Canada's Nuclear Regulator

Safety Analysis

Nuclear Fuel Safety and Qualification

REGDOC-2.4.5

April 2024

Canadian Nuclear Safety Commission
Commission canadienne de sûreté nucléaire

Canada

Nuclear Fuel Safety and Qualification
Regulatory document REGDOC-2.4.5

Cat. No. CC172-256/2024E-PDF
ISBN 978-0-660-70697-9

Également publié en français sous le titre : Sûreté et qualification du combustible nucléaire

Document availability
This document can be viewed on the CNSC website. To request a copy of the document in English or French, please contact:

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Publishing history
n.a

Preface

This regulatory document is part of the CNSC's safety analysis series of regulatory documents, which also covers deterministic safety analysis, probabilistic safety assessment and nuclear criticality safety. The full list of regulatory document series is included at the end of this document and can also be found on the CNSC's website.

Regulatory document REGDOC-2.4.5, *Nuclear Fuel Safety and Qualification*, clarifies requirements and provides guidance for the design, operation, monitoring, qualification and performance assessment of fuel for operating reactor facilities.

This document is the first version of REGDOC-2.4.5, *Nuclear Fuel Safety and Qualification*.

For information on the implementation of regulatory documents and on the graded approach, see REGDOC-3.5.3, *Regulatory Fundamentals*. [1]

The words "shall" and "must" are used to express requirements to be satisfied by the licensee or licence applicant. "Should" is used to express guidance or that which is advised. "May" is used to express an option or that which is permissible within the limits of this regulatory document. "Can" is used to express possibility or capability.

Nothing contained in this document is to be construed as relieving any licensee from any other pertinent requirements. It is the licensee's responsibility to identify and comply with all applicable regulations and licence conditions.

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Nuclear Fuel Safety and Qualification

1. Introduction

1.1 Purpose

This regulatory document clarifies the regulatory requirements and provides guidance for the design, operation, monitoring, qualification and performance assessment of nuclear fuel.

It articulates a set of comprehensive fuel-related regulatory requirements and provides risk-informed guidance that aligns with accepted national and international codes and practices.

1.2 Scope

This document focuses on fuel design, operation, monitoring, qualification and performance assessment for operating facilities, with implicit focus on operating CANDU reactors, but remains as technology-neutral as practicable. It applies primarily to existing fuel designs and to modified or new fuel designs envisioned for operating plants at the time of publication of this document.

The high-level concepts and technology-neutral information also apply to proposed new reactor facilities, including technologies other than water-cooled reactors. While this document focuses on CANDU fuel, high-level concepts herein may apply to other technologies. If a design other than a CANDU reactor, and specifically a solid-fuelled reactor design, is being considered for licensing in Canada, the associated fuel design, qualification and oversight will be subject to the safety objectives, high-level safety concepts and safety-management requirements associated with this regulatory document, where applicable.

Regulatory documents are applicable only if included in the licensing basis of the facility, such as being referenced in the licence conditions handbook. Given the wide range of fuel designs – especially that of advanced and small modular reactors, the applicant or licensee can take a risk-informed approach that includes grading and alternatives in accordance with REGDOC-3.5.3, *Regulatory Fundamentals*. [1]

This document will be revised as appropriate to incorporate operating experience (OPEX) with new reactor technologies.

1.3 Relevant legislation

The following provisions of the *Nuclear Safety and Control Act* (NSCA) and the regulations made under it are relevant to this document:

- NSCA, paragraph 3(a), subparagraph 9(a)(i), and subsections 24(4) and (5)
- *General Nuclear Safety and Control Regulations*, paragraph 12(1)(c)
- *Class I Nuclear Facilities Regulations*, paragraphs 6(b) and (g)

1.4 National and international standards

The key principles and elements used in developing this document are consistent with national and international standards.

The following standards are relevant to this regulatory document:

- CSA N286:12, *Management System Requirements for Nuclear Facilities* [2]
- CSA N299.1 series, *Quality Assurance Program Requirements for the Supply of Items and Services for Nuclear Power Plants* [3]
- IAEA SSG-52, *Design of the Reactor Core for Nuclear Power Plants* [4]
- NUREG-2246, *Fuel Qualification for Advanced Reactors* [5]

2. Fuel Safety

The primary safety functions of fuel are to retain all radionuclides within the fuel system to limit or prevent releases, maintain a coolable geometry, and support or not interfere with safe shutdown. A robust design, safety analysis, qualification and manufacturing process are used to produce the fuel, and strong operational oversight ensures that the fuel performs as expected.

Nuclear fuel is expected to retain its integrity under conditions of normal operation, including under the effects of anticipated operational occurrences (AOOs). Some degree of fuel failure can be accommodated for low-frequency design-basis accident (DBA) conditions (that is, those not expected to occur during the life of the plant). The ability to achieve safe shutdown in any scenario needs to be assured. Therefore, criteria need to be established to ensure that a coolable geometry is maintained in all scenarios and that fuel system damage is never so severe as to preclude the insertion of negative reactivity sufficient to hold the reactor subcritical.

The CNSC has formulated requirements and provided guidance regarding fuel design, degradation mechanisms and associated limits, qualification, monitoring, inspection and operations to ensure the application of defence in depth (DiD) principles to all fuel-related activities so that the fuel will perform in accordance with its design safety objectives during both operational states and accident conditions.

For more information on the concept and application of DiD, see REGDOC-3.5.3, *Regulatory Fundamentals*, [1] and REGDOC-2.5.2, *Design of Reactor Facilities*. [6]

3. Fuel Design

The fuel design must be controlled, accurately reflected in the safety analysis of the reactor facility, and properly qualified for the subset of all facility states considered in the fuel design process. Program measures must confirm that the fuel will remain within its safety limits at all applicable levels of DiD, where each safety limit is explicitly taken into account in the fuel design basis.

Requirements

Licensees shall have program measures that ensure that the fuel design is:

1. controlled
2. accurately reflected in the safety analysis of the reactor facility
3. properly qualified for the subset of all facility states considered in the fuel design process
4. within its safety limits at all applicable levels of DiD, where each safety limit is explicitly taken into account in the fuel design basis

3.1 Fuel design and fuel design limits

The licensee shall ensure that the fuel design and fuel design limits are established.

Requirements

The licensee shall ensure, for the fuel design, that:

1. all phases of the facility's lifecycle, and all levels of DiD, are taken into account
2. the fuel remains within its safety limits for the facility's design envelope
3. the design inputs are defined
4. the design requirements are defined
5. the design and safety analysis computer codes are validated
6. the fuel design is qualified for use

3.2 Control of fuel design and design process

Requirements

The licensee shall ensure that the fuel design, design process and manufacturing are established, documented and controlled.

The licensee shall ensure that the fuel documentation is updated when new information or understanding is gained.

Guidance

The licensee should ensure that fuel design and oversight comply with the management system requirements found in CSA N286:12, *Management System Requirements for Nuclear Facilities*, [2] or equivalent.

Measures for fuel design should include a manufacturing quality assurance (QA) program that ensures the supply chain for fuel and employs and justifies an appropriate standard supply chain QA, such as CSA N299.1, *Quality Assurance Program Requirements for the Supply of Items and Services for Nuclear Power Plants*. [3]

Licensees that are not using CSA N286:12 and/or CSA N299.1 should map their management system and QA control measures to the requisite standards to demonstrate that they satisfy the requirements for the fuel design process. Where gaps are identified, the licensee should ensure that the measures that address them are documented.

3.3 Fuel design authority

Requirements

The licensee shall identify a design authority or responsible designer for fuel, henceforth called the fuel design authority in this document, who is responsible for:

1. establishing a fuel design knowledge base that allows the licensee to understand and predict fuel behaviour for all plant operating states with established uncertainties
2. ensuring that the fuel design process was followed
3. controlling the documentation of the design and its technical basis
4. ensuring change control

5. ensuring the qualification of the fuel design for the application (see section 5.4)

Guidance

While activities may be carried out by third parties, the licensee remains responsible for compliance and safety.

4. Fuel Design Process

In the fuel design process, the designer identifies the requirements and limits the fuel must meet, produces a fuel design, and documents how the design meets the requirements. The fuel design process includes assessments that show how the fuel design requirements have been met. The complexity of the fuel design process, including the qualification stage, is a function of the novelty of the design. The design process must take into account all applicable facility states.

4.1 Design requirements

Requirements

The fuel design process shall identify:

1. functional requirements
2. performance requirements
3. safety requirements
4. environmental impact
5. inspection and testing requirements
6. requirements that are imposed on the interfacing systems by the fuel design
7. requirements that are imposed on the fuel by the interfacing systems
8. applicable codes and standards

Guidance

Applicable codes and standards should include those related to welding, transport packaging, workplace safety and the handling of hazardous materials.

Licensees should refer to CSA N286:12, *Management System Requirements for Nuclear Facilities* [2] for more information.

4.2 Design safety objectives

Requirements

The design process shall define the fuel design safety objectives.

Guidance

For current operating CANDU reactors, these objectives may be formulated as follows:

1. For normal operating conditions, including the effects of AOOs:
    a. fuel damage or degradation does not invalidate safety analysis assumptions
    b. fuel pellet, element and bundle dimensions will remain within operational tolerances
    c. the fuel bundle will maintain its structural integrity

   d. the functional capabilities of the fuel will not be reduced below those assumed in the deterministic safety analysis
   e. the damage that the fuel may cause to the fuel channel components is acceptable in the sense that these components remain fit for service
2. For accident conditions considered in the safety report (DBA):
   a. the fuel design achieves the safety functions commensurate with the event class
   b. fuel sheath failures will be kept as low as reasonably achievable (ALARA)
   c. the fuel assembly and its component parts will not remain in a position or have distortions that would prevent effective core cooling during or after the accident

If the fuel design is for a reactor other than a CANDU, the fuel design safety objectives shall be defined following international best practices and might differ significantly from the guidance provided for currently operating CANDU reactors.

4.3 Defence in depth

Requirements

The fuel design process shall take into account the core principles of level 1 DiD.

Guidance

Level 1 DiD should be achieved through:

1. careful selection of materials
2. use of qualified fabrication processes
3. use of proven technology
4. extensive performance testing
5. conservatism in the design
6. high quality in construction and manufacturing
7. use of appropriate standards
8. suitable safety margins
9. due consideration of facility design parameters and site characteristics

For more information on DiD, see REGDOC-3.5.3, *Regulatory Fundamentals*. [1]

4.4 Safety analysis

Requirements

Safety analysis shall begin at an early point in the fuel design process, with iterations between design activities and confirmatory analytical activities supported by experimental and qualification testing. The objective is to demonstrate an increase in scope and level of detail as the design process progresses.

4.5 Design consideration scope

Requirements

Reactor conditions, from commissioning to core end-of-life conditions, shall be taken into account in the design process.

Design considerations shall take into account all facility states within the facility's design envelope.

4.6 Input to design process considerations

Requirements

The design process shall document how the following were taken into account:

1. reactor physics and the nuclear design
2. reactor thermal hydraulics
3. nuclear criticality safety
4. interfacing systems such as:
    a. interfacing physical barriers (for example, the primary heat transport system components)
    b. fuel handling
    c. fuel storage
    d. transport
5. waste management, storage and minimization
6. OPEX

4.7 Degradation mechanisms

Requirements

The design process shall identify fuel degradation mechanisms and the performance limits associated with these mechanisms, which may challenge the fuel design. To this end:

1. damage mechanisms shall be identified and defined
2. failure mechanisms shall be identified and defined
3. conservatism shall be employed in setting limits associated with degradation mechanisms
4. limits associated with damage mechanisms shall be set such that, if complied with, they preclude, with margin, the fuel (element or bundle) and fuel channel components from being damaged (that is, the fuel and fuel channel components remain fit for service) during operational states
5. fuel damage and failure mechanisms and the associated limits shall reflect a verified and auditable knowledge base

Guidance

The design process should identify fuel failure limits. If a fuel failure limit is not well defined or known, a measurable surrogate limit should be defined. These surrogate limits should incorporate conservative engineering safety factors.

Appendix A provides examples of degradation mechanisms for CANDU reactors.

For more information on the concept and application of DiD, see REGDOC-3.5.3, *Regulatory Fundamentals*, [1] and REGDOC-2.5.2, *Design of Reactor Facilities*. [6]

4.8 Notification

Requirements

When considering possible changes to the fuel design, the licensee shall engage with CNSC staff to confirm that the changes are within the licensing basis before implementing the change.

Guidance

The CNSC encourages early engagement by the licensee to confirm that the changes are within the licensing basis.

4.9 Design change

Requirements

The licensee shall assess proposed changes to design specifications and manufacturing methods to determine whether the change can affect the licensing basis, design basis or safety case. If these might be affected, then the licensee shall treat the change as a design change.

Where the licensee is procuring a fuel design from a dedicated designer, the licensee must demonstrate that it has the technical processes and capabilities in place to assess and accept the requirements and limits the fuel must meet, including how the fuel is produced and how the fuel design is documented, to satisfy the licensee's specific requirements for its facility.

4.10 Documentation

Requirements

The fuel design process shall document the fuel design and describe how it meets the identified requirements.

5. Fuel Qualification Process

Fuel qualification is a key activity of the fuel design process. The aim is to ensure that the final design meets all of the fuel design requirements. Fuel design qualification is achieved through analysis using qualified methods and through qualification testing.

5.1 Qualification objective

Requirements

As part of the qualification process, it shall be demonstrated that the design meets all of the requirements and the associated limits.

Guidance

A qualification process should rely on a systematic analysis of all available data and operational experience for identification of gaps in knowledge and potential new failure modes. A research and development program should be employed to address gaps in knowledge. When necessary, separate effect testing and integral testing should be performed to confirm safety limits and fuel acceptance criteria. The use of demonstration irradiation or lead test assemblies in conjunction with surveillance is encouraged.

The qualification process should include the qualification of the fuel manufacturing specifications and process.

When establishing the fuel qualification process, fuel designs for advanced reactors should use appropriate international guidance, such as NUREG-2246, *Fuel Qualification for Advanced Reactors*. [5]

5.2 Technical basis

Requirements

The technical basis for the qualification process:

1. is based upon OPEX or is demonstrated through a process of experimental testing and analysis, or a combination of both, where:
   a. any referenced OPEX must be documented and auditable
   b. OPEX or experimental tests may be with the same or similar fuel design in the same or a similar reactor design; for any technical basis that is based upon "similar designs," the licensee shall document and assess the differences between both designs.
2. demonstrates the adequacy of:
   a. the qualification analysis and modelling
   b. the qualification testing regime
   c. the documented design and operating envelope of the fuel
3. shall reflect a verified and auditable knowledge base

Guidance

The technical basis for the qualification should show that the fuel is qualified for use by demonstrating that the evaluation models/codes used and the experimental data are appropriate and based upon sound science and techniques; that uncertainties, gaps and limitations with the models and experimentation are understood; and that cliff edge effects have been identified.

The models/codes should be verified and validated to the extent practicable against appropriate national standards, such as CSA N286.7, *Quality Assurance of Analytical, Scientific and Design Computer Programs*, [7] and be applicable over the range of the fuel performance envelope for which they are employed.

5.3 Management system and quality assurance

Requirements

The qualification process shall meet the licensee's management system and QA requirements.

5.4 Qualification certification

Requirements

The licensee shall ensure that the qualification of the fuel is certified by the licensee's fuel design authority.

Guidance

The certification of the fuel qualification is a written attestation that states that the fuel design authority has reviewed the design, accepted the qualification, and approved the use of the fuel design on behalf of the licensee. The attestation should demonstrate that the licensee fuel design authority is professionally qualified to be the design authority and has taken professional responsibility for ensuring that the fuel design is safe to use in the licensed facility.

6. Fuel Design Submissions

Requirements

Before loading a new or modified fuel design into a reactor core, the licensee shall submit, to the CNSC, the following information and obtain CNSC staff's confirmation that the design is within the licensing basis and is qualified for use:

1. for a modified fuel design, an assessment on whether or not the change is a licensing basis change
2. the fuel design requirements
3. a detailed description of the fuel design
4. the current/updated safety case
5. the technical basis for qualification
6. the documented qualification envelope
7. a summary of the qualification results
8. the certification of the qualification by the licensee's fuel design authority (see section 5.4)

Additional information shall be provided if requested by CNSC staff.

Guidance

The CNSC encourages early engagement for assessments of new or modified fuel designs.

For demonstration irradiations, where the number of bundles to be irradiated remains small, the graded approach may be employed.

For new reactor designs, the information pertaining to the fuel is expected to be part of the application for a licence to construct the facility.

7. Fuel Fitness for Service

Safe operation of fuel requires that the fuel conditions meet the criteria for fuel fitness for service (FFS). In this context, FFS is the physical condition necessary for the fuel barriers to remain intact, the fuel system dimensions to remain within operational tolerances, the structural integrity to be maintained, fuel parameters to remain consistent with the initial conditions assumed by the safety analysis report, and the fuel to remain compatible with interfacing systems such as the fuel channel components.

Typically, FFS assessments are performed through continual monitoring and inspection during normal operations and through post-AOO/DBA event reviews.

7.1 Fuel fitness for service criteria

Requirements

The licensee shall ensure that the fuel FFS criteria are identified and documented, to the extent practicable.

Guidance

The licensee should consider and the criteria should be consistent with:

1. the requirements placed on the fuel through the design and qualification process
2. licensing limits
3. OPEX
4. the challenges to which the fuel is subjected by AOO events
5. requirements for return to service after an AOO or DBA event

7.2 Technical basis

Requirements

The licensee shall have a documented technical basis for the set of FFS criteria and a methodology to demonstrate compliance.

7.3 Fuel fitness for service assessments

Requirements

The licensee shall implement a process that:

1. identifies when fuel FFS assessments are required
2. assesses fuel FFS

Guidance

FFS assessments should be performed with the intent of understanding degradation mechanisms and their respective degradation rate(s).

Computer codes used to perform FFS assessments should be validated for the application and should comply with appropriate national standards, such as CSA N286.7, *Quality Assurance of Analytical, Scientific and Design Computer Programs*. [7]

7.4 Record keeping

Requirements

The licensee shall keep records on the fuel condition as determined or inferred by operational data, inspections and/or assessments.

8. Fuel Monitoring and Inspection Program

The fuel monitoring and inspection program identifies the condition of the fuel and the extent of qualitative or quantitative graded degradations to determine whether the fuel remains fit for service.

Monitoring and fuel inspection activities play an important role in ensuring acceptable safety performance in a number of safety and control areas, including operating performance, physical design, and safety analysis. Information gathered during those activities ensures that events that are significant to safety and that occur at various levels of DiD are promptly detected, allowing adequate time for corrective measures to be effectively implemented to avoid repetitions.

8.1 Program

Requirements

The licensee shall establish a monitoring and inspection program that ensures that the fuel is fit for service.

Guidance

The monitoring and inspection program should:

1. confirm that fresh fuel's condition is acceptable before irradiation, such as by confirming the absence of foreign material or mechanical damage
2. monitor fuel conditions in the core to detect degradation or failure, such as by monitoring the coolant for radionuclides
3. ensure that fuel that is reshuffled is fit for service, either through analysis limits or inspection
4. infer the condition of fuel in the core by post-irradiation inspections
5. monitor fuel degradation rates

The monitoring and inspection of irradiated fuel as part of waste management is beyond the scope of this document.

8.2 Capabilities

Requirements

The licensee shall ensure that the monitoring and inspection program includes in-core monitoring, onsite inspections of fresh fuel, inspection of in-bay irradiated fuel and, if necessary, hot-cell examinations.

The fuel monitoring and inspection program shall:

1. have instrumentation or chemical sampling capabilities to identify fuel degradation or failure
2. require that only trained personnel perform inspections
3. include procedures and guidance on how to perform inspections
4. require that properly functioning and calibrated testing, measurement and inspection equipment be available
5. ensure the capability to perform the number of inspections required
6. require that equipment and qualified personnel needed to perform online fuel condition monitoring are sufficiently available
7. create and maintain a repository for recording fuel inspection findings

Guidance

The objective of the fresh fuel inspections is to ensure that the incoming fuel was manufactured in accordance with the appropriate quality standard and that the fuel has not been damaged or contaminated by transportation or storage. Once fresh fuel inspections are completed, the licensee should minimize interactions with the fuel prior to loading.

The objective of irradiated fuel inspections is to infer the existing in-core condition of the fuel and to trigger mitigating measures when required.

Data obtained from irradiated fuel inspections can also be useful in assessing whether fuel, under accident conditions, will perform in accordance with its design safety objectives and whether operators can take the necessary measures during postulated accident conditions.

8.3 Assessment of findings

Requirements

As part of the fuel monitoring and inspection program, the licensee shall regularly assess findings, trends, causes and their potential impacts and confirm that fuel remains fit for service and within the analyzed condition.

Guidance

The licensee should ensure that expertise from a diverse range of disciplines is involved in the program and in the assessment of findings. Some examples of disciplines that should be involved are fuel channels, safety analysis, fuel handling and reactor physics.

The impact on interfacing systems should be considered as part of the program.

8.4 Reporting

Requirements

The licensee shall report program findings in accordance with REGDOC-3.1.1, *Reporting Requirements for Nuclear Power Plants*. [8]

8.5 Corrective actions

Requirements

The licensee shall ensure that the fuel monitoring and inspection program identifies findings that have potential impacts on fuel FFS or on the analyzed condition and takes corrective or mitigating actions proportional to the level of risk presented.

8.6 Trending

Requirements

The licensee shall define levels related to expected fuel conditions and degraded states in order to identify negative trends.

Guidance

Training on fuel condition and degraded state levels should be a component of a fuel inspector's qualification to ensure that the data collected for trending is consistent and properly categorized.

8.7 Inspection process

Requirements

Where sampling is used, the licensee shall ensure that there is a documented inspection sample selection process.

The sample selection process shall include both random surveillance and targeted surveillance components.

Guidance

Generic surveillance, using random selection, should make up the majority of inspections.

Targeted surveillance should result in the selection of fuel samples that represent different conditions in the reactor.

The fuel inspection process should produce a robust plan for inspections, including the number of inspections that should be performed each quarter in order to meet annual inspection requirements (section 8.8).

8.8 Inspection

Requirements

For CANDU reactors, the minimum number of in-bay inspections for a normally operating reactor with no identified active degradation mechanisms is 20 bundles per normal operating year per reactor. For reactors of other designs, the licensee shall seek approval from the CNSC on an acceptable minimum level of inspections.

Additional inspections shall be performed when active degradation mechanisms or other challenges are present.

Guidance

Fuel removed from the core because it is not, or is suspected of not being, fit for service should be inspected to understand, document and address the root cause of the fitness for service concern.

Inspections done on fuel defects, in excess of the number typically performed for an operating year, should not be credited toward the minimum level of inspections. In cases where the fuel has been removed but the exact location (bundle or element) of the defect cannot be determined, all known information should be recorded.

A normal operating year is considered to be the expected full power operating time for a reactor of that technology considering its typical capacity factor. The number of inspections required can be prorated to account for long outages or refurbishment activities.

8.9 Maintenance of equipment

Requirements

The licensee shall ensure that equipment used to monitor for, locate and remove fuel that is not fit for service is capable and is functional when required.

Guidance

Monitoring equipment should be operating whenever the reactor is operating. Location and removal equipment is only required when fuel defects are detected.

8.10 Failed fuel and fuel not fit for service

Requirements

The licensee shall remove fuel that has been identified as failed or as not meeting the FFS criteria. If the fuel cannot be removed in a timely manner, the licensee shall take appropriate mitigating actions in the interim.

Guidance

The licensee should minimize failed fuel residency times, as fission product releases into the coolant and deposition on the primary heat transport system piping may result in higher worker doses.

The licensee should apply the ALARA principle when determining the resources and efforts being put toward failed fuel detection, removal and/or mitigation. Radiation doses received by personnel as a result of such efforts shall be kept ALARA.

8.11 Record keeping

Requirements

The licensee shall keep records of the fuel monitoring and inspection findings in a manner that is usable for analysis and trending.

9. Fuel Operating Limits and Conditions

Program measures shall ensure that fuel is operated within its design and operating envelope.

Operational limits and conditions (OLCs) to ensure that fuel is not damaged or the cause of damage to other barriers during normal operations or AOO conditions shall be set. The OLCs also provide a documented limit to degradation on the fuel to ensure that fuel remains within the design and qualification envelope.

9.1 Establishment principles

Requirements

The licensee shall establish fuel OLCs to ensure that fuel is operated in accordance with the licensing basis, the design of the reactor, and the qualification and operating envelope. The fuel OLCs shall include the limits within which the operation of the fuel has been shown to be safe.

9.2 Fitness for service

Requirements

The OLCs shall employ the FFS criteria defined in section 7.1 during and following all operational states, to the extent practicable.

9.3 Modes of operation

Requirements

The licensee shall use the fuel OLCs to establish the operational requirements applicable to each operating configuration before entering that configuration.

Planning and execution of new-build commissioning, refurbishment and post-refurbishment operations shall implement preventive measures that duly account for potential conditions that could result in fuel defects or damage.

Guidance

The operating configurations for normal operating conditions can include:

- cold shutdown
- hot shutdown
- power production operation
- refuelling
- shutting down
- starting up
- commissioning
- transitional states (moving from shutdown to full power)
- maintenance or outage
- life extension or refurbishment
- testing

For commissioning, refurbishment and post-refurbishment operations, the licensee should consider situations where fuel may be in-core and subject to non-standard conditions such as primary heat transport system (PHTS) pressure testing or hot conditioning.

Examples of preventive measures include chemistry control and foreign material exclusion practices.

9.4 Entering new operating conditions

Requirements

The licensee shall assess the fuel OLCs before entering operating conditions that are infrequent in nature. This assessment shall ensure that the existing fuel OLCs are adequate to ensure safety and FFS.

9.5 Aging

Requirements

In the fuel OLCs, the licensee shall take into account the impact of aging of the PHTS on fuel performance.

9.6 Corrosion

Requirements

The licensee shall define the operating parameters to minimize, within acceptable limits, corrosion of the sheath and the creation of deposits.

9.7 Changes in operation

Requirements

The licensee shall review significant changes to the operation of fuel and fuel handling against the fuel OLCs and update the fuel OLCs as required.

Guidance

Significant changes are those that potentially could affect neutronics, thermal hydraulics, or safety analysis assumptions, inputs or limits.

Examples of significant changes include:

- an increase in plant power rating
- an increase in burn-up
- major changes to the facility's PHTS
- changes in fuel placement/shift or fuelling direction

9.8 Periodic review

Guidance

The licensee should undertake periodic reviews of fuel OLCs to ensure that they remain applicable and are updated as needed.

9.9 Action limits and response timelines

Requirements

The licensee shall define and address actions and the timelines for taking action when fuel is not or is suspected of not being FFS.

9.10 Documentation of basis

Requirements

The licensee shall ensure that the basis on which the OLCs are derived is readily available in order to facilitate the ability of plant personnel to interpret, observe and apply the OLCs.

Appendix A: Key Degradation Mechanisms

This appendix lists the key degradation mechanisms for CANDU fuel, in normal operating conditions and in some cases anticipated operational occurrences. For other reactor designs and configurations, degradation mechanisms may be similar or unique to the fuel design.

Table A-1: Key degradation mechanisms affecting CANDU fuel

Degradation category	Observable effect	Key influencing parameters	Impacts relevant to safety
Deformation without material loss	• Sheath collapse and ridging	• Coolant pressure • Temperature	• Mechanical strength • Heat transfer
	• Sheath ballooning (uniform) or bulging (non-uniform)	• Internal gas pressure • Temperature	• Mechanical strength • Heat transfer • Loss of sheath integrity
	• Pellet/cladding mechanical interaction	• Power ramps	• Loss of sheath integrity
	• Element bowing	• Loads • Temperature	• Mechanical strength • Heat transfer
	• End-plate deformation	• Loads	• Mechanical strength • Heat transfer
	• Bundle drooping, sagging	• Loads	• Mechanical strength • Heat transfer
	• Athermal sheath strain	• Loads	• Loss of sheath integrity
Deformation with material loss	• Fretting	• Interaction with debris	• Loss of sheath integrity
	• Bearing pad wear	• Interaction with pressure tubes	• Heat transfer • Impact on pressure tube condition
	• Spacer wear	• Interaction with pressure tubes	• Heat transfer
	• Endplate wear	• Interaction between fuel bundles	• Fuel bundle structural integrity
	• Scratching, nicks	• Interaction with in-reactor components	• Loss of sheath integrity
Change in material properties	• Sheath oxidation	• Temperature • Coolant chemistry	• Mechanical strength • Heat transfer
	• Oxide or crud deposits	• Temperature • Coolant chemistry	• Heat transfer • Poison hideout

Degradation category	Observable effect	Key influencing parameters	Impacts relevant to safety
	• Hydriding	• Coolant chemistry	• Mechanical strength • Sheath temperature
	• Stress corrosion	• Power ramps • Internal gas composition	• Loss of sheath integrity
	• Crevice corrosion	• Coolant chemistry	• Impact on pressure tube condition
	• Material phase transitions	• Temperature • Irradiation	• Mechanical strength
	• Fuel grain growth	• Temperature • Irradiation	• Heat transfer
	• Internal gas pressure and composition change	• Burn-up • Temperature	• Heat transfer • Stress corrosion
Integrity failures	• End-cap to sheath weld failures	• Manufacturing defects • Loads	• Loss of sheath integrity
	• End-cap to end-plate weld breaks	• Manufacturing defects • Loads • Fatigue	• Mechanical strength
	• End-plate cracks	• Vibration • Loads • Fatigue	• Mechanical strength

Appendix B: Acceptance Criteria for CANDU Design-Basis Accidents

This appendix shows examples of acceptance criteria for design-basis accidents. For other reactor designs and configurations, the designer and the licensee are expected to derive the acceptance criteria and justify them as appropriate based on the level of available supporting evidence.

Table B-1: Examples of CANDU fuel system acceptance criteria for design-basis accidents

Barrier to fission product releases or fundamental safety function	Qualitative acceptance criteria as derived acceptance criteria
Fuel matrix	• No fuel centre line melting • No fuel breakup • No excessive energy deposition
Fuel sheath (fuel cladding)	• No excessive strain of fuel sheath • Fuel elements are to meet applicable limits for: o sheath temperature o local sheath oxidation o oxygen embrittlement of fuel sheath
Fuel assembly	• Maintain fuel coolability • Retain rod-bundle geometry or fuel assembly with adequate coolant channels to permit removal of residual heat • No impediment to reactor shutdown means because of geometry change

Glossary

For definitions of terms used in this document, see REGDOC-3.6, *Glossary of CNSC Terminology*, which includes terms and definitions used in the *Nuclear Safety and Control Act* and the regulations made under it, and in CNSC regulatory documents and other publications. REGDOC-3.6 is provided for reference and information.

The following terms are either new terms being defined or include revisions to the current definition for that term. Following public consultation, the final terms and definitions will be submitted for inclusion in the next version of REGDOC-3.6, *Glossary of CNSC Terminology*.

References

The CNSC may include references to information on best practices and standards such as those published by CSA Group. With permission of the publisher, CSA Group, all nuclear-related CSA standards may be viewed at no cost through the CNSC web page "How to gain free access to all nuclear-related CSA standards."

1. Canadian Nuclear Safety Commission (CNSC), REGDOC-3.5.3, *Regulatory Fundamentals*, Ottawa, Canada, 2023.
2. CSA Group, CSA N286:12, *Management System Requirements for Nuclear Facilities*, Toronto, Canada, 2012.
3. CSA Group, CSA N299.1 series, *Quality Assurance Program Requirements for the Supply of Items and Services for Nuclear Power Plants*, Toronto, Canada, 2019.
4. IAEA, SSG-52, *Design of the Reactor Core for Nuclear Power Plants*, Vienna, Austria, 2019.
5. United States Nuclear Regulatory Commission, NUREG-2246, *Fuel Qualification for Advanced Reactors,* Washington DC, United States of America, 2022.
6. CNSC, REGDOC-2.5.2, *Design of Reactor Facilities*, Ottawa, Canada, 2023.
7. CSA Group. CSA N286.7, *Quality Assurance of Analytical, Scientific and Design Computer Programs*, Toronto, Canada, 2016.
8. CNSC, REGDOC-3.1.1, *Reporting Requirements for Nuclear Power Plants*, Ottawa, Canada, 2016.
9. IAEA, TECDOC No. 1926, *Technical Review Of Acceptance Criteria For Pressurized Heavy Water Reactor Fuel*, Vienna, Austria, 2020.

Additional Information

The CNSC may recommend additional information on best practices and standards such as those published by CSA Group. With permission of the publisher, CSA Group, all nuclear-related CSA standards may be viewed at no cost through the CNSC web page "How to gain free access to all nuclear related CSA standards".

The following documents provide additional information that may be relevant and useful for understanding the requirements and guidance provided in this regulatory document:

- Canadian Nuclear Safety Commission (CNSC), REGDOC-2.4.1, *Deterministic Safety Analysis*, Ottawa, Canada, 2014.
- CNSC, REGDOC-2.5.2, *Design of Reactor Facilities*, Ottawa, Canada, 2023.
- United States Department of Defense, Systems Engineering Fundamentals, Washington DC, United States of America, 2001.

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