Response to
"Request for Information: CANDU 3 Fuel
Performance Acceptance Criteria"

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1. INTRODUCTION

In response to a request for additional information (RAI) from the U.S.NRC on "CANDU3 Fuel Performance Acceptance Criteria", a brief write up has been prepared. This response is largely based on information currently available to the U.S.NRC.

It should be noted that although the information on fuel failure being presented at this time does not follow the Standard Review Plan (SRP) Section 4.2 (Reference 3) format in detail, we believe it covers the substance of information needed by the U.S.NRC to understand fuel performance criteria used in the design and analysis of CANDU 3. Furthermore, we believe this format should be satisfactory for the pre-application review of CANDU 3, currently being conducted by the U.S.NRC. When formal application is made for Design Certification, the Safety Analysis Report will be formatted in accordance with SRP Section 4.2, Fuel System Design.

The information contained in Appendix A of Reference 2 should be used in conjunction with the information presented in this response to understand the CANDU 3 fuel performance acceptance criteria.

As stated in section 4.2 of the Standard Review Plan (Reference 3), the objectives of the fuel system safety review are to provide assurance that (a) the fuel system is not damaged as a result of normal operation and anticipated operational occurrences; (b) fuel damage is never so severe as to prevent control rod insertion, when it is required; (c) the number of fuel rod failures is not underestimated for postulated accidents; and (d) coolability is always maintained. The following sections describe the current status of the CANDU3 fuel with respect to the above four objectives.

2. DESCRIPTION

This response to the RAI is based on information and references currently available to the U.S.NRC. This brief description explains where the CANDU fuel performance acceptance criteria are presented in these references.

(a) Standard Review Plan, Objective (a) - Normal Operation:
Reference 1 is a collection of three papers dealing with CANDU fuel design and performance. These papers cover topics in current fuel design concepts, influence of fabrication variables on fuel performance, as well as information on power reactor experience. It is shown that CANDU fuel is well proven, with 99.9% of the more than 900,000 bundles (Reference 4) irradiated in commercial reactors operating as designed. It should be mentioned that Reference 1 covers all of the types of damage criteria specified in Section II.A.1 of the U.S.NRC's SRP Section 4.2 (Reference 3), which includes: stress/strain limits, fretting, oxidation/hydriding/crud build up, and effects of fission gas pressure.

(b) Standard Review Plan, Objective (b) - Prevention of Control Rod Insertion:

In a CANDU reactor, shutdown rod insertion may be impeded, only by fuel channel failure. In the case of combined pressure tube and calandria tube failures, either shutdown system acting alone has sufficient depth to compensate for any positive reactivity effects so that the reactors can be safely shutdown and maintained in the sub-critical state (Reference 5, Section 14.4.8).

The shutoff rod guide tubes of shutdown system no.1 (SDS1) are perforated and therefore prevent their collapse from the hydrodynamic forces. The safety assessment shows that local damage to shutoff rods may occur in the region surrounding a ruptured fuel channel. However, the distribution of the rods throughout the core does not reduce the system performance below its required capacity. Thus, although some of the shutoff rod guide tubes may be damaged, SDS1 will have sufficient reactivity insertion rates and depth to be effective (Reference 5, Section 14.4.8).

It is important to note that in a CANDU the shutoff rods are inserted in the low pressure calandria vessel, in contrast to PWR's, where the shutoff rods are inserted in the high pressure reactor vessel. This, of course, means that the possibility of a rod ejection accident does not exist in a CANDU reactor .

In addition to SDS1 (shutoff rods), the CANDU reactor has an independent and redundant poison injection shutdown system (SDS2). The operating pressure of SDS2 is much higher than the normal calandria pressure. The injection nozzles in the core are fed through piping designed to withstand any pressure waves from a fuel channel failure. Even if a nozzle is fractured, the flow of poison would not be prevented (Reference 5, Section 14.4.8).

The availability of SDS2 provides additional assurance that fuel or channel failure will not interfere with the ability to shutdown the reactor in an emergency.

(c) Standard Review Plan, Objective (c) - Fuel Failure During Accidents:

Several assumptions were made in the CANDU fuel analysis to ensure that the number of fuel rod failures is not underestimated for postulated accidents. Some of these assumptions are as listed below:

- It is important to note that a small or zero amount of damage is shown when ECCS is effective. But to ensure that the results are not underestimated, in the revised CANDU 3 Conceptual Safety Report, containment is assessed with half core free inventory release.

- During a large LOCA and loss of ECC (LOECC) an assumption of partial loss of emergency coolant, such that a certain constant steam flow is available to every channel, results in the highest fuel temperature. These flows are chosen in the analysis such that the convective heat transfer is limited, while the heat production due to chemical reaction of steam with the sheath is maximized (Reference 2, Section 3.2.2.1).

- In order to understand the entire core behaviour during a postulated loss of coolant with loss of emergency core cooling, the analysis is performed by subdividing the core into six power groups. The thermal behaviour of each channel in a given group is

approximated by representing it with the maximum power channel of the group. Temperatures of some channels will thus be overestimated (Reference 2, Section 3.2.4.1).

- Some assumptions were made in an end fitting failure, which ejects fuel into the containment vault area, to simplify the calculations while overestimating the fuel temperatures and fission product releases. To calculate the convective heat transfer, the fuel is assumed to be surrounded by dry air. No credit is taken for heat transfer to water. In reality, some, if not all, of the fuel will be able to discard heat to water by nucleate boiling. Furthermore, no credit is taken for heat transfer from fuel to the surface on which it is lying (Reference 2, Section 3.2.4.2).

Some sections of Reference 6 are also relevant to the quantity of fuel rod failures in accident analyses, which are as follows:

- The criteria that are used to assess fuel breakup during a LOCA are:" In an accident....to protect against fuel breakup, it is ensured that the total stored energy in the fuel does not exceed the lower limit of the threshold for fuel breakup, conservatively taken as 836.8 J/g (200 cal/g)...." (Reference 6, Section 3.3.1, Paragraph 3, Page 3-11).

- There are specific types of accidents which are unique to CANDU reactors and have been extensively analyzed by AECL. These include a fueling machine incident in which bundles from one fuel channel are ejected into the vault, and a complete blockage of flow in one fuel channel. The methods and criteria for analyzing these accidents are presented (Reference 6, Section 3.4.4).

- There are criteria and methods in analyses of single channel fuel failures, including a postulated end fitting failure in which bundles are discharged into the vault area. Methods and criteria are presented which support the conclusion that in such incidents, the fuel will be adequately cooled (Reference 6, Section 3.5.4.2).

It should be noted that in case of breaks in large inlet pipes (inlet header break) the discharge of coolant is rapid, the stagnant flow period is short, the reactor is shutdown quickly, and heatup of the fuel is relatively small. CANDU 3 analysis indicates that even in the case of the most severe stagnation (critical break) when ECCS refill is effective, the fuel cladding temperature does not exceed 1200 C (2200 F) (Reference 7).

It is important to note that the safety system design ensures that only a limited number of fuel sheaths, if any, will fail because of a pipe break of any size at any given location in the heat transport system. Therefore, the above discussion shows that the number of fuel rod failures is not underestimated for postulated accidents.

A complete description of the assumptions and criteria used to determine the extent and consequences of fuel failure during postulated accidents is contained in Reference 2, Appendix A.

(d) Standard Review Plan, Objective (d) - Coolability:

In a CANDU reactor, coolability of the fuel is always maintained. In a large LOCA, if sheath failures occur, the fission product free gap inventory will be released to the coolant in the heat transport system. Further releases from the failed fuel are not expected as ECCS and forced flow from the heat transport pumps prevent further damage. Under these conditions, the fuel cladding temperature remains below the 1200 C (2200 F) limit of the U.S.NRC regulations. If the ECCS malfunctions or offsite power to the heat transport pumps is lost, any increase in fuel temperatures would be limited by the heat transfer to the moderator through the pressure tube and the calandria tube (Reference 2, Section 3.2.2.1)

The pressure tube design of the CANDU reactor exhibits some fundamental differences from pressure vessel reactors with respect to cooling of fuel during some loss-of-coolant scenarios. Separation of the coolant flow into multiple isolated parallel paths in the CANDU design leads to a situation where a very small quantity of fuel may be heated to high temperatures very quickly. On the other hand, this same separation

allows for an alternative means of cooling all of the fuel in the reactor when the primary coolant is lost. The moderator is capable of cooling the fuel sufficiently to avoid melting of uranium dioxide fuel pellets. CANDU3 analysis has determined, for all postulated breaks involving overheating and failure of a single channel, that fuel cladding temperature remains below the 1200 C (2200 F) limit of the U.S.NRC regulations and higher temperatures occur only locally for the single channel.

These scenarios, which deal with fuel in a single channel, are flow blockage and feeder stagnation break. In these cases, the flow in the affected channel may be stagnated, while the reactor continues operating at full power. The fuel in the stagnated channel overheats which may be followed by fuel channel damage. Fuel cladding temperature may go beyond 1200 C (2200 F). The acceptability of this accident scenario is based on a combination of its very low probability of occurrence, and the limited amount of fuel and fission products contained in a single channel. Also, there is a similarity between the feeder stagnation break scenario in CANDU and the rod ejection induced LOCA in Light Water Reactors (LWR). That is, local high fuel cladding temperatures could develop as a result of both scenarios (Reference 7, Section 3.4). Therefore, the CANDU feeder stagnation break could be considered as an exception to the general core fuel cooling requirements, as is done for the rod ejection accident in LWR's.

The cooling conditions when fuel is ejected into the vault area after an end fitting failure accident are satisfactory. The rapid discharge of high pressure coolant results in very wet conditions surrounding the fuel and hence good heat removal from the fuel. The discharge is expected to cause turbulent conditions in the vault bringing a fine mist of water to the fuel wherever it might be. The discharged water will lie on the surface where most of the fuel will probably be scattered. This will give some of the fuel good heat transfer to the water (nucleate boiling). It should be noted that the effect of an end fitting failure on the thermalhydraulics of the primary heat transport system is similar to that of a small break. The response of fuel and fuel channels, except for the affected channel, is also similar to that of a small break. Integrity of other channels is not threatened as the ECCS replenishes water lost from

the heat transport system. Fuel in channels other than the one with the damaged end fitting does not fail because of the accident (Reference 2, Sections 3.2.2.2 and 3.2.4.2).

Large LOCA coincident with los f Class IV power may also lead to fuel cladding temperatures higher than 1200 C (2200 F). First of all, it is important to note that Class IV power is alternating current power, which is available from the grid/turbine-generator, and serves as the primary power source to the station. The heat transport pumps are driven by Class IV power. For a large LOCA in a specific location and size range, if there is also loss of heat transport pump power, there are major impacts which include heatup of the fuel and pressure tubes, and slowdown of the core refill. It is important to note that, in this scenario ECCS is fully operational, since the ECC pumps are driven by the standby diesel generators (Class III power). For these conditions, cooling by the ECCS is uncertain (because this cooling partly depends on continued operation of the heat transport pumps), but the heat can be rejected to the moderator system. Although the 1200 C (2200 F) limit may be exceeded, the fuel and fuel channel remain in a geometry that permits cooling by the ECCS and / or moderator heat sink.

3. CONCLUSION

Based on the above information and references, the U.S.NRC has been provided with fuel performance acceptance criteria. These criteria are used to demonstrate how the major objectives of SRP Section 4.2 (Reference 3), mentioned in the introduction (section 1), are met.

REFERENCES

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2. J.W.D. Anderson, Editor, " The Technology of CANDU Source Term Calculation", TTR-384, AECL CANDU; 1992 July

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