



Summary Report on Nuclear Power Plants Construction, Commissioning and Manufacturing Events

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1 INTRODUCTION

Nuclear Power Plant (NPP) operational experience has been used for many years to improve the safety of nuclear facilities throughout the world.

In the European Union, to support EU activities on evaluation of NPP operational events, a centralised regional 'Clearinghouse' on NPP operational experience feedback (OEF) was established in 2008 at the JRC-IE, at the request of the nuclear safety authorities of several Member States. Its purpose is to improve communication and information sharing on OEF, and to promote regional collaboration on analyses of operational experience and dissemination of the lessons learned.

One of the technical tasks of the European Clearinghouse is to perform in-depth analysis of families of events ('topical studies') in order to identify the main recurring causes, contributing factors and lessons learned, and to disseminate and promote recommendations to reduce the recurrence of similar events in the future.

This topical report has been prepared by the centralised office of the European Clearinghouse on OEF and focuses on experience from events related to construction and commissioning of Nuclear Power Plants.

Interest in constructing new nuclear power plants is increasing worldwide. Some countries are embarking on a nuclear programme for the first time, while others have decided to re-start construction of nuclear power plants after a hiatus of decades. According to the Power Reactor Information System (PRIS) of the International Atomic Energy Agency (IAEA), currently 55 construction projects have been launched or are being considered worldwide. Starting new build is very demanding, as much of the earlier experience and resources have progressively been lost from the nuclear industry. Circumstances are quite different from 1970s when most of the plants currently operating were constructed. Vendors had large experienced organisations ready to go ahead, and had less need to rely on subcontractors. In addition, there was no shortage of skilled manufacturing capacity in the market, and designs were often based on work done in similar ongoing or completed projects.

Consequently, lessons learned from the past construction periods or from the ongoing construction projects are very important for the increased number of utilities and regulators involved in building new NPPs. They will help to reduce the recurrence of past construction or commissioning problems.

This Topical Study covers construction, commissioning and manufacturing events originating prior to the start of the commercial operation, in order to highlight lessons learned and recommendations **for current and future construction programmes**.

The construction stage includes the construction of the buildings **and the initial installation of components**.

The manufacturing stage includes both on-site and off-site manufacturing.

However, **it must be stressed that operating plant modifications and design deficiencies are beyond the scope of the study.**

2 METHODOLOGY

The three main sources of information that have been used for this report are:

- the Incident Reporting System (IRS) database,
- the database of the Working Group on Regulation for New Reactors (WGRNR),
- the Licensee Event Reports (LERs) of the US NRC.

The IRS is an international system jointly operated by the International Atomic Energy Agency (IAEA) and the Nuclear Energy Agency of the Organisation for Economic Cooperation and Development (OECD/NEA).

For this study, **1090 events were screened and 247 are applicable.**

The WGRNR (a working group of OECD/NEA) has developed a new database for construction experience feedback to allow WGRNR members to share worldwide construction inspection findings. In December 2009, 100 event reports were available to the WGRNR members.

After screening these reports, **26 WGRNR events were identified as applicable for this report**, of which 7 overlap with the IRS database or with other WGRNR reports.

US commercial nuclear reactor licensees are required to report certain events under US NRC regulation 10CFR50.73. These reports, called 'Licensee event reports' (LER), are available to the public on the NRC's website [1].

After screening the NRC website, which contains LERs from 1980 onwards, **309 LERs were considered applicable.**

The events identified were classified in three categories for the purpose of this report, with definitions based on the IAEA glossary [2]:

- Construction: *'The process of (...) assembling the components of a facility, the carrying out of civil works, the installation of components and equipment (...)'*, prior to the start of commercial operation
- Commissioning: *'The process by means of which systems and components of facilities and activities, having been constructed, are made operational and verified to be in accordance with the design and to have met the required performance criteria'*
- Manufacturing of components and equipment which were installed in the plant prior to the start of commercial operation

Each of these categories is further classified according to the type of component concerned: pipe, valve, weld, civil work (for example buildings structure, anchorages, supports), electrical components, I&C, etc.

This structure enabled to make recommendations both for each different pre-operational stages and for each type of component. Moreover, it enables us to identify more generic recommendations than a classification into systems depending on the reactor design.

After this classification, each category and sub-category was screened to show the lessons learned for a given component at a given stage of construction. In addition, general recommendations were identified. The overall process is described in the figure 1 below.

latent failures for a long time and can have actual consequences for safety after the reactors start to operate. More information about latent failures can be found in [3].

This also emphasises the necessity of detecting the deficiencies at the construction stage, as it may be difficult to identify them during operation.

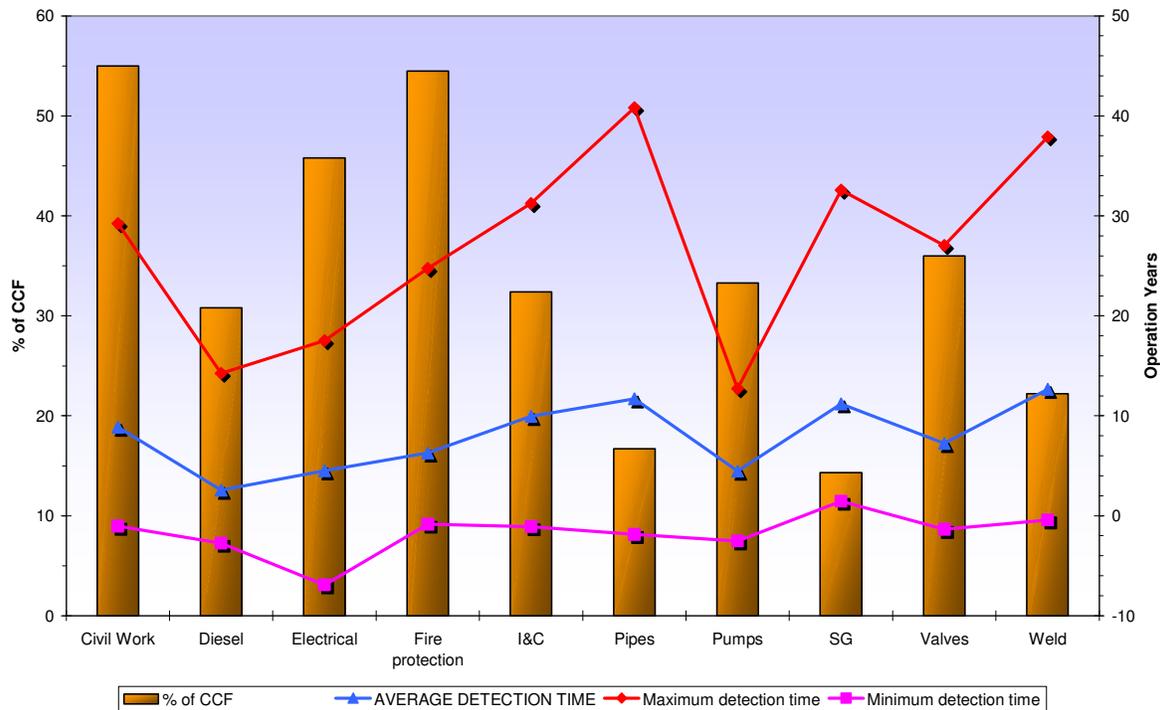


Figure 2 — Common Cause Failure (CCF) ratio and detection time

4 RECOMMENDATIONS

As explained above, this study allowed to raise about 50 concrete lessons learned for several types of components (electrical components, valves, pipes...) and about 30 more general recommendations which are valuable for any kind of component.

The lessons learned are listed in Appendix and the recommendations are given hereunder. These recommendations as well as the lessons learnt are fully described in the study report.

Safety culture

Adherence to nuclear safety principles should be the top priority already at the construction and manufacturing stages.

The safety culture and safety awareness of the personnel involved in the pre-operational stages should be ensured through appropriate training, highlighting the role and the safety significance of the components concerned. Every person participating in the project needs to understand the safety significance of his / her work, to promote personal responsibility.

This is necessary for all the staff involved in the process, including the manufacturer's staff, the vendor's staff, contractors and sub-contractors, the staff in charge of the surveillance of the activities, and the staff in charge of the acceptance of the components.

This safety awareness should be ensured not only for 'complicated' works like welding but even for 'more simple' tasks like anchoring or cable sheathing, especially since some sub-contractors may not have any experience of working for the nuclear industry.

Quality assurance and quality control scope

Handling, packaging, transportation and storage conditions of safety-significant components should be covered by and monitored through a Quality Assurance Programme.

Management of non-conformances

The requirements for handling non-conformances should be clearly identified. These requirements should define non-conformance and specify the roles and responsibilities of the licensee, the vendor and the subcontractor for reporting and correcting non-conformances, and the regulatory approval process.

Compliance with these requirements should be checked by the licensee and the regulator.

Communication

Special attention should be paid to communication between the different companies and/or entities involved in building a plant. This communication should be conducted through pre-defined and documented procedures, and submitted to a Quality Control Programme. Moreover, this communication should enable information about the safety significance of components or equipment to be transferred from the design stage to the contractors and their sub-contractors in charge of installing the components or equipment.

Task interfaces

The interfaces between different tasks should be clearly identified and managed in such a way that the departments or companies in charge of these tasks are aware of the precise scope of their work, and that works at the interface between two tasks are not omitted.

Change management

Any changes from the design, installation or manufacturing procedures should be properly documented and assessed.

Third-party quality control

Oversight and quality control of ongoing works should be provided by an organisation which is competent and experienced in the works, clearly identified as responsible for quality control, and independent of the organisation in charge of the works.

Foreign Material Exclusion

A full FME programme should be implemented as soon as construction starts and not just during operation.

Temporary devices

Temporary devices used at the manufacturing, construction and commissioning stages should be properly documented in order to ensure that all the temporary devices are removed after their use.

Specific nuclear requirements

Every call for tender about safety-related components should include and emphasise the specific nuclear requirements and local nuclear regulations particularly as regards quality management and safety culture. Compliance with those requirements should be properly checked at the stage of awarding contracts and until the work is fully implemented.

Housekeeping and Cleanliness

Cleaning activities should be submitted to the same quality process as other safety-related activities, and commissioning tests should be performed after the cleaning activities.

Handling devices

Handling devices should be included in the scope of the quality controls as well as in the commissioning tests, which should be performed prior to the lifting of loads.

Impact on nearby NPP units in operation

The potential consequences of construction works on the safety of operating units should be assessed (Risk Analysis). In particular, the consequences of potential contamination from a construction site for operating units should be assessed and if needed, the contamination should be monitored. All other potential risks should be assessed (digging, excavation, spurious fall of cranes, use of explosives, etc.).

Labelling

The labelling of components should be in place as soon as the components are installed.

Torque

The applied torque should be submitted to independent verification during the relevant sequence of assembly operations.

Welding

Special attention should be paid to quality control of welding and the control sampling rate should take account of the safety-significance of the welds and the welding technique. Welding should be carried out by appropriately trained and experienced welders and the supervision of the welding activities should be performed by trained and experienced staff.

Wiring

Wiring checks should follow any cabling installations — they should be part of the installation procedure or programme and should be verified by the regulator.

Fire

Special attention should be paid to the risk of fire during construction and commissioning, as the fire protection may not be fully installed at those stages and as construction works can generate dirt and heat.

Manufacturing

Special attention should be paid to the purchasing of commercial-grade components for safety-related equipment by the equipment manufacturer. The purchased parts should be properly documented and controlled by the manufacturer.

Technological expertise should be proven and verified by the licensee, not only through final acceptance tests but also by checking that proven state-of-the-art technology is used. An augmented regulatory approach and inspections should verify that new manufacturing techniques and new types of equipment meet the specifications set by the designer.

Time of the commissioning tests

The functionality of any standby component which is normally not in operation must be regularly tested, as a long period of inactivity and the construction of other equipment during this period could alter the test results.

Scope of the commissioning tests

Tests conditions

The safety systems should be tested in conditions that simulate real accident conditions, and if that is not possible, specific arrangements should be made for the systems concerned in terms of acceptance tests, quality assurance, etc.

Comprehensiveness of tests

The scope of the tests should include all the components and devices that are used during normal operation and those which could be used under accident conditions, including passive components such as pipes, as they may be clogged, and including manufactured components, with correct documentation, as the quality control at the manufacturing plant may be deficient.

The automatic start-up of systems after a power disruption should be tested during commissioning.

Fragmented tests

Safety systems should be submitted to overall functional tests as far as possible, to ensure not only the performance of each single component but the performance of the whole system, including the interactions between different components.

Non-actuation tests

The tests should be designed to detect an unexpected (spurious) actuation of a safety system.

Commissioning of different units.

The commissioning tests should be repeated with the same scope at all units, because each unit is unique at least from the installation point of view.

Simultaneous tests

The commissioning tests should be designed to take account of the fact that simultaneous tests may have an influence on each other's results.

Documentation of the commissioning tests

The acceptance or commissioning tests should not be designed to check the installation drawings, which may be wrong, but should refer to the original design drawings.

Commissioning tests acceptance criteria

The test acceptance criteria should allow testers to verify not only the functionality of a system or component but also its level of performance.

Systems reconfiguration after commissioning tests

The proper reconfiguration of the systems after the commissioning tests should be checked.

5 CONCLUSION

About 247 IRS reports, 26 WGRNR reports and 309 US-LERs were reviewed and distributed into categories related to technical items or components: civil structures, electrical components, mechanical components, etc.

A trend analysis of the IRS reports emphasises the need to minimise 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.

The qualitative evaluation of these events has allowed us to summarise specific lessons learned and to make generic recommendations. These recommendations relate for instance to the management of non-conformances, to communication, quality control and quality assurance, to the safety culture and to specific items related to construction, manufacturing and commissioning. Our analysis has shown that most of the generic recommendations relate to the management of the construction project (specific nuclear requirements, communication, task interfaces, safety culture) and the management of quality (management of non-conformances, change management, third-party quality control, management of temporary devices). This report shows that consequently special attention should be paid to these organisational issues in addition to the attention paid to the purely technical tasks. The licensee management's commitment to the quality system is a prerequisite.

This study shows that it is possible to extract lessons learned and recommendations for construction from **operational experience**.

Despite the value of these recommendations, it must be stressed that many more recommendations could have been made if more detailed information about construction had been available, as detailed as in some WGRNR reports. Indeed, the event reports do not always include information about non-conformances detected and corrected prior to plant operation, as they have no impact on the safety of the operating plant during the reported event.

Moreover, in most of the event reports resulting from construction deficiencies, the lessons learned for current and future construction projects were often not fully considered; instead they focused more on the corrective action required for the operating plant in question.

Therefore, it could be very valuable to share **construction experience** in a systematic and timely manner at international level, especially as more than 50 new reactors are currently being constructed or considered worldwide.

LIST OF ACRONYMS

CCF	Common Mode Failure
EQ	Environmental Qualification
HELB	High Energy Line Break
I&C	Instrumentation and Control
IAEA	International Atomic Energy Agency
IRS	Incident Reporting System
LER	Licensee Event Report
NEA	Nuclear Energy Agency
NPP	Nuclear Power Plant
OEF	Operating Experience Feedback
QA	Quality assurance
QC	Quality control
SG	Steam Generator
US NRC	United States Nuclear Regulatory Commission
WGRNR	Working Group on the Regulation of New Reactors (NEA)

REFERENCES

- 1 <https://nrcoe.inel.gov/secure/lersearch/index.cfm>
- 2 IAEA Safety Glossary, 2007 Edition
- 3 NEA/CSNI/R(97)5 Latent Failures of Safety Systems, published in 1997

APPENDIX: LIST OF LESSONS LEARNED

TOPIC	LESSONS LEARNED
Anchoring	<p>It must be ensured that the specified tools are used (for example, drill bits and drilling machine).</p> <p>As the anchoring devices are at the interface between systems and structures, so there must be sufficient cooperation between the departments for systems and the construction departments in the planning and control phase. This applies to the licensee as well as the technical supervisor organisation and the authority.</p>
Battery	<p>Batteries should be checked for damage before installing them on site.</p> <p>During manufacturing, special attention should be paid to the absence of impurities during welding of the plates and to the preparation of the resin used for sealing.</p>
Breakers	<p>The manufacturer's documentation should specify the adjustment of the breaker's draw-out unit and this adjustment should be checked.</p> <p>Special attention should be paid to the following items:</p> <ul style="list-style-type: none"> - The alignment of the linkage of the trip devices - The use of proper material - The removal of the temporary latches - The cleanliness of the parts <p>Special attention should be paid to the proper installation of the seismic positioners of the breakers.</p>

<p>Building structures</p>	<p>The humidity and the lubricant inside the channelling device of the pre-stressing cables should be monitored during construction.</p> <p>The minimum thickness of lubricant on the external wire layers following manufacture of containment pre-stressing system cables should be precisely specified.</p> <p>A procedure should be developed to restore the lubricant on external wire layers after assembly of containment pre-stressing system cables at NPP units, in order to prevent metal corrosion in the cable wires during operation of the containment pre-stressing system.</p> <p>The size of concrete sections of the basemat could have an influence on the appearance of cracks.</p> <p>Special attention should be paid that concrete block walls and masonry walls are constructed with regard to the seismic response of the walls and potential damage to any safety-related equipment in the vicinity.</p> <p>Concrete pouring should be validated by mock-up for locations where access may be difficult for concrete consolidation (high density of steel reinforcement, etc.)</p>
<p>Cable</p>	<p>A comprehensive cable condition monitoring programme should be implemented in the construction stage. The cable sheathing of the safety-significant systems should be checked after installation where it is accessible, more especially at the bends and at the electrical connection. During construction, inspection should be performed in the cable trays before there are closed.</p> <p>The cable fire rating should be checked and the cable route should be verified to ensure the separation of trains and units</p> <p>An individual and specific procedure should be written for installation of multiple cables in a single penetration, in order to avoid damage during installation. The installation of designed separations in the penetrations should be checked.</p> <p>During manufacturing, special attention should be paid to the following points:</p> <ul style="list-style-type: none"> – homogenous blending of additives in the PVC sheathing – eccentric positioning of the conductor in relation to the protective sheath.

<p>Electrical connections</p>	<p>The installation procedures should be written, and the quality controls should be performed, so as to ensure the right type of connection, proper fastening and avoidance of damage during the connection activities. For that reason, the connections should not be covered by insulation until checked.</p> <p>Attention should be paid to connections between two different types of cables and conductors.</p> <p>Special attention should be paid to the crimping of the conductors during manufacture and installation of the electrical panels to ensure the connection quality, and to the quality of the connection lugs. Stamping, in particular, should not impair the mechanical properties of the lugs.</p> <p>During installation, the size of the connection lugs should be monitored in order to ensure a good connection with the conductors.</p> <p>Special attention should be paid to the Environmental Qualification of supplied conduits or junction boxes, and more especially to the electrical splices. In addition to document review, inspection should be performed at the manufacturing stage when the inspection itself does not test the EQ.</p> <p>Specific attention should be paid to the openings of the junction boxes which allow drainage of the accumulated water inside the boxes during some accidents.</p>
<p>Emergency Diesel Generators</p>	<p>Special attention should be paid to the alignment of the off-gas compensators.</p>
<p>High-voltage bushings</p>	<p>The condition of stored bushings should be checked periodically and the power factor of stored bushings should be checked before putting them in service.</p>

<p>I&C</p>	<p>The I&C modules' overvoltage protection should be tested.</p> <p>The probe installation should be closely monitored during construction and appropriate commissioning tests should be prepared and carried out to detect any defect in every single component of a measuring channel.</p> <p>The initial calibration of measurement transmitters should be checked against vendor documentation.</p> <p>Closure of the valve motor contactors at the minimum expected voltage for design basis conditions should be tested.</p> <p>Control software with known or suspected faults should not be used as this may have unexpected influences on other software.</p> <p>The clearance of the reed switch contacts should be checked during manufacturing.</p> <p>The minimum distance allowing functional redundancy should be ensured between redundant impulse lines.</p>
<p>Metallic liner</p>	<p>When liners are welded on the construction site, care should be taken that the welding environment is compliant with the construction code.</p> <p>It is also proposed that maximum allowed sizes of containment liner bulge should be determined through a risk-informed approach, to help decide when corrective action is needed.</p>
<p>Other mechanical components</p>	<p>Cranes should be included in the commissioning programmes and the tests and verifications should be done prior to the main load lift.</p>
<p>Penetrations and building seals</p>	<p>Every single penetration and building seal should be properly documented (location, role, design) to ensure proper follow-up during further plant operation.</p> <p>The initial design of inter-building seals should take into consideration the need to be able to conduct checks on the quality of installation at the construction stage and subsequently. To do so, the seals should be accessible over their entire length and close to floor for ease of repair.</p> <p>When a penetration seal functions as both a fire barrier and a flood barrier, it is important for licensees to consider both functions in the design, installation, inspection, and maintenance. This includes accounting for static head pressure to ensure watertight seals do not get dislodged.</p>

<p>Pipes</p>	<p>The pipes should be exhaustively inspected during construction.</p> <p>The grain size should be specified for hot-formed austenitic tube bends.</p> <p>Special attention should be paid to the proper installation of pipe supports and restraints intended to mitigate the consequences of earthquakes or HELB.</p> <p>The installed pipe insulation weight should be verified to comply with the seismic specifications for pipe supports.</p> <p>Measures should be taken to avoid clogging pipes with construction debris and other foreign materials. A FME + cleanliness / housekeeping policy should be implemented from the very beginning of the project.</p> <p>Rigorous management of temporary devices should be implemented, to avoid leaving temporary blind flanges, orifices, etc. inside the pipes after commissioning of the plant.</p>
<p>Pumps</p>	<p>The visual 'minimum' and 'maximum' markings on the pumps' oil inspection glass should be checked.</p> <p>The dimensions of the internal parts should be checked during the acceptance inspection.</p>
<p>SG</p>	<p>Pre-service inspections of the SG should be carried out after the flushing of the SG.</p> <p>Special attention should be paid to the tube expansion process and to cleanliness during manufacturing and assembly of the SG in order to avoid stress corrosion cracking.</p> <p>Tube acceptance inspections should also be performed at the SG manufacturing site and any quality deviation should be known by the pre-service inspection staff on the NPP site, in order to facilitate reviewing of inspection data.</p> <p>The location of the SG tube supports should be checked.</p> <p>The path of the SG tubes through the corresponding holes in the tube sheets should be checked.</p>
<p>Switches</p>	<p>The installation instructions for switches should specify if stop screws have to be installed and the mechanical stops of the switches should be checked during start-up tests.</p>
<p>Transformer insulators</p>	<p>Attention should be paid to the shelf life of the insulators prior to installation.</p>

Transformer windings	The presence of the transformer winding supports should be checked in order to avoid winding deformation in the event of high current.
Valves	Special attention should be paid to the proper installation of drains in the safety valves' actuator boxes.
Ventilation	<p>Flow balance and differential pressure measurements should be conducted on the control room ventilation systems in order to detect potential deficiencies.</p> <p>Special attention should be paid to the proper installation of the buildings' overpressure protection devices (blow-out panels or tornado venting panels).</p>
Weld	<p>All welds should be inspectable at the construction stage.</p> <p>The original welding documents and inspection results should be carefully kept as they are needed for further in-service inspections.</p> <p>Extra attention should be paid to bi-metallic welding, and more specifically to the border between buttering and base material.</p> <p>Care should be taken that the welding environment (on the construction site) allows compliance with the construction code.</p> <p>Events related to welds show the very high importance of appropriate weld QA, QC & inspection programmes.</p>

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Abstract

Interest in constructing new nuclear power plants is increasing worldwide. Some countries are embarking on a nuclear programme for the first time, while others have decided to re-start construction of nuclear power plants after a hiatus of decades.

Starting new build is very demanding, as much of the earlier experience and resources have progressively been lost from the nuclear industry. Circumstances are quite different from 1970s when most of the plants currently operating were constructed. Vendors had large experienced organisations ready to go ahead, and had less need to rely on subcontractors. In addition, there was no shortage of skilled manufacturing capacity in the market, and designs were often based on work done in similar ongoing or completed projects.

The aim of this study is to collect lessons learned from past and current construction projects and to raise recommendations for the regulators and the licensees.

The present document summarises the main trends and the main recommendations concerning construction, commissioning and manufacturing.

This work is part of the European Clearinghouse on Nuclear Power Plant Operational Feedback (NPP-OEF) activity carried out at the Joint Research Centre/Institute for Energy (JRC/IE).

It describes the results of the analysis of the events related to the construction of new NPP and reported to the IAEA International Reporting System (IRS) database, to the Licensee Events Report (LER) database of the US NRC and collected by the Working Group on the Regulation of the New Reactors (WGRNR) of the NEA.

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