reactors (WGRNR)



**Unclassified**

**NEA/CNRA/R(2012)2**

Organisation de Coopération et de Développement Économiques  
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**NUCLEAR ENERGY AGENCY  
COMMITTEE ON NUCLEAR REGULATORY ACTIVITIES**

**First Construction Experience Synthesis Report  
2008-2011**

**Working Group on the Regulation of New Reactors (WGRNR)**

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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.

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## **ACKNOWLEDGEMENT**

This report and the ConEx procedure that supports it were prepared by a small subgroup of the WGRNR. This subgroup was composed of Guillaume Wack, Andras Toth, Ladislav Haluska, Marc Noel, Seon Ho Song, Tapani Virolainen, Steve Gibson and Jose Balmisa, on the basis of discussions, and input provided by, the members of CNRA's Working Group on the Regulations of New Reactors listed below. Ms. Laura Dudes (NRC, United States) and Mr. Alejandro Huerta (NEA Secretariat) skillfully chaired the meetings and the work of the group.

The ConEx procedure would not have come to fruition without the knowledgeable contributions of Yasunori Bessho and Mitsuhiro Kajimoto.

## TABLE OF CONTENTS

EXECUTIVE SUMMARY .....	7
INTRODUCTION .....	11
1. LESSONS LEARNED FROM THE CURRENT CONSTRUCTION EXPERIENCE IN OLKILUOTO-3, FLAMANVILLE 3 AND THE COMMISSIONING OF SHIN-KORI 1.....	13
1.1 Construction events .....	13
1.2 Steel liner events.....	14
1.3 Concrete related events.....	17
1.4 Main component events. Integrity of the primary system. Olkiluoto-3 experience .....	21
1.5 Causes, safety analysis and lessons learned. ....	29
2. LESSONS LEARNED FROM OTHER EVENTS REPORTED TO THE WGRNR .....	33
2.1 Fires .....	33
2.2 Cables .....	34
2.3 Containment / liner .....	35
2.4 Essential service water / component cooling water.....	35
2.5 Welds.....	36
2.6 Seismic events .....	37
3. OTHER REPORTS ON CONSTRUCTION EXPERIENCE.....	39
3.1 JRC-Petten, “Summary Report on Nuclear Power Plants Construction, Commissioning and Manufacturing Events” (2011).....	39
3.2 US NRC, NUREG-1055, “Improving Quality and the Assurance of Quality in the Design and Construction of Nuclear Power Plants” (1987).....	39
3.3 UK Royal Academy of Engineering, “Nuclear Lessons Learned” (2010).....	40
4. CONCLUSIONS AND LESSONS LEARNED.....	43



## EXECUTIVE SUMMARY

The objective of the construction experience (ConEx) programme is to identify the major deficiencies that occurred during the design and construction of nuclear power plants, assess the adequacy and supplement, if necessary, the current regulatory activities to detect and correct such events and prevent them from remaining undetected until the plant becomes operational and finally, to disseminate information to ensure appropriate regulatory attention is given to the lessons learned from past events.

The ConEx programme started in 2008 and besides exchanging construction experience within the members of the WGRNR, the main activity has been the development of the ConEx database that allow the members to report, collect and analyze construction events. With this database, the WGRNR has tried to capture events initiated before the first fuel loading related to design, manufacturing on-site or off-site, construction, and commissioning, that are detected at any stage of the plant life, such as:

- events involving vendors, contractors, sub-contractors, manufacturers, designers, licensees.
- events presenting a potential interest, especially to other regulators (lessons learned).
- events with real or potential safety impact or radiation protection impact on workers or public.
- recurrent events that would indicate quality assurance or safety culture problems in any of the organizations involved in the design or construction.

Focusing on these kinds of events is the main attribute of the ConEx database that makes it a valuable tool for the timely sharing of construction experience with other regulators, to periodically assess the analysis of events and to providing the members with topical reports of interest.

This first synthesis reports summarizes the lessons learned from current construction experience events in Flamanville 3, Olkiluoto-3, Shin Kori 1 and from other plants included in the database related to construction issues.

Although in the report there are lessons learned applicable to different organizations, the main goal of the report is to highlight the lessons learned applicable to regulators. The most important specific lessons learned drawn from the ConEx database, with reference to the sections of the report where there is additional information, are grouped in the areas of: regulation, licensing process and construction oversight.



Specific Lessons Learned from ConEx database.

**Regulation**

**The Regulatory Body should review their regulatory infrastructure with respect to the following :**

- Safety culture needs to be established prior to the start of authorized activities such as the construction phase, and it is applied to all participants (licensee, vendor, architect engineer, constructors, etc). (Sections 1.2, 1.5)
- Licensees establishing an integrated management system prior to the start of authorized activities that would allow, among other things, to have a global approach to the management of non conformities. (Section 1.2, 1.3, 1.5).
- The licensee's operating experience feedback system which should cover other construction projects of a similar type. (Section 1.2)
- The licensee's demonstration, in an early stage of the project, of the sufficiency of the organizational and technical provision for the proper management of construction activities. (Section 1.2,1.5, 2.5)
- The adequacy of the licensee's design change management process to demonstrate the fulfillment of the licensing basis for any design change made throughout the project paying special attention to potential side effects on relevant SSC. (Section 1.2)

There are some lessons learned that have to do with the regulatory body's organizational structure during construction activities:

- Although the prime responsibility for the oversight of contractors lies with the licensee holder, the legal framework should provide the regulator the capability (authority and responsibility) to oversee construction activities including the supply chain and contractors. (Section 1.4)
- The regulatory body should reinforce the organization for the oversight of the commissioning process to ensure it is composed of suitably experienced staff. (Section 1.5)
- The regulatory body should acknowledge that commissioning of an NPP is equivalent to the normal operating NPP in terms of safety culture.

**Licensing process.**

The licensing process for a new build should include the following aspects:

- An assessment of the adequacy of the methods chosen to implement design requirements by sampling using regulatory reviews and inspections. (Section 1.3, 1.5).
- An assessment and inspection of the internal hazard analysis of the impact of non safety related SSC on safety related ones. (Section 2.1, 2.4).

- In case of use of an unproven technology or manufacturing method, sufficient tests (like mock-ups) and qualifications should be performed by the licensee or its vendors with a supporting information provided to the regulatory body to allow the independent assessment of the safety implication of the use of the technology or manufacturing method. (Section 1.2, 1.4)
- An assessment of aging issues in an early stage. (Section 2.2)

### **Construction oversight.**

The regulator should include in the inspection process the following provisions:

- Specific inspection of the engineering services companies on the definition of construction methods. (Section 1.2, 1.3, 2.2, 2.5)
- Check or inspect the effective implementation of safety culture and the management system. (Section 1.2)
- Check the impact of the environmental and working conditions on the quality of the construction. (Section 1.2, 2.1, 2.2).
- Check the welding process including metrics such as the defects rate, etc. (Section 1.2.)
- Check the level of awareness at different working levels onsite (task distributions, responsibilities, communications, hold points, etc). (Sections 1.2, 1.3, 2.3)
- Check the level of awareness at different working levels onsite of the impact of specific jobs on safety. (Section 1.2, 1.3, 2.3)
- Check the sufficiency and competences of resources allocated by the licensee to perform oversight and supervisory activities. (Section 1.3, 1.5)
- Check the configuration control management in all phases: design, construction and operation of the plant. (Section 1.3)
- Check that during construction a graded oversight approach appropriately took into account the potential safety impact of the activity being performed. (Section 1.1, 1.2, 1.5)



## INTRODUCTION

According to the CNRA mandate, the Working Group on Regulation of New Reactors (WGRNR) has the following goals:

- Constitute a forum of experts for the licensing of new commercial nuclear power reactors that should facilitate a cooperative approach to identify key new regulatory issues and promote a common resolution.
- Co-ordinate its work with the one performed by the Multinational Design Evaluation Programme (MDEP).
- Ensure that construction inspection issues and construction experience are shared through existing CNRA working groups or new working groups as appropriate.
- Plan for the transition of new reactors into the operational phase and established CNRA programs.
- Identify support needed from CSNI.

To take forward these goals, the WGRNR has the following specific tasks:

- To analyze construction experience events and propose regulatory actions to aid in the prevention of safety events in the operating phase.
- To review site licensing practices in different countries and propose recommendations to the community.
- Identify regulatory body resources to license a new nuclear power plant.

This report is focused on the analysis of construction events currently reported to the WGRNR. In order to carry out this analysis, a construction event database (ConEx) has been developed within the group. The main goal of this database is to collect events that have occurred before the first fuel loading but were detected at any time during plant life.

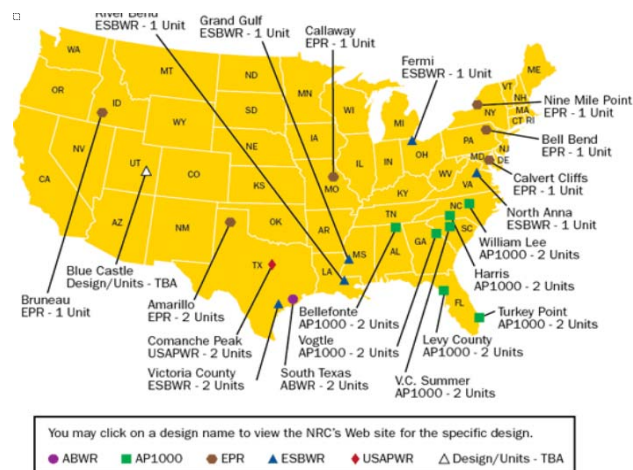


Feedback on construction events available to WGRNR can be grouped into the following categories:

- Construction events at Olkiluoto-3, Flamanville 3, and Shin-Kori 1.
- Other events reported to the WGRNR.
- Other construction events from the Incident Reporting System (IAEA/NEA).
- Other documents and reports.

This report focuses mainly on the lessons learned from construction events and provides a quick report on these events. There is a summary of the most significant events in each group.

The lessons learned are grouped in technical areas of expertise, components or systems.



## **1. LESSONS LEARNED FROM THE CURRENT CONSTRUCTION EXPERIENCE IN OLKILUOTO-3, FLAMANVILLE 3 AND THE COMMISSIONING OF SHIN-KORI 1**

### **FLAMANVILLE 3 AND OLKILUOTO 3**

#### **1.1 Construction events**

The Finnish Government granted the construction license for Olkiluoto 3 on the 17th February 2005. Since then, the most significant construction events at this EPR reported to the WGRNR are:

- Olkiluoto 3 - Strength of the base slab concrete for the reactor building.
- Olkiluoto 3 - Leak tightness of the containment.
- Olkiluoto 3 - Integrity of the primary pipes.

The other nuclear power plant being built currently in Europe is Flamanville-3 on the north west coast of France. The authorization decree was issued in April 2007 and since then the most relevant construction events are the following ones:

- Flamanville-3. Cracks in the poured concrete basemat of the reactor building (January 2008).
- Flamanville-3. Non compliances with steel reinforcement requirements at several buildings (March-July 2008).
- Flamanville-3. Welding process deficiencies (June 2008-February 2009).
- Flamanville-3. Deficiencies of the joint treatment of the steel reinforcement of the gusset area of the reactor building (December 2008).

Finally, the Korean construction experience is included in the report. During the commissioning of Shin-Kori 1, an inadvertent opening of the containment spray isolation valve due to a human error led to a discharge in the containment of 430 tons of borated water.

There was no radiation exposure to the workers or release of radioactive materials to the environment, but during the event progression, major plant safety systems including the emergency diesel generator (EDG) and containment purge isolation were actuated as designed.

The lessons learned from these events relating to structures, systems and components are summarized below.

## 1.2 Steel liner events



In Olkiluoto-3 in June 2007 following welding of the steel liner some imperfections were detected that exceeded the acceptance criteria.

The direct cause of the poor quality of the welding was the change in the welding environment (wetting of the concreted area nearby causing extra humidity) and human error of the welders.

The imperfections were the result of stresses created in the welding process due to incompatibilities of the bottom and upper ring module (the upper part circumference was 17 mm greater than the circumference of the bottom module) which was not adequately considered in the fitting and welding process by the manufacturer.

The repair of these welds continued until the end of October 2007 and affected the steel rebar installation of the inner containment wall.

Besides this, during a construction inspection at the Polish manufacturer in September 2008, STUK detected that welding of the liner parts were done according to a welding procedure which was qualified to a lower safety class than required.

The licensee corrected the deficiency by replacing parts of the liner by new steel plates (sized at 0.5 m<sup>2</sup> average).

The main causes and contributing factors related to this event are the following:

- Inadequate management of the welding environment (increased and unacceptable humidity during welding due to wetting of the concrete surface).
- Incorrect pre-job briefing to understand the safety significance of the welding process.
- Incompatibility of the liner parts not adequately taken into account in the fit up and welding of the liner.
- Inadequate control of the welders and welding quality during the welding process.

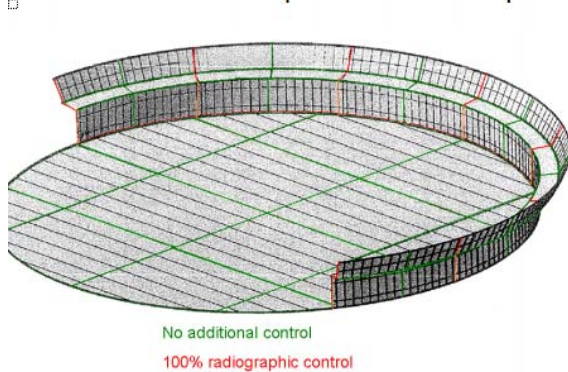
The corrective actions performed by the licensee were the following:

- Repair of the welding deficiencies.

- Continuous control of the subcontractor (welding and welders) during welding by the licensee and vendor.
- Full radiographic inspection of the weld seams.

The main regulatory activities were:

- In July 2007, STUK required the licensee to stop all the welding activities on the liner modules and to perform a root cause analysis of the poor welding results. QA and QC deficiencies were identified and corrective actions developed and implemented.
- 
- STUK performed an additional inspection in August 2007 with the focus on the management and oversight of the welding process. This inspection resulted in several findings (i.e. quality control procedures did not include proper readiness inspections for large welding works at the site, welding procedures were not updated, welding parameters were not followed, welding materials were not adequately managed on site) that raised questions about the manufacturer's, vendor's and licensee's QA and QC activities.
- Welding activities on the liner were allowed to continue after the licensee performed corrective actions.



September 2009

ASN – Flamanville 3 oversight - WRG NR meeting



In June 2008 at Flamanville-3 the licensee, after several questions raised by ASN about the welding activities on the liner, decided to stop all welding activities. That same month an inspection by ASN found that the welding processes used were not permitted by the construction code. ASN required a justification for the lack of compliance with the construction code to ensure the quality of the liner in such conditions.

In the following months ASN detected an excessive number of repairs (especially on the reactor building basemat area), they found inadequate consideration of adverse environmental conditions (water, wind, etc.), and required the licensee to demonstrate the quality of the liner welds and to define preventive actions to reduce the repair or rework rate of welds. As a response to this, the licensee submitted a report that concluded that the defects were due to gas cavity, inclusion, and only 4% of the defects due to lack of fusion, wormhole, etc. It also indicated that the repair rate in the reactor basemat area was between 13% to 34% while this same figure in the prefabrication area was between 5% and 15%.

The direct cause of these events was poor manual welding, worsened due to the bad weather conditions. The automatic process was not possible in the environmental conditions of the building site.



The safety consequence of these deficiencies in the liner welds was the loss of the pressure boundary of the containment.

The main actions taken by the licensee were to develop suitable protection of the welding areas to improve the environmental conditions, reinforcing the control of its subcontractors and performing a 100% radiographic test of the liner welds.

In relation to the ASN actions, the most important ones are the following:

- Assessment by the IRSN (ASN's TSO) of the safety impact from the liner quality issues.
- Additional controls over the manual welding process.
- Increase to 100% the radiographic testing until there was a significant decrease of the repair rate.
- The performance of additional tests to determine and confirm the resilience and ductility levels of the welds.

### Lessons learned

Safety culture should be maintained at very high level from the beginning of the project.

- The licensee should be aware and ensure that workers know the safety significance of their work and the importance of following procedures.
- The regulator should emphasize the importance of the safety culture arrangements during the construction phase.

Proven technology and manufacturing or construction methods should be used.

- Before the use of an unproven technology or manufacturing method, sufficient tests (like mock-ups) and qualifications should be performed.
- Risk analyses should be used as a tool to evaluate and prevent deviations during construction.
- Both the regulator and the licensee should be aware that the ratio of defects in field welding seams can be considerably higher than that in prefabrication and should develop procedures that take account of this effect.

All controls, including those related to environmental conditions, should be maintained during the performance of work.

- The licensee should have mechanisms to guarantee the adequate maintenance of all controls.
- Regulator should also ensure that the licensee learns from the construction experiences of other construction projects, especially similar at kinds of projects. International coordination (i.e., through WGRNR) facilitates this prompt and efficient communication of lessons learned among regulators.

### 1.3 Concrete related events

- *Strength of the base slab concrete for reactor building (Olkiluoto-3) and cracks in the poured concrete basemat of the reactor building (Flamanville 3).*

In Olkiluoto-3 concreting of the base slab was done in three phases starting in mid August 2005 with the concreting of the fuel building base slab. In early September, concreting of two safeguards buildings was performed. Concreting of the base slab was finished by the largest concreting (12,000 m<sup>3</sup>) of the reactor building and other two safeguards buildings in October 2005.

Some discrepancies in the concrete composition were found during the third concreting and the plant vendor performed a root cause analysis. These discrepancies were the result of changes in the water-cement ratio during the concreting.

The amount of filler in the concrete mixture was changed by the batching plant to improve the pumpability and workability of the concrete.

This change was made after a request from the plant vendor. However, the change was made without due consideration of the effects on the concrete properties. As a result, the water-cement ratio was higher than calculated because of increase of moisture content of filler material.

Analyses and additional tests (post-cast sampling at selected locations) showed that in spite of the changes, the final strength of the concrete exceeded the technical specifications.

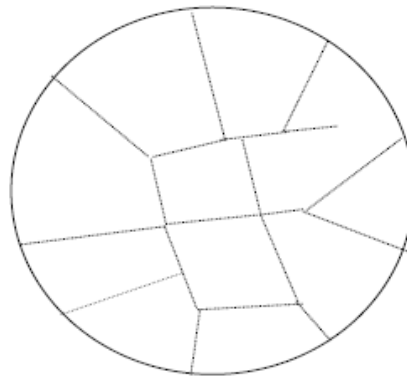
The licensee, vendor and subcontractor performed following corrective actions:

- The design and concreting documentation for concrete batches was improved in content and quality.
- The testing of concrete mixes was improved to verify both the pumpability and workability of the approved concrete mixes.
- Third party oversight for the quality control of batching plant was increased.
- Responsibilities related to the management and oversight of subcontractors on site were clarified.

Lessons learned and corrective actions for the regulatory body :

Regulatory inspections were established for large concreting activities to ensure;

- Proper organisational arrangements for concreting were established (task distribution, responsibilities between parties, communication and co-operation between parties, concrete batching plan and site provisions for abnormal situations)
- Proper technical arrangements for concreting were written (implementation and results of the quality control plan for concreting, approval of non-conformance reports related to the concreting)
- Proper resources for concreting supervision on site were put in place.



Configuration of cracks in the circular basemat

In Flamanville-3 in January 2008 the licensee reported to the ASN the appearance of cracks in the poured concrete basemat of the reactor building. The transverse cracks ran the full depth of the first layer for the reactor building basemat (1.75m - 4200 m<sup>2</sup>). The biggest cracks were 3.5 mm wide, but as time went on, the licensee observed that the width of the cracks were decreasing. The pouring activities of the second layer of the basemat were deferred by the licensee to wait for the conclusions of the assessment performed by ASN and IRSN on this non-conformity.

The direct cause was the lack of steelwork reinforcement at the level where pouring was stopped.

The main safety consequence of this deficiency is the impact on the mechanical strength of the basemat.

Immediately after the discovery of the deficiency, the licensee treated the cracks by filling them with epoxy resin under pressure to protect the exposed steelwork and close ground water paths. Also, the licensee demonstrated to the ASN that by applying this resin there would be no loss of mechanical strength and that the basemat would be leak tight against underground water.

As a preventive action, the licensee has adopted the appropriate pouring strategy (i.e. improving the concrete formulation) to minimize cracks.

In relation to the actions of the ASN, besides carrying out an inspection on the treatment of the cracks, the ASN requested the licensee to demonstrate the fulfillment of the safety requirements of the basemat (mechanical strength and leak tightness).

- *Non-conformities during steel reinforcement activities in several buildings (March-July 2008).*

In March 2008, ASN detected non-conformities associated with the steel reinforcement arrays for the reactor fuel building basemat (lack of stirrups). ASN required the licensee to improve the quality control of construction activities relevant to safety.

Similar problems were detected in May 2008 and ASN required the licensee to put off concreting activities on the buildings of the nuclear island and the pumping station, to submit a detailed analysis of the event and deliver an action plan to improve the effectiveness of its quality management system.

The main consequence of all of these events is the potential impact on the mechanical strength of the basemat of the buildings. However, later engineering analysis identified no mechanical impact on the structure.

The root cause of these events is the deficiencies of the licensee and its constructor to properly handle the quality of construction activities relevant to nuclear safety.

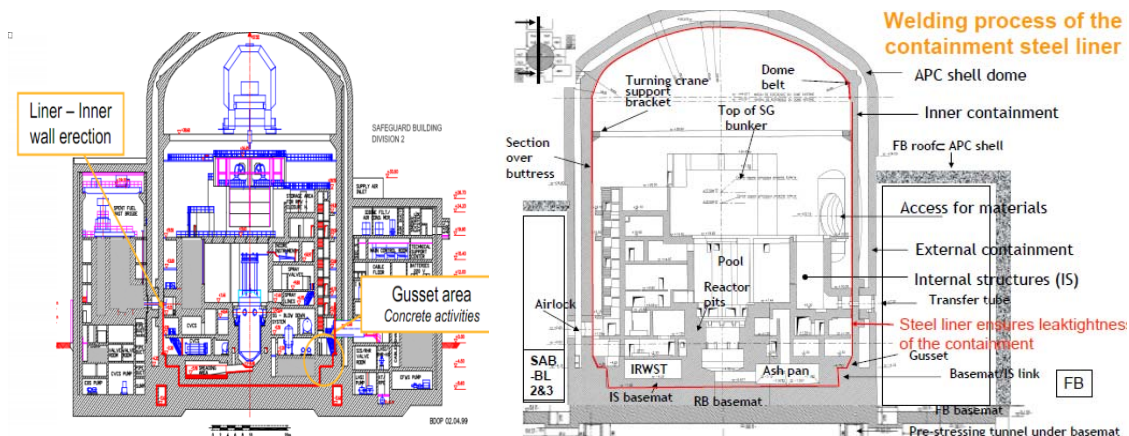
The licensee, as an immediate action, corrected the deficiencies by putting in place the missing stirrups. In addition, the Licensee established the following actions to avoid future recurrence:

- Implemented training sessions on safety culture to the whole licensee and constructor staff involved.
- Improvements in quality management procedures.
- Improvements of the supervision of all steel reinforcement activities. This was done through the use of third party technical experts independent of the licensee and the contractor.

Also, besides the initial action to suspend all the steel reinforcement activities, the ASN required of the licensee to take the following actions:

- Consideration of independent third party supervisions for steel reinforcement activities.
- Improvements of the quality control system.
- To submit a report every 6 months on the progress of the effectiveness of all the actions.

- Deficiencies of the joint treatment of the steel reinforcement of the gusset area of the reactor building (December 2008).



In October 2008 the licensee's procedure for the concrete pouring of the gusset area considered two concreting lifts without joint treatment. The installation of the steel reinforcement of the gusset area without the joint treatment is not in compliance with the construction code ETC-C.

The safety consequence of this deficiency is a potential loss of the mechanical strength of the gusset and also a loss of the leak tightness of the barrier.

According to the ASN, the root cause of this event was the lack of preparedness and planning of the licensee and its contractors to perform safety-related activities.

The licensee provided a justification to demonstrate that the concreting procedure satisfied design margins; however, it will have to implement mechanisms to avoid the absence of joint treatment in future concreting activities.

The ASN required the licensee to fulfil the design margins without joint treatment and to ensure better compliance with the applicable construction codes.

Lessons learned

- Safety culture
- Before the start of the concreting all the technical and organizational arrangements required to avoid deviations during concreting should be demonstrated by the licensee and inspected by the regulator.

#### 1.4 Main component events. Integrity of the primary system. Olkiluoto-3 experience



##### - *Inhomogeneous grain size*

In Olkiluoto-3 the main coolant lines (Hot and Cold Legs) of the primary circuit are manufactured from large forgings to minimize the number of welds. Tests performed on the main coolant line forgings revealed coarse and inhomogeneous grain size areas in the forgings. In addition, tensile and hot tensile strength values were somewhat too low for some forgings. Grain size exceeded the criterion which was specified in the Preliminary Safety Analysis Report (PSAR).

The size of the main pipe forgings (especially for Cold Legs) is much larger than manufactured earlier by the forgemaster. The large size together with the heat treatment and forging sequence was not fully optimised (the number and sequence of heat treatment and forging).

Because the grain size criterion was not met, the vendor and manufacturer decided to remanufacture all main coolant lines. As a result of a new manufacturing programme, there were still some non-conformances in the grain size, but the manufacturer and vendor have been able to show that the main coolant lines can be reliably inspected before and during the operation of the plant. STUK has also performed UT inspections on one main coolant line.

In relation to corrective and preventive actions, the vendor and manufacturer studied the manufacturing programme and provided an optimised heat treatment and forging sequence. With the new manufacturing programme the number of heat treatments and forging especially at the ends and on the nozzle area of the forging were minimised.

- *HAZ micro-cracking of Main Coolant Lines*

EPR MCL girth welds are made using a narrow-gap TIG (GTAW) welding process. In two of the hot legs, weld intermediate PT tests 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 proceeding to the final weld surfacing passes.

First (HL3) and third (HL1) shop welds had PT indications of 190 and 145 mm in the length respectively. The PT test was intermediate and its purpose was to test the pipe surfaces shortly before the final surface overlay welding passes would take place. The remaining un-welded welding groove was 0 – 2.5 mm from the pipe surface at the time of this PT test. The maximum crack depth was 1.8 mm. The indication line's distance from the weld fusion line was 1-3 mm. The maximum temperature due to welding was estimated to be in the range of 800 – 1200 °C in this position.

A metallographic replica study, 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 as the most relevant mechanism. The phenomenon occurred at a thick section outer surface. Since no effect deeper in the wall thickness was seen as possible, the case was considered to have minor safety significance.

*Cause analysis*

Metallurgical phenomena considered possible for the HAZ micro-cracking are 1) ductility dip cracking and 2) liquid metal embrittlement due to pollution by copper or other foreign constituent. This kind of micro-cracking is not common for austenitic stainless steels.

*Safety assessment*

The micro-cracking was located at the component outer surface. It was concluded that the cracking depth was shallow and that it would not be likely to occur as a buried under-surface defect. In case this type of defect remained in the component undetected, it 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 would be covered by a weld surfacing overlay when welding the final passes were completed.

*Corrective and preventive actions*

According to reports provided to STUK, the vendor did not take corrective actions. However, the defects were only reported in two of the first welds. A total of 36 welds of this type were made including both shop and on-site welds.

*Regulatory actions*

Extra PT and UT testing was required. A thermo-mechanical weld modelling was required and reported for a clearer picture on the strain-temperature-deformation history of the weld area.

*Lessons learned.*

- During the manufacturing of first of a kind evolutionary components, even qualified and long used manufacturing processes may produce surprises.
- Following welding and materials technology research is essential in order to understand possible component failure mechanisms.
- *Non-documented weld repairs of Main Coolant Lines*



*Hot leg weld root and a base material weld repair.*

VT after pipe pickling revealed small non-documented welds on the MCL inner and outer surfaces at off-site manufacturer Fives Nordon. Non-documented welds were found on 10 out of 12 pipes with weld depths of 0-5 mm.

The reason for making the welds had been a habit to finalize small scratches and dents by welding and to re-melt MMA weld toes using a TIG welding process. TIG welding and the filler metals used were qualified for nozzles welding, but the repair welding was done without documentation (violation of RCC-M S 7120 and S 7600) and without non-conformance reporting controls. Many of these weld repairs could have been omitted, if designers would have evaluated the right repair method for each case. The company engineering and quality assurance units were probably not fully aware how the practical work was going on at the shop floor level.

Technical NCRs were opened and the welds' properties were evaluated using VT, PT, UT, RT, PMI (chemical analysis) and metallographic replicas. Most of the weld properties were acceptable for use. Some welds had peculiarities like increased copper content and they were ground off. None of the repair welds were located on highly loaded areas of the pipes, such as close to the nozzles, where thermal



fluctuations are present during operation. Some welds were removed using smooth grinding while the majority were left in the products as-is. New repairs were not needed.

The off-site 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 the 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 program to update the quality management system to fulfil the nuclear quality standards. As the update work was in progress, manufacturer's approval of welding fabrication according to YVL 3.4 (Approval of the manufacturer of nuclear pressure equipment) was suspended.

#### *Cause analysis*

Causes for the deficiencies were lack of communication between fabrication and design departments, inadequate education of welders (welding without specification and documentation), and failures in the implementation of the quality management system. These causes reflect a lack in the implementation of a nuclear safety culture.

#### *Safety assessment*

The repair welds are not located at highly stressed areas. Pipe internal repair welds are not considered likely to have an effect on component ageing. Pipe external repair welds are considered insignificant.

#### *Corrective and preventive actions*

Implementation of nuclear specific quality management system as well as nuclear safety culture enhancement and education programs were started at Fives Nordon.

#### *Regulatory actions*

Manufacturer's approval of welding fabrication according to YVL 3.4 (Approval of the manufacturer of nuclear pressure equipment) was suspended.

#### *Lessons learned*

##### *Licensee*

Licensee audits of manufacturers should be capable of assessing the implementation of the required quality management systems and QA requirements, especially nuclear standards. This is specially the case if the manufacturer has not been involved in nuclear fabrication for years. More intense licensee presence in the early manufacturing stages should be considered.

##### *Vendor, manufacturer, contractor*

Open and continuous communication between the manufacturing and the design departments are necessary. The presence, support and setting a good example by the fabrication foremen are needed during fabrication.

*Regulator*

The regulator should ensure that the licensee's supervision of manufacturing activities are in accordance with the requirements and that it is effective at ensuring that deficiencies in the manufacturer's quality activities are revealed in an early stage of the procurement process.

- *Internal indications in bend areas of Main Coolant Lines*



*Hot leg bend.*

Inside surfaces of induction bent main coolant line areas showed circumferential VT and PT indications after pickling right before delivery to the site. The majority of the indications were found more than a year after the induction bending and where the result of the bending process. Qualification of the induction bending process had not been completely successful and the quality of the post-bending PT tests was poor in revealing material discontinuities. Contrary to the RCC-M code, sand blasting had been used immediately before PT testing and it obviously smeared the metal surface ruining the PT testing performance.

The majority of the indications had successfully gone through two previous VT and PT tests associated with the bending process. The possibility of common cause for the indications had not been properly evaluated when some material discontinuities were found soon after bending.

Forging is conducted by the vendor-owned manufacturer Creusot Forge in France and induction bending is performed by its sub-contractor Mannesmann in Germany. After bending, the spools are shipped back to Creusot Forge for finalization and inspection (VT, PT, UT). Then the spools are shipped to the off-site manufacturer, Fives Nordon, who conducts outfitting of nozzles and conducts component pressure testing. The vendor's welders performs spool welding at Fives Nordon and then later conduct the welding on-site for the production of whole loops that connect the RPV, SGs and RCPs.

During construction inspection of HL1 after pressure test and pickling at Fives Nordon, weak visual indications were seen in the intrados of the bent part on the inner pipe surface. Indications were circumferentially orientated and the longest discontinuous indication length was 700 mm, while the longest continuous indication length was 150 mm. An extra PT also revealed the same 700 mm and 150 mm indications, but not the weaker VT indications at the bent extrados.

*Cause analysis*

Direct causes have not yet been properly evaluated by the vendor/sub-contractor. However, material discontinuities have obviously formed when at elevated temperature during induction bending. The two possible theories for the formation mechanism are: 1) metal folding or 2) grain boundary cracking.

An indirect cause was that the qualification of the induction bending process failed to identify the possibility of the development of these material discontinuities. Preparation for PT testing was unacceptably done using sand blasting, which resulted in hiding the indications and improper evaluation of the qualification pieces. Further, even if some indications were found at Mannesmann soon after bending, an enhanced test program was not started and the common cause was not properly evaluated.

*Safety assessment*

As a result of the static and fatigue strength analysis performed by the licensee, apparently the component strength would not be questioned due to corrosion or other ageing mechanisms even though the discontinuities were left.

*Corrective and preventive actions*

Extra PT and VT were conducted by the vendor and indications that were found were repaired by grinding.

*Regulatory actions*

Extra NDT testing for surface opening and buried defects of the type considered was required to be made before system pressure test at the plant. This action was required to get proof of the vendor/licensee claim of the good performance of the previous extra PT and VT results.

A Proper root cause analysis has not yet been supplied.

*Lessons learned*

*Licensee*

PT testing should be done as soon as possible after the forming process.

The manufacturing code should be followed during component non-destructive testing. Sand blasting before PT testing should not be permitted.

Root cause and common cause analyses should be raised by default when unacceptable indications are found during manufacturing.

*Vendor, manufacturer, contractor*

The 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.

The manufacturing code should be followed during component non-destructive testing.

Surface preparation may ruin PT testing reliability, as should be commonly known, by hiding indications under plastic lip (metal smear).

*Regulator*

PT testing should be done as soon as possible after the forming process.

The manufacturing code should be followed during component non-destructive testing. Sand blasting before PT testing should not be permitted.

Root cause and common cause analyses should be required by default when unacceptable indications are found during manufacturing.

If the regulator establishes a requirement in addition to the contractor's original quality control plan, the regulatory should follow-up on the extra requirement shortly after it is performed.

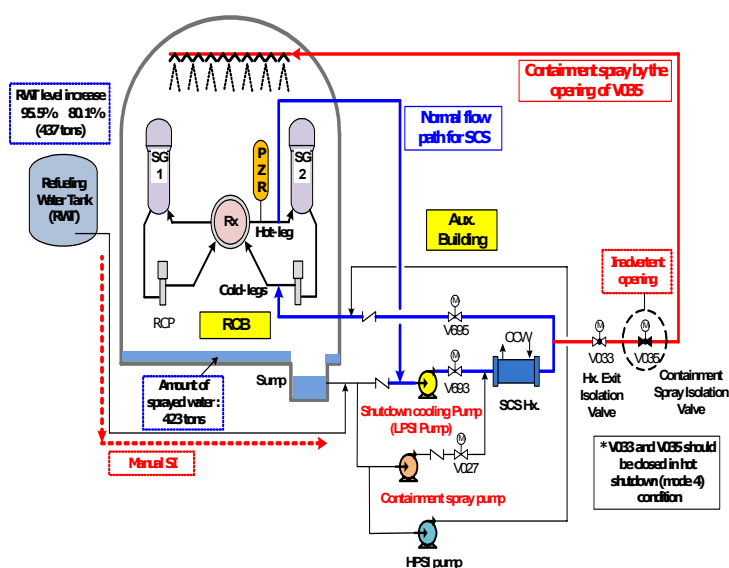
## COMMISSIONING TEST IN SHIN-KORI UNIT 1 “INADVERTENT CONTAINMENT SPRAY”



Shin-Kori Unit 1, was licensed by the Korean Government (Ministry of Education, Science and Technology) on May 19, 2010. Under a power raising test to 50% of full power, it was manually shutdown on September 14, 2010 to re-adjust the ex-core detector position. After completion of the maintenance on the ex-core detector, the plant restarted the power raising test, controlling the reactor coolant temperature utilizing the shutdown cooling system. The plant was in mode 4 with the RCS pressure and temperature at  $28\text{kg/cm}^2$  and  $145^\circ\text{C}$ , respectively. Both the shutdown cooling system and the containment spray system share the shutdown heat exchanger and are separated by the heat exchanger outlet isolation valve (CS-V033) and the containment spray isolation valve (CS-V035). CS-V033 was opened and CS-V035 was closed when the incident happened.

On September 17, at 14:17, CS-V035 opened inadvertently due to human error, and reactor coolant was sprayed into the containment through the containment spray system. The RCS experienced a severe transient; the pressure decreased rapidly from  $28\text{ kg/cm}^2$  to  $3.9\text{ kg/cm}^2$  and the temperature and water level were lowered quickly. Rapid decreases in RCS pressure and water level were identified by the MCR operators, and they carried out responsive actions in accordance with the emergency operating procedure (EOP) including stopping reactor coolant pumps (RCPs), isolation of the letdown line, and increasing the charging flow. Also, additional safety measures were taken including manual actuation of safety injection to recover the RCS inventory, and manual actuation of containment isolation to prevent any radioactive material release to the environment.

After taking a series of initial responses, the MCR operators identified that the containment spray isolation valve (CS-V035) was incorrectly in the open position and the valve was manually closed at 14:54. At this time the plant entered into a stable condition. The analyses results based on the changes of refueling water tank (RWT) level and RCS inventory showed that the amount of borated water sprayed into the containment was 423 tons.



During the event, the major plant safety systems including the emergency diesel generator (EDG) and containment purge isolation were actuated as designed. As a result of the event, most of the Structures, Systems, Components (SSCs) inside the containment were affected by the sprayed borated water; especially the reactor cavity and the containment floor level were flooded.

Since the operating parameters, such as leakage rate of reactor coolant, was within the emergency declaration condition, the operator declared an emergency (Alert level) at 15:00, and then cleared it at 18:00 after confirming the plant operating conditions were stable and no longer within the emergency declaration condition.

### 1.5 Causes, safety analysis and lessons learned.

The inadvertent opening of containment spray isolation valve (CS-V035) occurred due to human error associated with (1) the MCR operator's mishandling of the CS-V035 hand-switch and (2) the test engineer's local equipment manipulation without approval of the MCR, which directly caused the spray of borated water into the containment.

Although there were some design changes for the containment spray system when compared to the reference plant (Ulchin Unit 5 and 6 of Korea), they were not reflected in the operating procedure; also the shutdown heat exchanger outlet isolation valve (CS-V033), up-stream of CS-V035, that should have been closed during the heat-up operation had been opened and was a contributing root cause to the event.

An additional causal factor for this event was the inappropriate organizational development for plant commissioning including; (1) delayed organization for commissioning operation and (2) insufficient training of the operating staff that may have contributed to poor plant familiarization of the operating staff. Therefore, it was concluded that the potential for human error had already existed.

#### Safety assessment

There was no radiation exposure to the workers caused by the sprayed reactor coolant because no one was in the location during the event, and the exposure dose of the workers who performed the decontamination

and recovery was negligible. The containment inner surface had been decontaminated below the allowable surface contamination criteria (40 kBq/m<sup>2</sup>).

Furthermore, there was no release of radioactive materials to the environment because the impact of the event was limited to within the containment. As a result of the environmental impact assessment utilizing IERNet (Integrated Environmental Radiation Monitoring Network) of KINS, the volumetric radiation dose rate nearby Shin-Kori site was kept at the background level.

Also, the assessment of the soil sample and the sea water sample from the site intake and discharge showed that the variation of radiation was within the normal environmental level. Therefore, it was confirmed that this event caused no radiation impact on the environment.

During the transient, caused by the spray of reactor coolant, it was estimated that coolant boiling at the core had occurred for a brief time (less than 5 minutes). However, the condition of DNB (departure of nucleate boiling) was not reached due to the small decay heat. The core integrity was also confirmed based on the limited increase (5~6 °C) of the fuel surface temperature and the analysis results of fission products concentration within the reactor coolant.

KHNP (Korea Hydro & Nuclear Power Co., Ltd.) identified that during the transient the cool-down rate of the RCS exceeded the allowable limit specified in the plant technical specification of Shin-Kori Unit 1. In response KHNP conducted an integrity evaluation for the equipment and piping installed as part of the reactor coolant pressure boundary.

Considering that the results of the assessment of brittle fracture for the major components of the RCS and the integrity assessment of the reactor vessel beltline satisfied the allowable criteria of KEPIC (Korea Electric Power Industry Code), its integrity was confirmed.

The integrity of the RCP and the shutdown cooling pump affected by the transients was evaluated, and it was verified that the performance of the pumps was sound through a review of pump manufacturers' data, the verification of the seal integrity, and the start up test.

In summary, although almost all of the SSCs within the containment were affected by the sprayed borated water, their integrity including functions after recovery was confirmed based on the results of inspections and evaluations in detail.

Reactor Vessel Head



Corrective actions

To ensure the prevention of event recurrence considering the causal analysis, the following corrective actions were implemented;

- Borated water was removed from the containment and the integrity of the major SSCs affected was reviewed and inspected.
- Verification of the operating procedures and documentations to ensure proper identification of the plant's characteristics focusing on design changes.
- Organizational improvements and training of the workers responsible for conducting the commissioning and linking operating experiences to the subsequent units.

In line with the long-term findings, the following counter actions were taken;

- The general management plan for SSCs affected by the sprayed reactor coolant, including the impact evaluation of boric acid corrosion, was established.
- The plan for the prevention of human errors and to improve levels of safety culture for the commissioning plant were established and implemented.

#### Lessons Learned

For the prevention of a recurrence and future safe operation of the plant, the lessons-learned should be focused on the following;

- Reinforcing the commissioning organization to ensure it is composed of suitably experienced staff.
- Requiring plant familiarization prior to the commencement of the commissioning operation.
- Reflecting design changes into procedures and training in a timely and adequate manner.
- Requiring acknowledgement that commissioning of an NPP is equivalent to the normal operating NPP in terms of safety culture.

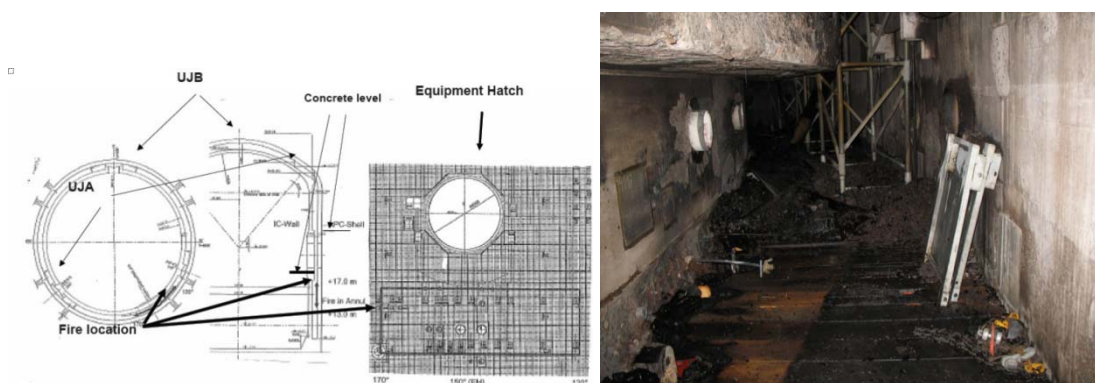




## 2. LESSONS LEARNED FROM OTHER EVENTS REPORTED TO THE WGRNR

Of the remaining events reported to the WGRNR related to the construction which affected or could have affected the safety of the plant in operation, the most relevant ones are highlighted below:

### 2.1 Fires



In Olkiluoto-3, on 30 July 2008 a fire initiated in the annulus space (space between the containment and reactor building wall) at level + 13 m and + 17 m, below the equipment hatch.

Initial investigations after the fire revealed damage to the concrete structures in the fire area (local spalling of protective concrete cover of reinforcement) and to the surface paint of the sleeve of the equipment hatch.

As a result of more detailed investigations no significant damage to the concrete or steel structures in the fire area was detected. The damaged protective concrete cover needed to be repaired.

To improve fire protection on site, the licensee and vendor have ensured that a fireproof tarpaulin is available and used during hot work (welding, grinding), fire extinguishers are available in hot work areas, and sub-contractors are reminded to secure conditions in hot work areas. In addition, a dedicated housekeeping duty team will be established to keep working areas clean and a temporary fire water network will be extended to the reactor building wall during the period of civil works.

#### Lessons learned.

- Use fireproof materials as much as possible.
- A housekeeping duty team should be established to keep working areas clean as possible of flammable materials during all construction phases.

## 2.2 Cables

- *Event 1. IRS 7740. Penly-2. France. 2001. Defective cable insulation.*

Electrical cables (>600V) associated with containment isolation valves in a connection box at Penly 2 NPP failed due to cable “insulation cuts” and improper shrink-fit sheathing which resulted in exposed copper conductors to external ground paths. EDF expanded the inspections of cables and connection boxes to other NPPs and found similar problems at Flamanville-2, Gravelines-3, Dampierre-4 and Tricastin-1.

The event was revealed during a non-routine engineering audit and reactive inspections.

- *Event 5. IRS 7618. Cattenom. France. 2004. Fire in electrical cable penetration due to faulty design.*

The primary cause of fire was attributed to undersized cables for circulating water pumps. The event was revealed in a non-routine engineering audit and reactive inspections.

### Lessons learned

The Licensee should improve the quality control arrangements for the dimensioning and calculation of qualified methods for cables.

- *Event 17. Palisades. 2007. Degraded electrical cables for CCW and SW due to the close proximity to an uninsulated section of a carbon steel steam generator blowdown line that was routinely as hot as 248C.*

There are several relevant events that were observed across the nuclear industry with cable degradation due to environmental conditions.

### Lesson learned

During the commissioning phase, attention should be paid to the impact of environmental qualification (radiation, temperature, etc.) of cables.

Also if the measured values exceed accepted ones, corrective actions should be taken (in order to maintain qualification status).

- *Event 33. Browns Ferry. 2007. Refueling crane cable deformation.*

The cable on the Browns Ferry Refueling Floor Crane became worn over a three year period because of improper assembly during installation. This crane was used for heavy load lifts. Failure of the crane cables could result in a fuel assembly drop and potential fuel failure. As such it is treated as a loss of passive barrier. The scope of this event could affect all nuclear power plants.

- *Event 46. IRS 7885. Hunterston-B. UK. Degraded cable penetrations.*

In a non-routine engineering audit and reactive inspection in February 25, 2003, it was reported that the cable penetration fire barriers separating the 4th floor and the central control room located on the 5th floor could have several inches of breaches. In many occasions in the past, inadequate fire barriers and cable penetration seals have been discovered.

Lessons learned

Possible undersizing of cable cross section during design or failure in change management should be taken into account.

Initial environmental qualification and maintenance of the qualified status should be inspected (by the regulator).

**2.3 Containment / liner**

Besides the events of Olkiluoto-3 and Flamanville- 3, in the group of events reported to the WGRNR we found the following:

- *Event 60. Yonggwang 2008. Korea. Containment liner Bulge.*

A large bulge (15ft by 12ft) in the containment liner was observed during construction (1995); grease was leaking through a gap between a tendon duct and duct drain, and the angle anchors attached to the liner plate were deformed. The primary cause was a large concrete void (42in by 48in). Right below a personnel airlock sleeve that existed due to improper concrete construction (loose concrete may have consolidated). In addition, the volume of the injected grease was not monitored and over injection was not prevented. This event is applicable to construction of the containment for all reactor designs. A large bulge in the liner would reduce the containment strength during severe accident conditions where containment pressurization occurs. The failure of containment as a passive barrier could result in increased releases to environment as well as impact the operation of some mitigating systems.

Lessons learned

Pre-job briefing, adherence to the procedure by the constructors and adequate supervision for safety relevant work.

**2.4 Essential service water / component cooling water**

- *Event 8.IRS 7832 Nogent. France. Flooding caused by leak in bonna CW pipe.*

A significant water leak occurred in the circulating water system (CWS) at a manhole of train 1 of unit 2 near the pump discharge. The causes of this event were: (a) improper design and construction of the manhole; (b) improper construction of leak tight sleeves; and (c) shared systems and interconnections between the two units. The flooding scenario described by this event affected both units and also partially affected ESW and one train of CCW. The flooding started in a non-safety related area and propagated to a safety related area.

Lessons learned

During the construction of non safety related SSC's attention should be paid to those failures which could possibly impair the delivery of safety functions.

- *Event 42. Byron 1,2. 2007. ESW riser degradation.*

The licensee was cleaning the Essential Service Water System riser piping when a ¾” leak occurred. The licensee declared the ultimate heat sink inoperable and shut down due to entry into Technical Specification 3.7.9. The primary cause is the use of carbon steel for a SW system with the resulting corrosion of carbon steel pipe in the vicinity of warm moisture (SW riser pipe).

#### Lessons learned

Environmental qualification is an essential precondition for safe operation of not only electrical and I&C equipment, but in some cases of mechanical equipment as well.

## **2.5 Welds**

Besides the events from Olkiluoto-3 and Flamanville-3 the following events occurred during the construction of other plant and were detected during operation.

- *Event 13. Wolf Creek. 2006. Dissimilar metal weld flaws.*

In October 2006, several indications of circumferential flaws were reported in the pressurizer nozzles at Wolf Creek. The indications were located in the nickel-based Alloy 82/182 dissimilar weld material, which is known to be susceptible to primary water stress corrosion cracking (PWSCC). The primary cause was identified to be the susceptibility to Primary Water Stress Corrosion Cracking (PWSCC) in welds that contain Alloy 600/82/182.

- *Event 59. Yonggwang 3. 2008. Korea. Piping weld joint concerns.*

During NDE inspection of adjacent weld joints, KINS inspectors found 44 unidentified (undocumented) weld zones including some in safety injection systems and some in non-safety class systems in YGN units 3 & 4. Events of this nature could not be easily detected during plant operation.

#### Lessons learned

Documentation should be kept properly according to the licensee’s quality assurance manual.

The regulator should inspect the as-built documentation for inclusion of all information from the construction life time cycle of SSC’s. The up-dating of the as-built documentation is essential for good configuration management during operation.

## 2.6 Seismic events



- *Event 55. Kashiwazaki-kariwa.2007.Japan.*

A seismic event of 6.8 on the Richter scale occurred 16 km from the site at 10:13 A.M. on 7/16/07. A small fire occurred in an electrical transformer in the switchyard of unit 3. It took two hours for the fire to be extinguished. About 315 gallons of radioactive contaminants leaked from Unit 6 and reached the Sea of Japan (1621 nano-curies total). The primary cause of this deficiency was determined to be an earthquake greater or comparable to SSE.

Lessons learned applicable to construction are the following:

- All loose canisters, gas cylinders, radioactive waste drums, etc., should be stacked and restrained.
- Large heavy machinery such as a crane should be secured at all times.
- Alternate methods for evacuating personnel from radiological controlled areas are needed. Reliance on city water (for showers) and other means which are not seismically qualified for decontamination should be reduced.
- In-depth analyses of earthquake hazards are needed that include vibratory ground motion, fault displacement, and secondary effects such as liquefaction, subsidence, slope failures and ground collapse.
- Coordination between on-site and off-site actions in response to the event including communication to external agencies is needed.
- Plans are necessary to deal with seismically induced falling objects, unsecured items (cylinders, cranes, etc.), and the interaction of non seismic category 1 systems and components with seismic category 1 components including ducting and HVAC units.
- Consideration should be given to seismic interactions causing damage to structures, systems, or equipment that are not in a seismic category but result in other hazards such as fire and flood.



### 3. OTHER REPORTS ON CONSTRUCTION EXPERIENCE.

#### 3.1 JRC-Petten, “Summary Report on Nuclear Power Plants Construction, Commissioning and Manufacturing Events” (2011)

The report summarizes the lessons learned from assessing operational experience of NPP’s with events originating prior to the start of the commercial operation.

The report covers construction, commissioning and manufacturing events but dcover events related to design deficiencies.

The lessons learned relate to anchoring, batteries, breakers, cables, emergency diesel generators, high-voltage bushing, I&C equipment, metallic liners, penetrations and building seals, pipes, pumps, steam generators, switches, transformer insulators and windings, valves, ventilation systems and welding.

From the lessons learned the report presents recommendations on:

- Safety culture issues; including special nuclear requirements.
- Task interfaces and communication between different participants involved in construction.
- Management of changes in design, installation and manufacturing procedures.
- Quality assurance and quality control in manufacturing, welding, wiring, assembly operations, labeling, handling, packaging, transportation and storage, third-party control, management of non-conformances, foreign material exclusion, removal of temporary devices, housekeeping and cleanliness.
- Impact on nearby units in operation.
- Scope, time, acceptance criteria and documentation of commissioning tests.

The conclusions emphasize the need to minimize the number of deficiencies during construction, manufacturing and commissioning of a new reactor, as they can be major latent failures for a long time and can have actual consequences for safety after the reactors start to operate.

#### 3.2 US NRC, NUREG-1055, “Improving Quality and the Assurance of Quality in the Design and Construction of Nuclear Power Plants” (1987)

This comprehensive study performed by the NRC in 1987 contains an analysis of several large construction projects and focuses on why some projects do not show significant quality issues and why others do. The root causes and the lessons learned are grouped around the two following questions:



A. Why have several nuclear construction projects experienced significant quality-related problems while others not?

The main conclusion is the inability or failure of the utility management to effectively implement a management system that ensured adequate control over all aspects of the project.

The report contains some important lessons learned:

- Before nuclear design and construction starts, an adequate project team (defined as the architect-engineer, NSSS manufacturer, construction manager, constructor, and owner) is essential.
- The regulator must adequately assess the management capability before construction through audits and inspections.

Some of the characteristics of a successful nuclear construction project included in NUREG-1055 are:

- Project management approach that includes adequate financial, organizational and staffing support for the project.
- Good planning and scheduling.
- Management oversight of the project and contractors.
- Strong management commitment to quality.
- Careful selection of key project staff.
- Effective project communications vertically and across project interfaces.
- Understanding of the symptoms of poor management practices.

B. Why have the NRC and the utilities failed or been slow to detect and/or respond to these quality-related problems?

The NUREG-1055 explains that in some cases the NRC was slow to detect and/or take strong action in the construction problems mentioned in the report for several reasons:

- The NRC made a tacit but incorrect assumption that there was a uniform level of industry and licensee competence.
- The NRC inspection program was slow to synthesize scattered quality-related findings coming in over a period of time into a comprehensive picture of a project-wide breakdown.
- The NRC inspection resources were prioritized to address operation first, construction second and design last. The threshold for reacting to construction-related problems was set higher than for operational problems.
- The inspection program was orientated to focus heavily on paperwork at the expense of examining either actual work in progress or QA program implementation.
- The Inspection program focused on detail rather than on whether the overall management process for the project was working.

### **3.3 UK Royal Academy of Engineering, “Nuclear Lessons Learned” (2010)**

This report contains the lessons learned from recent and current nuclear build projects that are relevant to new power station projects in the UK. Based on assessment the focus was limited to the EPR and

AP1000, because these types were going forward for consideration in the UK. The assessing experiences are from:

- Sizewell B (a PWR completed in 1995),
- The installation of waste processing facilities (at Sellafield),
- Olkiluoto 3 (the EPR plant under construction in Finland),
- Flamanville 3 (the EPR plant under construction in France),
- Taishan units 1 & 2 (the EPR plants under construction in China),
- Sanmen and Haiyang (the AP1000 plants under construction in China).

The report discusses lessons learned during the planning and construction and, in the case of the Sizewell B, also during the commissioning and operational phase, which are relevant to the construction of new PWRs today.

Besides lessons such as follow-on replica stations are cheaper than first-of-a-kind, need for mature design before starting of construction, need to establish a highly-qualified team for all areas related to the project, good communications with the community local to the site, which are similar for all large technologically-complex project, the following lessons learned were identified, which are specific to the nuclear industry:

- The importance of appropriate nuclear quality arrangements and an understanding of nuclear safety culture during construction must be emphasized. And in case of companies without previous nuclear experience must be taught.
- Safety requirements must be clearly understood.
- Regulatory requirements must be understood.
- The quality assurance programme and associated procedures should be established to cover the design as well as manufacture and construction.
- There must be a rigorous, efficient and auditable design change process.
- Management of subcontractors.
- Communication within the vendor consortium.
- Mastering the manufacturing technologies.
- Licensee responsibility.
- Importance of regulatory oversight of construction.

All these safety-related lessons in the nuclear industry come into effect at the time a nuclear plant is commissioned and operated. Therefore, an expansion of culture and style of incident reporting among all participants on new nuclear build would be of immense use not just for the companies involved in the nuclear supply chain but in ensuring that the nuclear plant operators take delivery of plant built and commissioned with the benefit of that critical knowledge exchange.



#### 4. CONCLUSIONS AND LESSONS LEARNED

In this first report of the WGRNR we have tried to summarize the main lessons learned from construction events included in the ConEx database and also to collect the main lessons learned from past and current construction experiences that may be helpful to new builds.

The main goal for this group is to learn from experience and to avoid the recurrence of causes that led to past events.

The lessons learned included in the different chapters of this report vary in nature, some of them are applicable to the licensee and other to the contractors and regulators. Besides that, some of them are high level lessons learned and are related to organizational issues and others are specific lessons learned from reported construction events.

As the WGRNR is a forum of regulators, we present a non exhaustive list of lessons learned that regulators embarking on a new build should pay attention to. These lessons learned have been collected from the ConEx database and other reports related to construction experience. The lessons below are more general and broader in scope than the specific concrete lessons learned included in the executive summary and drawn from the construction events in ConEx.

High level lessons learned:

- Safety culture issues can affect all organizations involved in the project. Awareness of nuclear quality and understanding of nuclear safety culture and their necessity during construction must be emphasized. And in case of companies without previous nuclear experience must be taught.
- Effective project communications vertically and across project interfaces of the licensee and their contractors is an important factor for safety during NPP construction.
- An operating experience feedback system should cover other construction projects of a similar type.
- It is critical to effectively implement the management of change in design, installation and manufacturing procedures.
- There needs to be an integrated management system for quality assurance and quality control in: manufacturing, welding, wiring, assembly operations, labeling, handling, packaging, transportation and storage, third-party control, management of non-conformances, foreign material exclusion, temporary device removal, housekeeping and cleanliness.
- Consider the impact on nearby units in operation.
- Implement project management within the licensee and the regulator that includes adequate financial, organizational and staffing support for the project.
- There needs to be good planning and scheduling.
- Licensee's need to implement management oversight of the project and contractors.

- The licensee should demonstrate, in an early stage of the project, the sufficiency of organizational and technical provision for the proper management of construction activities.
- There needs to be an understanding by all organisations involved of the symptoms of poor management practices.
- Safety requirements must be clearly understood, and this requires many “flight hours” between the licensee and the regulator.
- There needs to be effective management of subcontractors.
- Communication within the vendor consortium facilitates the exchange of operating and construction experience and the development of consistent approaches in resolving similar challenges.
- It is important to minimize the potential for nonconformance to master manufacturing technologies. And in case of the use of an unproven technology, sufficient tests (like mock-ups) and qualifications should be performed.
- The licensee has the primary responsibility for safety.

Importance of regulatory oversight during construction.