Regulatory Assessment of Integrated Safety Reviews for Nuclear Plants Refurbishment

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Abstract

An Integrated Safety Review (ISR) is initiated when a licensee intends to refurbish a nuclear installation for the purpose of extending its life beyond that originally anticipated by its design.

The ISR is a systematic and comprehensive approach to determine the actual plant state; the quality of plant documentation; and reasonable and practical modifications to improve or maintain plant safety in line with current national or international codes, standards and practices.

This paper presents ISR main regulatory expectations as well as the approach to perform regulatory assessments. Areas of challenge are discussed along with lessons learned from recent refurbishment projects in Canada.

1. Introduction

A licensee may wish to operate a nuclear installation beyond the originally anticipated design life by selecting either to refurbish the installation for the purpose of life extension or to continue its operation under a life management plan that would eventually lead to decommissioning. For such circumstances, an Integrated Safety Review (ISR) should be initiated to generate and gather necessary and sufficient information to assist in decision-making.

The ISR is a systematic and comprehensive approach that is employed to determine the actual state of the plant's structures, systems and components (SSCs); adequacy and quality of plant design, licensing and operational documentation; and reasonable and practicable modifications to improve or maintain plant safety in line with current national or international codes, standards, and practices. This paper will focus on the use of the ISR for the purpose of life extension of nuclear power plants (NPPs).

2. Refurbishment for Life Extension

2.1 Life Extension

Life extension means the continued operation of a nuclear power plant beyond its originally anticipated design life (typically 30-40 years) that was established and justified by conformance with codes and standards, safety analyses, and characteristics of the plant structures, systems, and components (SSCs) including consideration of life limiting aging processes [1].

2.2 Continued Safe Operation

The early research, demonstration and commercial nuclear reactors were built in Canada from the 1950s to 1970's. Ever since, there have been substantial developments in safety standards and practices, regulatory requirements and expectations, and technology and know-how. As well, a cumulative wealth of lessons has been learned from national and international operating experiences.

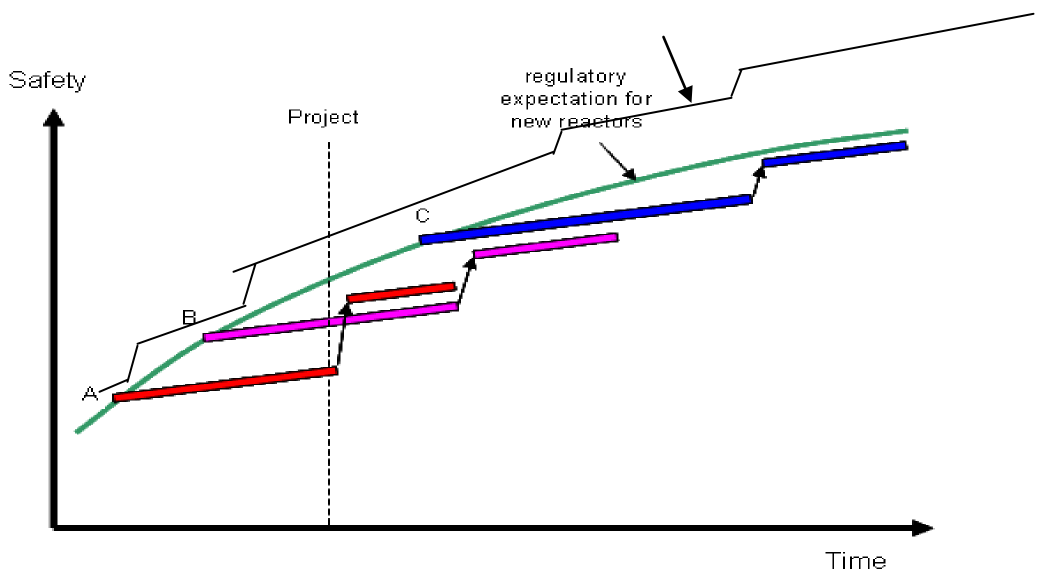

Figure 1: Continuous development of safety requirements and corresponding safety improvements of existing nuclear power plants.

Figure 1 illustrates this idea of continuous development of safety requirements and the corresponding safety improvements of existing NPPs. The top curve shows regulatory expectations increasing with time. Note that this curve is drawn as a continuum but in reality it changes in step increments as stipulated on the graph. The safety performance of plant A is shown as an example of an early NPP design that has met regulatory expectations when it was originally licensed and has continued to improve. However, with the regulatory expectations advancing over time, plant A slowly gives the impression that it is lagging behind the regulatory expectations of the time. Plant B had to meet or probably exceed more stringent requirements when it was licensed. A future reactor, plant C, would have to meet, or probably voluntarily surpass, more stringent requirements that would exist or be drafted at that time. The vertical dashed line shows a hypothetical present day where the early reactor (plant A) is applying for life extension, shown here as a step change to a higher level of safety requirements.

At this time, significant changes would be implemented in order to bring the plant as closer as practicable to the requirements of the codes and standards of the day. Full conformance is not necessarily achievable; costs and benefits must be considered. Note that safe operation of the plant is not compromised under any circumstances during the early or extended NPP life.

3. Regulatory Requirements/Expectations for Life Extension

3.1 Evolution of the Integrated Safety Review (ISR) Approach

In the 1990's, few countries initiated methodical safety reassessments, termed in Canada Systematic Review of Safety (SRS), to evaluate the cumulative effects of plant ageing and to complement the routine and special safety reviews required by the licensing regime. Such reassessments were the seeds for the current life-extension approach in Canada.

From 1999 to 2006, International Atomic Energy Agency (IAEA) documents were used to guide the Canadian SRSs - first the Safety Guide No. 50-SG-012, and then Safety Guide No. NS-G-2.10 "Periodic safety Review of Nuclear Power Plants" issued in 2003 [2]. In 2007, based on experience gained from the restarts of four reactor units in Canada, a CNSC Regulatory Document - RD-360 "Life Extension of Nuclear Power Plants" [3] - was issued requiring that licensees carry out an Environmental Assessment (EA), if necessary, and an ISR to establish the scope of an NPP life-extension project.

To ensure consistency, a set of documentation comprising a process, a procedure and a staff review guide has been prepared to support the application of RD-360 to assess the licensee's ISR submissions by the staff of the Canadian Nuclear Safety Commission (CNSC), the Canadian regulatory body. Also, these documents proved to be useful for the licensees as they provide clear indications of regulatory expectations, and of acceptance criteria used to assess the licensee's ISR submissions.

Currently, the ISR approach is, or can be, used to generate information to support the decision-making process and the regulatory determination for refurbishment for the purpose of life extension; long-term operation beyond the anticipated design life.

3.2 General Considerations

The IAEA safety standard NS-R-2 [4] requires that "Systematic safety reassessments of the plant in accordance with the regulatory requirements shall be performed by the operating organization throughout its operational lifetime, with account taken of operating experience and significant new safety information from relevant sources". Although operational NPPs are subject to routine and special safety reviews as well as regulatory oversight, these activities do not always take into account the improvements in safety standards and operating practices; the cumulative effects of plant ageing, modifications, and feedback of operating experience; and wider developments in science and technology. Thus, it is currently a common international practice for operating organizations to undertake periodically proactive, strategic, detailed and comprehensive safety reviews in order to complement their routine operating and licensing activities.
In Canada, the ISR fulfills this objective, for it is considered a systematic and effective approach to obtain an overall view of actual plant safety, and determine reasonable and practicable

modifications that should be made in order to ensure a high level of safety for continued operation. Furthermore, ISRs can be used as means to identify time limiting features of the plant in order to determine if, or to which extent, the designed lifetime of an NPP can be extended.

4. ISR vs. PSR

In essence, the ISR process as described in RD-360 [3] is very similar to the Periodic Safety Reviews (PSR) process included in IAEA NS-G-2.10 [2]. However, differences exist as detailed in Table 1. It is important to emphasize at this point that the ISR is once-in-a-life-time approach as opposed to the PSR which has a periodicity of 10 years.

The ISR is applicable to various nuclear facilities of any age, and may have wider applicability when used with a graded approach, for example, to research reactors and radioactive waste management facilities. For an operating NPP, an ISR is not intended to deal with the safety issues during the decommissioning phase; however, documentation resulting from an ISR is an important input for planning an end-of-life, and thence decommissioning, of an NPP.

Table 1: Differences between the ISR and the PSR

ISR as per RD-360 [3]	PSR as per NS-G-2.10 [2]
Performed one-time for refurbishing a facility or extending its life (e.g., by 25 to 30 years).	Performed periodically normally every 10 years.
May require the initiation of an Environmental Assessment (EA) process.	Does not require the performance of an EA.
The focus is on continued safe operation, including SSCs conditions and fitness for service, for the proposed period for life extension (25 to 30 years).	The focus is on continued safe operation for next 10 years till next PSR.
Performed outside the licensing cycle, ISR results are then transferred into the licensing process	PSR and its results are part of the licensing process.
RD-360 expects 17 Safety Factors to be covered (added: Security, Safeguards and Quality Management to those mentioned in [2])	NS-G-2.10 calls for 14 Safety Factors.
Resulting Integrated Improvement Plan (IIP) includes results of both the ISR and EA, and factors such as station-specific Action Items, Generic Action Items, etc.	Resulting IIP includes results of the PSR and consideration of elements that were not completed as a result of the previous PSR.
Refers to NS-G-2.10 for the objectives and review elements.	Includes detailed guidance on process objectives, safety-factors description and review elements.

5. ISR – Conduct and Assessment

5.1 ISR Objectives

The objectives of the ISR are to determine by means of comprehensive reviews:

1. The extent to which the plant conforms to modern codes, standards and practices;
2. The extent to which the (updated) licensing basis and associated safety documentation remain valid to the end of the proposed extended operating life;
3. The adequacy and effective implementation of the arrangements that are in place to ensure and maintain continued plant safety; and
4. The improvements to be implemented to resolve the safety issues that have been identified.

Objective 1 aims at comparing the actual state of the plant condition with the requirements of codes and standards of the time. Non-conformances are recognized as findings that will be assigned safety significance, and be subject to cost-benefit analysis for potential practicable implementation of corresponding corrective actions or safety improvements. As illustrated in Figure 1, the target here is to bring the plant as close as practicable to the design, safety, and operating requirements of the day.

Objective 2 aims at updating the licensing basis of the plant based on the corrective actions resulting from the ISR and the mitigating actions resulting from the EA.

Objective 3 assumes that operation documentation and ongoing programs are adequate and effective for the successful long-term operation of the plant. Examples of such operations programs include:

- Programs and documents required to support the plant design, actual condition of SSCs, equipment qualification, and ageing management;
- Operation programs that address quality assurance and configuration management;
- Governance procedures for updating safety analyses,
- Management programs, including those for safety culture, and organizational structure that are focused on the pursuit of excellence in all aspects of safety management and human factors.

Objective 4 ensures that the results of the ISR and EA are clearly translated into remedial actions and safety improvements that are implemented in accordance with a schedule agreed between the licensee and the regulatory body.

5.2 ISR Approach

The ISR, similar to the PSR, provides a comprehensive reassessment of the safety of the NPP. Since this task is complex and multi-faceted, such a reassessment is generally subdivided into manageable parts, which are labeled Safety Factors [2]. The PSR approach [2] recommends the use of 14 safety factors. The Canadian ISR approach [3] recommends the use of 3 additional safety factors; namely, Quality Management, Safeguards, and Security.

5.3 Outputs of an ISR

Four sets of documentation are prepared by the licensee in the ISR process. These are:

- ISR Basis Document
- Safety Factors Reports
- Global Assessment Report
- Integrated Implementation Plan

The ISR Basis Document establishes the objectives, scope, methodology, and plant boundaries for the conduct of the ISR; as well as a statement of the proposed period of extended life for the facility. The terms of the current licensing basis are defined since they constitute the minimum licensing and operating requirements of the plant. Modern codes, standards, methods and practices must be listed for use as benchmark for identification of remedial actions and possible improvements.

The Safety Factor Reports demonstrate how the review elements are systematically covered; methods used to disposition findings; and rationale, justifications and evidence are stated in support of conclusions reached. The material reported in each SFR must be complete and comprehensive; as well as well-structured, logical, factual, and self-contained to allow the regulatory body to make determination on the merits of the reported information. Site-specific conditions must be considered to determine the feasibility of continued long term safe operation. For example, the scope of the safety factors on ageing and actual condition of SSCs should include evaluation of time-limiting-aging-analyses, identifying ageing mechanisms and re-evaluating ageing management programs [4, 5].

The Global Assessment Report (GAR) describes the methodology used by the licensee for evaluating the overall risk for plant's continued operation, taking into account individual and aggregate effects of findings, plant strengths, and generic and plant-specific safety issues.

Based on the results of the ISR and EA, detailed proposals for corrective/mitigating actions or safety improvements along with corresponding schedule are developed by the licensee and presented in an Integrated Implementation Plan (IIP). The aim is to complete as many of these activities as is practicable within a reasonable time frame of the proposed operational period.

5.4 Dispositioning of Findings – Methods and Approach

The review safety factors should identify strengths and good practices, as well as differences between current codes and standards or industry practices and the current licensing basis, and operating plant documentations or procedures.

Findings resulting from the systematic review of compliance with the current licensing basis which negatively affect safety are addressed without delay in the form of design or operational remedial actions, or safety improvements. Non-conformances with modern codes, standards and practices are identified as gaps. Resolution of gaps is then carried out through a licensee's structured and agreed process that may include, for example, prioritization by safety significance and application of cost-benefit analysis.

5.5 Evaluation of Overall Risk

To integrate the results of the individual safety factors the licensee should perform an evaluation of the global risk to justify the continued safe operation of the plant. To perform this task, the licensee proposes and uses a global assessment method which should consider facility strengths, weaknesses, ensuing safety issues, generic safety issues, site specific issues, and decisions made on gap resolution. The global assessment should demonstrate compliance with the current licensing basis, and compare the safety of the facility with that which would be expected for new NPPs.

The evaluation of the overall risk should be based on individual findings as well as on the aggregate effects of findings. Methods should be proposed and used by the licensees to identify interdependencies and clustering trends that could lead to proposing remedial actions based on the global effect of a phenomenon or a collection of safety or operational issues.

5.6 Approach to ISR Regulatory Assessment

Working processes, procedures and staff review guides have been developed by the CNSC and used by the staff as guidance documents to assess licensees' ISR submissions. These guidance documents enhance the efficiency and effectiveness of the regulatory assessment and ensure consistency of the results. These guidance documents may also be used to assist licensees in preparing their ISR submissions, as they provide licensees with insight into how their ISR outputs are assessed by CNSC staff.

6. Lessons Learned, Challenges, and Benefits

In Canada, seven projects are currently at different stages of the ISR process; some at the stage of developing the ISR Basis Document and others are at the stage of refurbishment outage. Invaluable experience was gained from these projects not only by licensees but also by the regulatory body. Part of the Canadian experience also came from two restart projects that were completed earlier.

6.1 Lessons Learned up to 2008

An exercise of gathering of lessons learned was performed internally at the CNSC on the ISR activities for on-going projects. The intent was to identify areas of improvements for similar future endeavours. Table 2 lists some of the lessons learned and outcomes of implementing improvement measures.

Table 2: Lessons learned on conduct by licensees and conduct of regulatory of ISR related documents

Lessons Learned	Improvement and Outcomes
Use of contractors	
Licensee did not necessarily ensure appropriate quality or ownership of work performed by contractors.	Licensee's review and approval process for contracted work was enhanced. Thus, significant improvement observed in quality of submissions.
Piecemeal submissions	
Piecemeal submission of specific Safety Factor Reports led to missing reporting of key information on interface or interrelation between documents.	Licensees submitted concurrently closely related Safety Factor Reports (e.g., plant design, actual condition of SSCs, ageing, equipment qualification, and safety analyses), resulting in streamlining of reviews, improved demonstration of the safety case, reduction in requests for additional information, and better use of resources.
Effective use of resources	
Significant resources needed to perform regulatory assessments, necessitating improvement in task and resource planning and management.	CNSC delivered information workshops to its staff and the industry, implemented mentoring schemes of staff newly involved in ISR assessments, and used its experienced resources strategically.
Assessment structure and guidance	
In many cases, staff did not share a common understanding of the objectives of the assessments carried out.	CNSC assessment process was formalized, including clear acceptance criteria, initial "sufficiency" check of submissions, and use of sampling (e.g., vertical and horizontal slices) to perform the assessments. Guidance documents were developed and used by CNSC staff, and provided to licensees, resulting in enhanced consistency and improved structure.
Rules of engagement	
Establishment of agreed rules to control and limit the number of iterative communication before a final determination is made.	Steps were established and agreed, resulting in a more rigor, disciplined and streamlined process, and improved quality of documents (both on the CNSC and licensees sides).

6.2 Recent Challenges

The following sub-sections describe recent challenges relating mostly to the later phases of the ISR; primarily, the conduct of the global assessment, and establishment of the Integrated Improvement Plan.

6.2.1 Consideration of aggregate effects of findings

Safety Factor Reports tend to disposition identified gaps individually; leading to the potential conclusion that such gaps may have minimal effect on safety improvement. However, it could be illustrated that interdependent gaps can be grouped in "clusters" under topical areas that correspond to high-level requirements common to all the gaps in the cluster. Examples of such topical areas include:

- Single-failure-criterion requirements

- Deterministic safety analysis (including computer-code validation and updating safety reports, and trip coverage)
- Fire hazards analysis
- Severe accidents management
- Integrity of containment structure
- Risk contribution due to fire and external events

The challenge at this stage is to develop a process that would allow consideration of the impact of aggregate effects and trends from multiple gaps that share a common theme.

6.2.2 Global assessment tools and process

It proved to be a challenge to establish and develop a credible approach for the evaluation of the global risk relating to the continued safe operation of a plant beyond its anticipated design life. The industry does not currently employ a consistent manner to perform the global assessment. The following are example of challenges observed:

- There is no common agreement on the definition of “global risk” and how it is evaluated
- Inadequate comparison of assigned risk-levels for gaps resulting from different safety factors (for example, plant design, safety analysis, or management related)
- Inadequate consideration of aggregate effects of interdependent gaps

The definition of, and the methodology to carry out global assessments are expected to be the subject of further and continued discussions between the licensees and the regulatory body.

6.2.3 Application of Cost Benefit Analysis

One key tool developed and used by the industry for decision making is the Cost Benefits Analysis (CBA) process. CNSC position on this matter is documented in Policy Document P-242 [6] which confirms that the decision making process will consider relevant information on costs or benefits. However, the policy also states that such information is only one factor that may be considered in decision-making, and does not displace legal requirements and other valid regulatory considerations.

As such, integration of the Cost Benefit considerations into the regulatory process has proven to be a challenge. On the licensee side challenges include:

- Development of a systematic process that is demonstrably unbiased (that is, confidence should be obtained that application by different experts will lead to the same results)
- Identification of decision criteria on balance of levels of cost and risk
- Balance between deterministic and probabilistic considerations

On the regulatory side, challenges include:

- Acceptance of a process versus acceptance of its application
- Balance with other regulatory considerations such a defense-in-depth

- Consideration in isolation of multiple applications of the process

It is expected that the application of the CBA will still be evolving in the years to come, and that regulatory process will correspondingly manage to integrate such information in a documented regulatory decision-making process.

6.3 Benefits

The systematic assessment of safety factors occasionally identified deviations from the current licensing basis. In such cases, immediate actions were effected to devise and implement corrective measures.

Taken in isolation, some resulting ISR gaps may not constitute significant safety concerns. However, aggregates of gaps may highlight a safety issue which if addressed would result in positive impact on the safe operation of the plant.

The number of improvements identified as a result of the ISR reflects on the benefits of performing systematic assessments at the level of ISR for operating facilities.

7. Conclusions

The ISR process is relatively new in Canada. The process has been applied in numerous forms since the early 2000's by Canadian licensees; but formally described in the CNSC RD-360 [3] in 2007. Through the application of this process significant experience was gained by the industry as well as by the regulatory body. The ISR has been proven to be a systematic approach that is useful in collecting information to decisions-making related to continued safe operation of an NPP.

Challenges remain to be addressed in areas such as:

- Consideration of the aggregate effects of findings
- Development of a process and tools to evaluate the global risk associated with the continued safe operation of an NPP beyond its anticipated design life
- Balancing the results of applying Cost Benefit Analysis with legal requirements and other regulatory considerations

Employing the ISR process reflects positively on the potential use of integrated and systematic review of safety for operating NPP.

8. References

[1] IAEA Safety Standards Series, Requirements No. NS-R-1, "Safety of Nuclear Power Plants: Design", Vienna, 2000.

[2] IAEA Safety Standards Series, Safety Guide No. NS-G-2.10, "Periodic Safety Review of Nuclear Power Plants", Vienna, 2003.

[3] CNSC Regulatory Document RD-360, “Life Extension of Nuclear Power Plants”, February 2008.

[4] IAEA Safety Standards Series, Requirements No. NS-R-2, “Safety of Nuclear Power Plants: Operation”, Vienna, 2000.

[5] IAEA Safety Standards Series, Safety Guide No. NS-G-2.12, “Ageing Management for Nuclear Power Plants”, Vienna, 2009.

[6] CNSC Policy P-242, “Considering Cost-benefit Information”, October 2000.