11th International Conference on CANDU Fuel
Sheraton Fallsview Hotel and Conference Centre
Niagara Falls, Ontario, Canada, 2010 October 17-20

CNSC FUEL OVERSIGHT PROGRAMME

A. El-Jaby*, K. Conlon, W. Grant, and M. Couture
Physics and Fuel Division, Canadian Nuclear Safety Commission
P.O. Box 1046, Station B, 280 Slater Street, Ottawa, Ontario, Canada
**Tel.: 613-943-4918; Fax: 613-995-5086; Email: Ali.El-Jaby@cnsc-ccsn.gc.ca*

ABSTRACT

Nuclear power plant licensees are required to submit an *Annual Fuel Performance Report* to the CNSC pursuant to *Regulatory Standard S-99*, clause *6.4.10 – Report on the fuel monitoring and inspection programme*. This paper summarises how the information in the annual *Report on the fuel monitoring and inspection programme* is used by CNSC staff to provide an assessment of fuel performance and licensing compliance, the results of which are used as input into the annual *CNSC Staff Integrated Safety Assessment of Canadian Nuclear Power Plants*. Lastly, possible changes and improvements aimed at simultaneously enhancing and streamlining the current reporting template are discussed.

1. INTRODUCTION

The safety issue which triggered *Generic Action Item 94G02 – Impact of Fuel Bundle Condition on Reactor Safety* (hereafter referred to as *GAI-94G02*) stems from the fact that, in some instances, the condition and degree of degradation of fuel bundles discharged from CANDU reactors was not what was expected and accounted for in the design, operation, and safety analysis of these reactors [1].

Excessive (or unexpected) bundle degradation typically manifests in the form of end-plate cracking, end-cap separation, extensive bundle deformation, sheath strain, as well as abnormally high degrees of wear in the spacer pads, bearing pads, and sheath material. Moreover, increased occurrences of defective fuel lead to higher than expected quantities of oxidised fuel and fission products released into the primary heat transport system (PHTS). Lastly, fuel bundle degradation is often associated with fretting and scratching of pressure tubes, the effects of which are compounded by other factors such as pressure tube diametric and axial creep.

GAI-94G02 identified a greater need for CNSC staff to monitor fuel behaviour at operating nuclear power plants (NPPs). Moreover, revelations of changes in fuel design and manufacturing, difficulties with surveillance tools at site, and new fuel behaviour operating experience (OPEX) after the closure of *GAI-94G02*, highlighted the need for CSNC staff to be informed of significant developments in fuel design and behaviour in a consistent and timely manner. Accordingly, requirement *6.4.10 – Report on the fuel monitoring and inspection programme* (hereafter referred to as *6.4.10*) was included in *Regulatory Standard S-99*[1] (hereafter referred to as *S-99*) [2].

[1] *S-99* is mandated in the licensing requirement for each NPP under guidelines of the *Canadian Standards Association N286 – Management System Requirements for Nuclear Power Plants*.

2. CNSC FUEL OVERSIGHT PROGRAMME

2.1. Programme Objectives

The CSNC Fuel Oversight Programme has three main objectives:

i. Ensuring licensing compliance.

ii. Obtaining assurance that the fuel is being operated within the conditions assumed in safety analysis, i.e., within the design and operating envelope for which it was qualified.

iii. Observing and tracking reactor core behaviour and health.

2.2. Programme Activities

In order to achieve the programme objectives, CNSC staff conducts the following six main activities:

i. Reviews of unscheduled fuel related event reports; including reports of fuel related phenomena identified by research findings or revised analyses.

ii. Reviews of each licensee's annual report (under clause *6.4.6* of *S-99*) on the progress of research and development activities.

iii. Reviews of each licensee's annual report on their fuel monitoring and inspection programmes (under clause *6.4.10* of *S-99*).

iv. Review of weekly CNSC site inspector reports.

v. Attend licensee's quarterly meeting of their fuel and fuel channel programme.

vi. Performance-based inspections (Type I and Type II) as required.

2.3. Programme Outcome

CNSC staff use three main tools to regulate: enforcement, verification, and promotion. Depending upon the severity of the issues identified by the oversight programme activities, CNSC staff determines the appropriate response or follow-up action.

i. Enforcement (regulatory action):
    a. Issue orders
    b. Requests for Action under General Regulations 12(2)
    c. Raise Generic Action Items

   d. Request action under a formal letter
   e. Amend licences

ii. Verification (increased regulatory scrutiny):
   a. Conduct Type I and Type II inspections
   b. Request additional analysis and reporting
   c. Meetings with licensees

iii. Promotion (reporting and disseminating information):
   a. Identification of Industry Best Practices
   b. *CNSC Staff Integrated Safety Assessment of Canadian Nuclear Power Plants*

Through the measured use of these tools, CNSC staff encourages safe operation and when necessary imposes it through regulatory action. CANDU fuel has been performing well, and the industry's co-operation and dedication to safe operation has meant that the majority of CNSC staff efforts have gone towards verification and promotion activities.

It is not the intent of this paper to discuss in-depth all aspects of the CNSC Fuel Oversight Programme, thus the remainder of the paper will focus on *S-99 6.4.10* and how the information from it is used within the CNSC Fuel Oversight Programme.

3. S-99 6.4.10 REPORT ON THE FUEL MONITORING AND INSPECTION PROGRAMME

S-99 6.4.10 is an invaluable input to the CNSC Fuel Oversight Programme. When considering the overall operation, licensing, and compliance, the objectives of *S-99* are [2]:

i. To help the Canadian Nuclear Safety Commission (CNSC, Commission) collect information that it needs to assure that a nuclear power plant (NPP) is operating safely and to verify that the licensee is complying with regulatory requirements.

ii. To help applicants for operating licences for NPPs design programmes for collecting and reporting information in accordance with regulatory requirements.

iii. To facilitate CNSC evaluations of the appropriateness, completeness, and timeliness of information reported to the CNSC by the operators of NPPs.

Requirement *6.4.10* of *S-99* specifically provides the means for CSNC staff to carry out the mandate of the Fuel Oversight Programme, whereby [2]:

> *"…a licensee shall, by April 30 of each calendar-year, unless otherwise approved in writing by the Commission or a person authorised by the Commission, file with the designated CNSC contact, a report that describes the licensee's fuel monitoring and inspection programme over the previous calendar-year."*

The report submitted by the licensee must include [2]:

i. *A description of the objectives, elements, procedures, limitations, results, and conclusions of the programme that the licensee conducted over the calendar year for the purpose of monitoring, inspecting, and assessing the condition of the irradiated reactor fuel.*

ii. *Include the name and address of the sender of the report, the date of completion of the report, and the signature of the designated representative of the licensee.*

4. REVIEW RATIONAL AND OBJECTIVES FOR S-99 6.4.10 SUBMISSIONS

The current reporting template of *S-99 6.4.10* is made up of six tables provided in APPENDIX A and is designed to give CNSC staff insight into an NPP's fuel monitoring and inspection programme [3][2]. The rationale for the information provided by the licensee and the review objectives (i.e., what CNSC staff is looking for) for each table of the reporting template [3] is outlined in sub-sections 4.1 to 4.6.

4.1. Table 1 – Summary of Fuel Performance

The intent of *Table 1 – Summary of Fuel Performance* is to provide CNSC staff with a broad snapshot of the fuel performance, compliance, and corresponding trends, as well as the monitoring capabilities of the NPP in question. CNSC staff also use the summaries (*1.1 – Summary of compliance programme* and *1.3 – Summary description of surveillance capabilities*) to inform them of programmatic or capability changes that may affect the interpretation of results elsewhere in the report.

4.2. Table 2 – Fuel Operating Conditions

The reporting requirements of *Table 2 – Fuel Operating Conditions* are objective in that they are based on numerical performance indicators, which provide the basis for CSNC staff evaluation. The aim of this table is to provide CNSC staff a summary of the fuel operating conditions in order to highlight non-compliance events. By ascertaining the number of non-compliance events, and comparing such events across the board for all NPPs, CNSC staff is able to determine if there are any systematic design, manufacturing, operational, or procedural causes and/or trends behind a particular non-compliance event.

4.3. Table 3 – Design and Manufacturing Changes

Depending on the changes in fuel design and in the manufacturing process, the impact on fuel performance will vary. *Table 3 – Design and Manufacturing Changes* provides CSNC staff a

[2] The use of the sited letter [3] to Darlington NGS is used exclusively as a reference to the reporting template (table). Similar letters pertaining to the same issue were sent to all licensees.

summary description of all design and manufacturing changes in the reporting year, and more importantly, a qualitative and quantitative description of the corresponding impact on fuel performance.

4.4. Table 4 – Inspection Results

Table 4 – Inspection Results is separated into two groups: i) inspection results of fresh fuel and ii) of irradiated fuel, the latter of which consists of in-bay inspections and post-irradiation examinations (PIE). CSNC staff examines inspection results to gauge the extent of an NPP's inspection programme and to determine if there any common phenomena between NPPs impacting the condition of the fuel pre- and post-discharge. This, in turn, allows CNSC staff to gain a better understanding of the nature of the artefact(s) impacting fuel performance. Specifically, CSNC staff seeks to determine if any observable trends with respect to the fuel condition pre- and post-discharge can be traced back to a design, manufacturing, operational, or procedural cause, and tries to determine if such a cause is plant specific or endemic to several or all NPPs.

4.5. Table 5 – Fuel Defects

In the context of *S-99 6.4.10*, fuel defects are separated into two groups: i) confirmed fuel defects and ii) suspected fuel defects. *Table 5 – Fuel defects* summarises the trends in the occurrence of fuel defects in addition to tracking event details for each defect occurrence. Two of the event details that are tracked are the method of detection and the actions taken to identify the defect location. CNSC staff use this information as an indicator in evaluating the effectiveness of various defective fuel detection methods.

4.6. Table 6 – Additional Information Relevant to Fuel Performance

Table 6 – Additional information relevant to fuel performance provides CNSC staff insight into NPP events or operations that may have an impact on fuel performance, including the irradiation of special or modified fuel designs, the occurrence of abnormal plant transients that may affect fuel performance, and a description of OPEX from other stations that may be relevant to fuel performance at the NPP in question.

5. INTEGRATION OF REVIEW RESULTS WITHIN THE CNSC FUEL OVERSIGHT PROGRAMME

The information compiled by CNSC staff in the review of the annual *S-99 6.4.10* is organised in such a manner so as to reflect significant trends and/or indicators with respect to fuel performance. Significant trends and events are reviewed and brought to the attention of the CNSC Regulatory Programme Director, who determines the appropriate regulatory response. Findings are also used to determine the regulatory efforts required for each station in the next fiscal year. For example, poorly performing plants are scheduled for reactive Type I or Type II inspections depending upon the nature of the findings.

The compiled information is also input into the *CNSC Staff Integrated Safety Assessment of Canadian Nuclear Power Plants*. The information depending upon its nature is integrated into the Operating Performance, Performance Assurance, or Design and Analysis safety areas within the report, thus forming part of the overall plant performance rating.

6. IMPROVEMENTS TO THE S-99 6.4.10 REPORTING TEMPLATE

The current reporting template of *S-99 6.4.10* has proven to be a valuable tool to CNSC staff in gaining a clear picture of NPP fuel performance. However, this does not preclude the possibility of introducing changes and improvements in an effort to enhance and streamline the current reporting template.

The following are some of the improvements that CNSC is considering as part of an update to *S-99 6.4.10* reporting template. CNSC staff will hold formal meetings with stakeholders on changes to the templates before any permanent changes are made.

6.1. Streamline the Current Reporting Template

CNSC staff acknowledges that the current reporting template contains certain redundancies that can be eliminated and information requirements that can be framed in differently or as part of a broader context, which can be more effective and less cumbersome for NPP licensees. This work is on-going, and CNSC staff anticipates communicating with licensees throughout the process.

6.2. Coolant Activity Data for the Reporting Year

Currently, I-131 is the only fission product for which the coolant activity concentration is measured at all NPPs. It would be informative for CNSC staff to have the coolant activity concentration data (graphs) included in *S-99 6.4.10* for review. This would give a clearer picture of the in-core defective fuel condition for the reporting year, especially when the data is presented in conjunction with reactor power. Reactor power data corresponding to coolant activity measurements is an excellent indication of fuel performance as it provides a timeline for the defect occurrence in both steady-state and transient conditions.

Radioiodine chemistry inhibits any tangible defective fuel analysis during steady-state conditions [4]. The inclusion of noble gas coolant activity measurements (i.e., Xe-133 and Kr-88) in *S-99 6.4.10* would be ideal for non-transients event review [4]. Notwithstanding the fact that not all stations have viable noble gas measurement capabilities, it would be in the best interest of the NPP to include this data in order to demonstrate optimum defective fuel performance.

6.3. Bundle Inspection Logic

Currently, NPPs are required to inspect a minimum of 20 bundles per year. This number is applied to all NPPs regardless of their core size, health, and status. Thus, CNSC staff is currently considering modifying the minimum number of bundles inspected to be more risk informed.

The logic behind the selection of certain bundles for inspection should be articulated, especially in the context of identifying channels that have become increasingly affected by the effects ageing. Moreover, the time at which inspections are initiated should reflect the fuel performance and core health for the entire reporting year and not just for a portion of that year.

It is proposed that the number of inspections should be core dependent and based on the following factors:

i. The number of defects and/or anomalies discovered in the previous year.

ii. Amount of fuel used: a consistent sampling frequency should be maintained, with smaller reactors inspecting the same percentage of bundles as larger reactors.

iii. The age of the core: older cores are susceptible to incurring more defective bundles due to changes in operating conditions and margins.

iv. Time dependence: justification for inspection as either event-based or statistically mandated in order to reflect fuel performance and core health for the entire year.

7. CONCLUSION

The CNSC Fuel Oversight Programme is one of the programmes that make up the overall CNSC compliance programme. CNSC staff use the Fuel Oversight Programme to ensure that licensees comply with fuel related licensing conditions, to ensure licensees operate their fuel within the design specifications, and to monitor the core health of the reactor fleet.

S-99 6.4.10 is an important component to this programme and has proven useful in the evaluation of fuel performance and core health. It also provides important information and data which are used as input into the annual *CNSC Staff Integrated Safety Assessment of Canadian Nuclear Power Plants*. CNSC staff will continue to evaluate and improve the effectiveness of the reporting template and anticipates communicating with NPP licensees throughout the process.

APPENDIX A. S-99 6.4.10 REPORTING TEMPLATE

Table 1 – Summary of fuel performance

1 – Summary *State the overall conclusions from the annual evaluation of fuel performance*
1.1 – Summary of compliance programme *Briefly describe the programmatic activities in place to verify fuel performance.*
1.2 – Summary of surveillance results *Briefly summarise any events of notice related to fuel performance. Discuss any changes in fuel performance compared to previous years.*
1.3 – Summary description of surveillance capabilities *Briefly describe the status of expertise and tools required to monitor and evaluate fuel performance, including any changes in inspection practices.*

Table 2 – Fuel operating conditions

2 – Fuel operating conditions *State the conclusions regarding conformance of fuel performance to applicable limits.*					
2.1 – Power and burnup envelope: *Characterise compliance to power and burnup limits and the power-burnup overpower envelope.*					
Provide the following details for each case of non-compliance: (Attach figures of actual maximum power-burnup envelopes vs. the reference overpower limit cure for each unit.)					
Date of non-compliance	Unit, channel, bundle	Bundle power [kW]	Burnup [$MWh \cdot kgU^{-1}$]	Cause of non-compliance	Results of in-bay inspections and PIE (if applicable)
2.2 – Coolant flows *Characterise compliance to flow limits (including cross-flow).*					
Provide the following details for each case of non-compliance:					
Date of non-compliance	Unit, channel, bundle	Duration [h]	Flow [$kg \cdot s^{-1}$]	Cause of non-compliance	Results of in-bay inspections and PIE (if applicable)

2.3 – Mechanical loads *Characterise compliance to mechanical load limits (including impacts and loads during fuelling operations).*				
Provide the following details for each case of non-compliance:				
Date of non-compliance	Unit, channel, bundle	Maximum load [kN]	Cause of non-compliance	Results of in-bay inspections and PIE (if available)
2.4 – Degraded cooling conditions *Characterise compliance to limits ensuring adequate fuel cooling (including during fuelling operations).*				
Provide the following details for each case of non-compliance:				
Date of non-compliance	Unit, channel, bundle	Duration [s]	Cause of non-compliance	Results of in-bay inspections and PIE (if available)

2.5 – Coolant chemistry *Characterise compliance to coolant chemistry limits.*		
Provide the following details for each case of non-compliance:		
Date of non-compliance	Cause of non-compliance	Assessment of impact on fuel
2.6 – Operational events *Describe any events that may have imposed condition affecting safe fuel performance.*		
Provide the following details for each event:		
Date of event	Even characterisation	Assessment of impact on fuel

Table 3 – Design and manufacturing changes

3 – Design and manufacturing	
Describe any changes in fuel design, manufacturing process, and manufacturing QA requirement.	
3.1 – Design changes	
Date	*Describe design modifications or concession applications and impact on fuel performance.*
3.2 – Manufacturing changes	
Date	*Describe changes in manufacturing process or QA requirements and impact on fuel performance.*

3.3 – Manufacturing occurrences	
Date	*Describe any unintended deviations in manufacturing process that may have impact on fuel performance.*

Table 4 – Fuel inspection results

4.1 – Fresh fuel inspection *Summarise results of fresh fuel inspections, in particular document instances of fuel being quarantined due to:*			
Phenomena/ occurrence	Number of bundles in the reporting year	Additional characterisation of inspection results (i.e., causes, follow-up, impact, quarantine)	Number of bundles in the previous 5 years
4.1.1 – Visibly damaged bundles, including scratches, nicks, or pitting			
4.1.2 – Weld defects			
4.1.3 – Foreign material inclusions			
4.1.4 – Interlocked spacer pads			
4.1.5 – Incorrect serial numbering			
4.1.6 – Other unusual observations			
4.2 – Irradiated fuel in-bay inspection *Describe the inspection plan; explain significant deviations form the planned scope of inspection.*			
In addition, provide the following information:			
Planned for inspection	Total number inspected during the reporting year	Total number discharged and inspected during the reporting year	Number of bundles inspected during the previous 5 years

Phenomena/occurrence	Number	Number in previous 5 years
4.2.1 – Broken assembly welds		
4.2.2 – End-plate cracks		
4.2.3 – Bundles with significant end-plate damage, wear, or deformation		
4.2.4 – Debris fretting marks		
4.2.5 – Observable element bow		
4.2.6 – Observable sheath strain		
4.2.7 – Significant or abnormal bearing pad wear		
4.2.8 – Bundles with bearing pad crevice corrosion		
4.2.9 – Bundles with excessive oxide indications		

4.2.10 – Bundles with crud deposition		
4.2.11 – Bundles with any other unusual indications		
4.2.12 – Summarise the results of irradiated fuel in-bay inspections		
Discharge date	Unit, bundle, and bundle serial number	Phenomena/occurrence

4.3 – Irradiated fuel post-irradiation examination *Describe the objectives of each post-irradiation examination.*
For each examination, provide the following information:

Unit	Bundle	Element	Date discharged	Date inspected

4.3.1 – Root cause of defect			
4.3.2 – Sheath strain measured		***Sheath strain limit***	
4.3.3 – Element bow measured		***Element bow limit***	
4.3.4 – End-plate deformation measured		***End-plate deformation limit***	
4.3.5 – Fission gas released measured		***Fission gas release limit***	
4.3.6 – Oxide layer thickness measured		***Oxide layer thickness limit***	
4.3.7 – Surface deposits: thickness and composition			
4.3.8 – Additional observations			
4.3.9 – Summarise results of post-irradiation examination			

Table 5 – Fuel defects

5.1 – Confirmed fuel defects *Summarise trends in occurrence of fuel defects.*			
Number of confirmed defects		Number of confirmed defects in previous 5 years	
For each confirmed defect, provide the following information: (Attach photographs)			
Unit, bundle, element	Date detected	Date discharged	Date inspected
5.1.1 – Channel		***5.1.2 – Bundle position in channel***	
5.1.3 – Bundle burnup		***5.1.4 – Bundle power***	

when defected		***when defective***	
5.1.5 – Method of detection			
5.1.6 – Characterise extent of sheath damage			
5.1.7 – Characterise root cause of defect			
5.2 – Suspected fuel defects			
Summarise trends in occurrence of suspected fuel defects. Attach graphs of radiochemistry measurements (activity of I-131, I-133, Xe-133, Kr-88, and other fission products in the PHTS) for each unit for the time period when the suspected defect occurred.			
Number of confirmed defects		Number of confirmed defects in previous 5 years	
For each suspected defect, provide the following information:			

Unit	Channel	Dates of observation

5.2.1 – Method of detection	
5.2.2 – Actions to identify defect location	

Table 6 – Additional information relevant to fuel performance

6.1 – Special irradiation *Describe any irradiation of a fuel design other than used for routine fuelling.*		
Unit	Channel	Date
6.2 – Plant transients *Describe any unusual plant transients that may have had an effect on fuel performance*		
Unit	Channel	Date
6.3 – OPEX from other stations *Describe any irradiation of a fuel design other than used for routine fuelling.*		

Station	Date

REFERENCES

[1] CNSC Position Statement PS-94G02, Rev. 01, “Generic Action Item 94G02 ‘Impact of Fuel Condition on Reactor Safety’”, January 1999.

[2] Canadian Nuclear Safety Commission Regulatory Standard S-99, “Reporting Requirements for Operating Nuclear Power Plants”, March 2003.

[3] Letter, G.R. Schwarz to W. Robbins, “Darlington NGS – Annual Reports on Fuel Monitoring and Inspection Program”, August 31, 2007, E-DOCS-#3075629.

[4] A. El-Jaby, B.J. Lewis, W.T. Thompson, F.C. Iglesias, and M. Ip, “A general model for predicting coolant activity behaviour for fuel-failuremonitoring analysis”, *J. Nucl. Mater.* **399** (2010) 87.