BEST ESTIMATE SBLOCA ANALYSIS OF CANDU 9 SYSTEMS

PART II: CONTROL SYSTEM MODELLING

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Abstract

To quantify the uncertainty and seek a better understanding of small break loss-of-coolant-accident (SBLOCA) as a design-basis accident (DBA) of the CANDU 9 reactor system, the best estimate analysis approach is proposed. Due to the relatively long transient that needs to be simulated, the key component of the Best Estimate SBLOCA analysis is the accurate modeling of the control system. The detailed modeling of the reactor shut down system, Reactor Regulating system bulk power control and reactor step back routine, and Pressure and Inventory Control system are discussed Some preliminary results calculated by the code coupled between CATHENA and my Control System simulation code are also given at the end of paper.

1. Introduction

The small break loss-of-coolant-accident (SBLOCA) is a class of accidents whose break sizes are smaller than that of a single feeder guillotine rupture. As a design-basis accident (DBA), SBLOCA determines many of the safety-related operating and special safety system limits for the plant.

Historically, nuclear safety analyses of LOCAs adopted conservative methodologies, assuming that choosing conservative values of key parameters will ensure that the outcome of analysis would envelope those expected during a postulated accident. However, this stylized and bounding deterministic approach results in the reduction in operating margin. To quantify the exact margins to safety limits, the United States Nuclear Regulatory Commission (USNRC) has already revised its acceptance criterion for Emergency Core Cooling Systems (ECCS) response to allow for use of best estimate methods [1, 2]. The Canadian Nuclear Safety Commission (CNSC) has recognized that best estimate predictions of plant response, along with accurate assessments of uncertainties, is an acceptable alternative to more limiting and bounding analyses for demonstrating safety system response [1, 3].

A unique challenge for the best estimate analyses in SBLOCA is related to the length of the transients considered (spanning from 20 to 200s) wherein control system actions play an important role in determining the outcome of the event. Therefore, the accurate modelling of the control system is crucial in the analysis.

When a CANDU 9 reactor, which has two primary heat transfer loops, four main circulation pumps and four steam generators, is at power, the control systems that are functioning includes mainly: Reactor Regulating System (RRS) and Reactor Step Back Routine, Primary Heat Transfer System Pressure and Inventory Control System (PICS), Steam Generator Pressure and Level Control programme, Reactor shut down system control, and Emergency coolant injection (ECI) to both Primary Heat Transport and Secondary System. In the analysis for SBLOCA, the most important events related to safety are all located in the Primary Heat Transfer system and happening before ECI. Hence, only the RRS and Reactor Step Back Routine, PICS and the Reactor shut down system are modelled. The neutronic power response in this analysis is approximated by the point kinetics model; thus, no special power control in RRS is modelled.

All the control systems are modelled by coupling FORTRAN code to CATHENA. The flow chart that illustrates the control system code coupling and application can be shown in Figure 1.

Figure 1 Main Flow Chart

2. The Reactor Shut Down System Modelling

The CANDU 9 reactor has two independent shut down systems, SDS 1 and SDS 2. SDS 1 shuts down the reactor by inserting the shut off rods and dropping the absorber rods into the core; SDS 2 shuts down the reactor by injecting neutron absorbing solution, poison, into the moderator. The two systems have independent sets of trip parameters. SDS 1 is normally triggered first.

The reactor shut down simulation code monitors the trip parameters from the output of thermal-hydraulic and point kinetics calculation; and if pre-determined set point levels exceeding are detected a negative reactivity insertion table will be put into point kinetics calculation to simulate the reactor shut down.

Due to the characteristic of the SBLOCA accident and point kinetics approximation on reactor physics side of the analysis, not all trip parameters need to be considered. Table 1 and 2 list all the trip parameters that are modelled in my code.

Trip Parameters	Set Point
High HT Pressure	10700 [kpa(a)]
Low HT Flow	a) at power > 0.7FP, set point = 0.7 (Nominal Flow)
High Power	1.26 FP
High Log-Rate	15 %FP/s
Low Pressurizer Level	a) at power > 0.7FP, set point = 2.5m,
Low HT Pressure	a) at power > 0.7FP, set point = 8600 kpa(a)

Table 1 SDS 1 Trip Parameters

Trip Parameter	Set Point
High HT Pressure	11700 [kpa(a)]
Low HT Flow	a) at power > 0.7FP, set point = 0.7 (Nominal Flow)
High Power	1.17 FP
High Log-Rate	15 %FP/s
Low Pressurizer Level	a) at power > 0.7FP, set point = 2.0m,
Low HT Pressure	a) at power > 0.7FP, set point = 8300 kpa(a)

Table 2 SDS 2 Trip Parameters

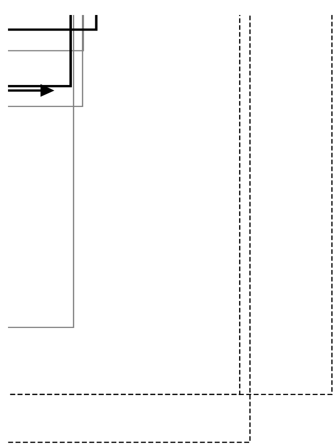

Figure 2 RRS Modules Block Diagram

3. The Reactor Regulating System (RRS) and Reactor Step Back Routine Modelling

The Reactor Regulating System (RRS) is an integrated digital computer programme that runs in the digital control computers (DCC) of the reactor unit. The step back routine is also a digital computer programme that reduces the power quickly due to some ill conditions detected in the operation. Since only bulk power control is modelled, the RRS simulation code modelled is made up of following modules: Demand Power Routine, Set Back Routine and Regulating programme for control of the reactivity devices. A RRS module block diagram can be shown in Figure 2, when the effects of Reactor shut down system and Reactor Step Back routine are also presented.

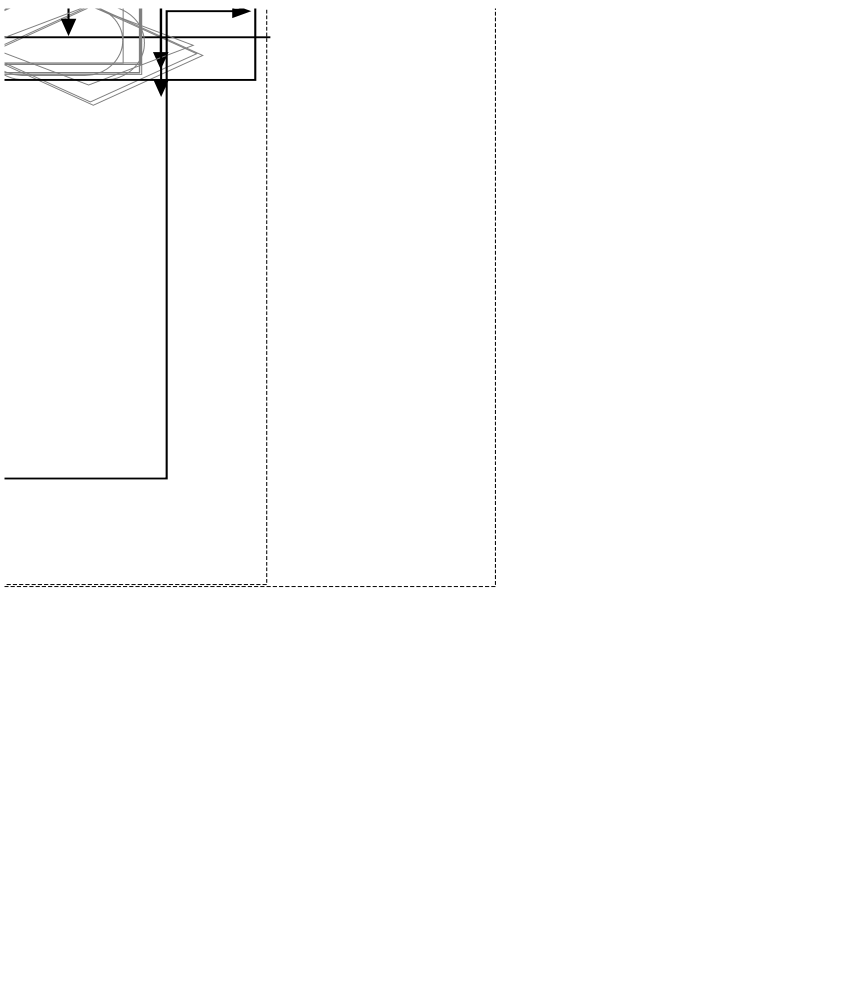

Figure 3 the Demand Power Routine Flow Chart

3.1 The Demand Power Routine

The Demand Power is the required reactor power level from a power set point. The Demand Power Routine calculates the Demand Power and the permissible change rate it. A power error is determined based on the difference between measured power and demand power as well as the difference between the rate of power change and the permissible power change rate. It is the control parameter output from the program for subsequent calculations for the demand to the reactivity devices. The Demand Power Routine itself is made up of two segments, a slow program which runs at every 2s and a fast program which runs at every 0.5s. The slow program calculates the change in power demand. The fast program computes the demand power, demand power change rate, and effective power error. Figure 3 is the float chart of the Demand Power Routine.

3.2 The Set Back Routine

A set back as part of RRS initiated when abnormal conditions are detected in the station operation. Reactor power is to be reduced until the abnormal station operating condition is cleared or power has reached a targeted value.

Set Back	Initiating Condition	Clearing Condition	Set Back Rate in (fracFP/s)	Set Back End Point (fracFP)
High Local Channel Power	>110%	<110%	-0.001	0.6
High Steam Generator Pressure	>5421 kPa	<5251 kPa	-0.005	0.11
High Pressurizer Level	>7.10 m	<7.00 m	-0.001	0.02

Table 3 Step Back Parameters

The set back routine monitors a number of station plant parameters and compares them with their corresponding set points. If a set point is exceeded and current reactor power is higher than the targeted set back end point power, a set back is initiated. The reactor demand power is to be decreased at a specific rate calculated by the Demand Power Routine. The Set Back parameters that can be related to the SBLOCA analysis are listed in Table 3.

3.3 The Regulating Programme for Control of the Reactivity Devices

The reactivity device positions are illustrated in Figure 4. [5]

Based on the power error calculated in the fast program of the demand power program, the Reactor Regulating System program calculates the demand to the various reactivity control devices so that reactor power is maneuvered to or maintained at the desired level.

The systems modelled are light water zone controllers and mechanical control absorber rods. The systems that are not modeled are adjustor rods, since it is for special power control only. The flow chart of entire reactivity device regulating system is shown in figure 5.

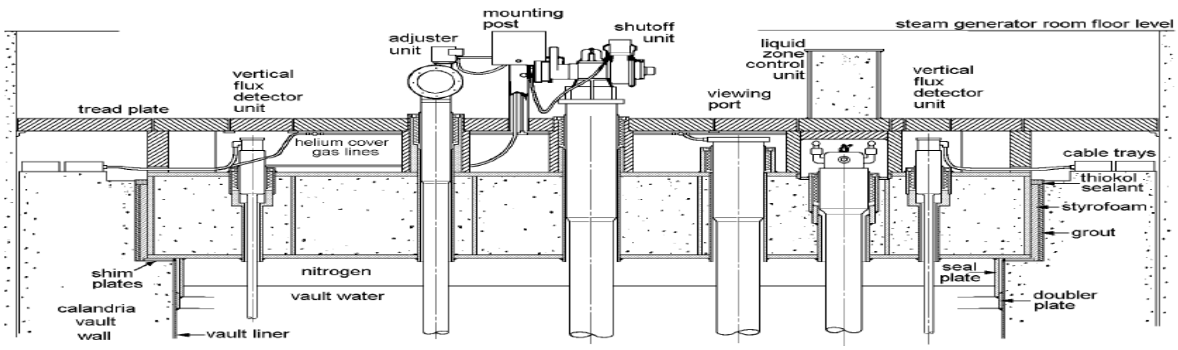

Figure 4 Reactivity Devices in the Core

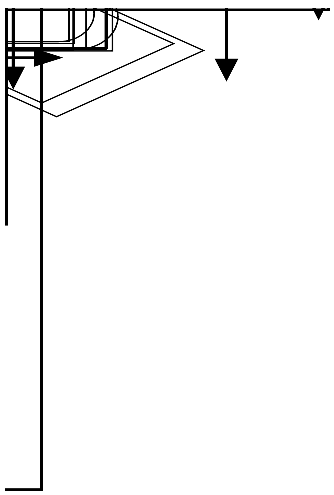

Figure 5 Reactivity Device Regulating System

3.3.1 Liquid Zone Controller

Light water zone is controlled by the liquid zone valve based on the Power Error. The valve opening is governed by the following second order equation

$$\frac{d^2(S_Z)}{dt^2}+2\zeta\omega\frac{d(S_Z)}{dt}+\omega^2(S_Z)=\omega^2(S_{ZD})$$

Where S_{zD} is the demand zone valve opening. It is proportional to the power error. The reactivity change rate then can be determined based on zone valve opening.

3.3.2 Mechanical Absorber Rods

The four Mechanical Absorber (MCA) Rods are grouped into two sets and are normally fully withdrawn from the core. As they are inserted neutron flux is absorbed and power is reduced. The MCA Rods are used for reactor power control in two ways. They are driven at a control speed in or out of the core to provide additional reactivity change to supplement the reactivity from the zone controllers when more rapid control of the reactor bulk power is required by the RRS. Or when there is a reactor step back in progress the rods are dropped rapidly into the core under gravity to rapidly decrease in reactor power. The step back condition overrides the drive demand from the Reactor Regulating System.

In the driven mode, the MCA rods motion and speed are controlled based on both power error and LZC level.

3.4 The Step Back Routine

In order to reduce power quickly due to some specific conditions detected in the unit operation, MCA rods will drop controlled by the Step Back Routine. The Step Back Routine monitors specific plant parameters and issues demand to drop the four mechanical control absorbers when one or more of the parameters are out of limits. When the power reaches the suitable power level or the Step Back condition is cleared, the MCA rods will be stopped

The Step Back parameters modelled for the SBLOCA analysis are listed in table 4.

Step Back Parameter	Initiating Condition	Target Power
Reactor Trip	SDS1 or SDS 2 tripped	0.0
High HT Pressure	HT ROH pressure > 10301 kpa(a).	0.005 Full Power
High Log Power Rate	Log Power Rate > 6.91%/s	0.0

Table 4 Step Back Parameters

4. The Primary Heat Transfer Pressure and Inventory Control System

The control systems related to the Primary Heat Transfer systems include pressurizer pressure and level control, bleed condenser pressure and level control, feed and bleed valve control, PHT system liquid relief valve control, and D2O purification circuit control valve control. Among them, the pressurizer pressure and level control, the bleed condenser pressure control, and feed bleed valve control combined as PICS are important in the SBLOCA analysis.

4.1 Pressurizer Pressure Control

PHT pressure is controlled by the pressurizer heaters and steam bleed valve. If the pressure is lower than the set point, the heaters will add heat to the vapour in the pressurizer thus increase the pressure. If the pressure is higher tan the set point the steam bleed valve will open to bleed vapour in the pressurizer into D2O tank to reduce the pressure.

4.2 PHT Inventory Control

The inventory is controlled by the PHT feed and bleed valves based on the water level in the pressurizer as an indication on the amount of inventory in the system. The bleed valves are also controlled based on the bleed condenser pressure.

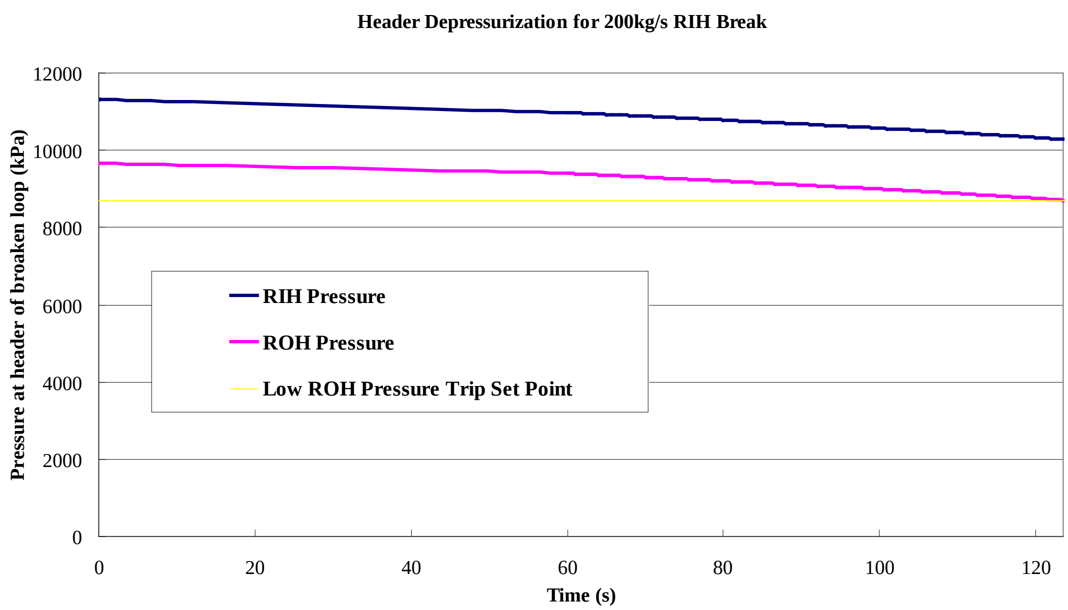

Figure 6 Header Depressurization for 200kg/s Break of Coupled Simulation

5. Preliminary Results

The preliminary results calculated by the code coupled between CATHENA and my Control System simulation code shown from Figure 6 to Figure 9.

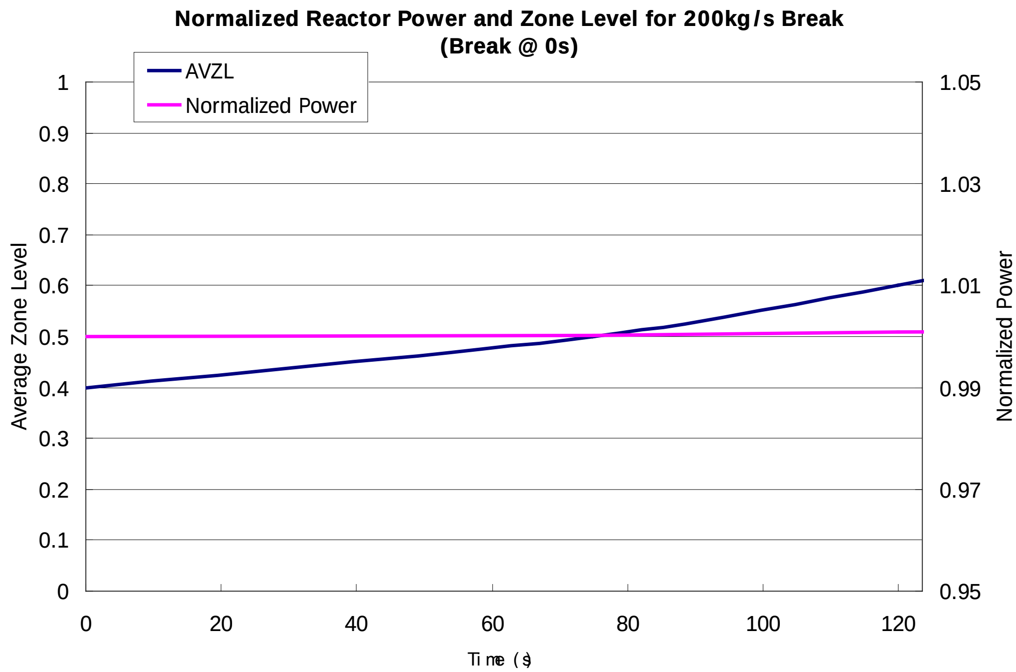

Figure 7 Power and Zone Level for 200kg/s Break of Coupled Simulation

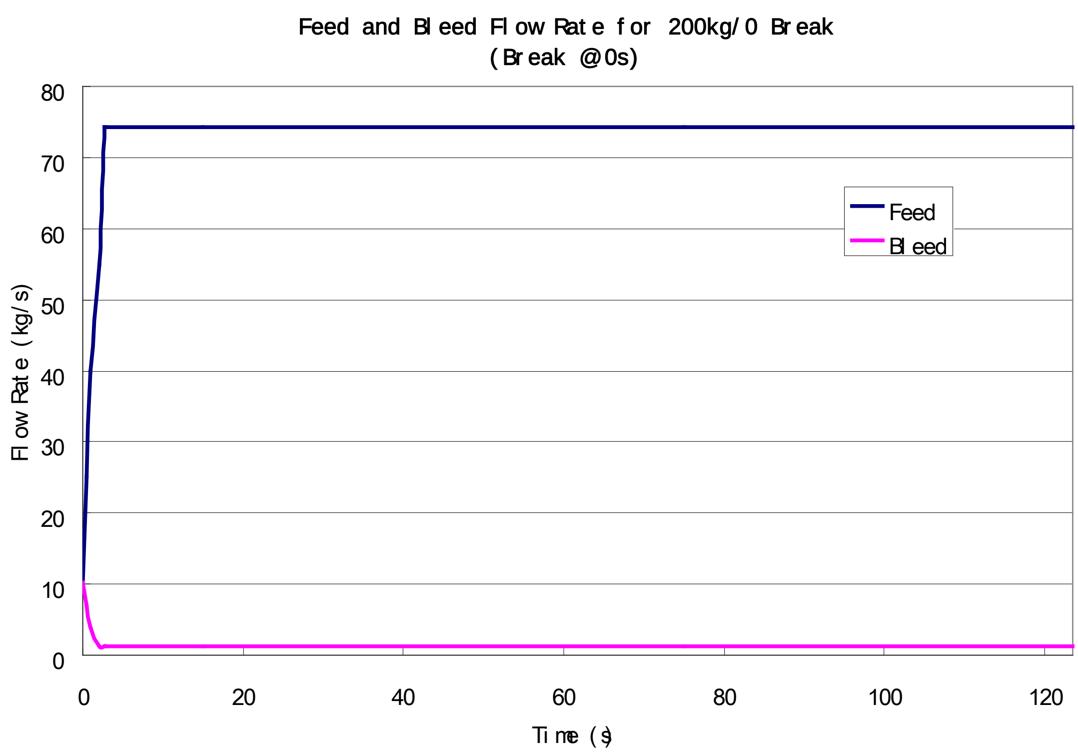

Figure 8 Feed and Bleed Flow for 200kg/s Break of Coupled Simulation

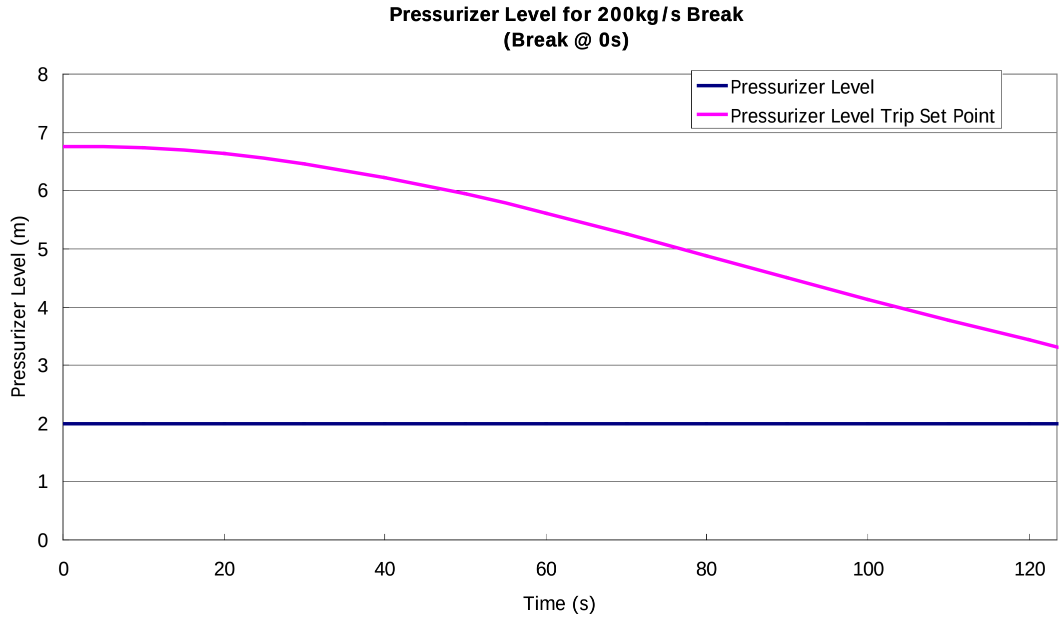

Figure 9 Pressurizer Level for 200kg/s Break of Coupled Simulation

Acknowledgement

This work is supported by a grant from the University Network of Excellence in Nuclear Engineering (UNENE). The author would also like to thank Atomic Energy of Canada Limited (AECL) for providing the software.

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