STARTING UP A CANDU REACTOR

Abbreviated Step-by Step Procedure

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Introduction

The theoretical basis for operation of neutron chain reactors is very well established. During most of a power reactor's operating life, the chain reaction is self-sustaining at constant power (i.e. the system is 'critical'), with a very large population of neutrons present.

Before a reactor reaches its self-sustaining condition, each primary neutron (from some source independent of the neutron chain itself), if and when it causes a fissile atom to undergo fission, releases two or more neutrons that generate a 'cascade' of fission reactions. This cascade dies out in time, of course, because the reactor state is such that the cascade is less than self-sustaining.

As operating staff change the state of the reactor in the maneuver usually known as the 'approach to critical', or 'startup', the cascade of reactions that follow a single fission become longer. Hypothetically, it is possible for an operator to change the state of a reactor that momentarily contains no neutrons whatever, in such a way that the cascade following the introduction of the next neutron actually diverges, so that power production increases with time. Such an event is known as 'inadvertent criticality', whose consequences can be very serious. Dozens of accidents of this type have occurred over the past 50 years (insert ref. to Los Alamos compendium document).

CANDU power reactor designers and operators are fully aware of the need for caution in starting up power reactors. However, the open literature describing these established methods is quite sparse, especially with regard to the unique advantages in operability and safety that arise from the computer-driven Reactor Regulating System (RRS). The following text provides a general outline of one procedure appropriate for start-up of a CANDU 6 reactor. Actual operating procedures may vary from one operating organization to the next; further, such procedures include many more operating steps, checks, and verification requirements – simply because the whole power plant must be started up in harmony, and the reactor state is only one part of the whole plant state, albeit a very important part.

Prerequisites for a clear understanding of the following are a general knowledge of the components and systems of the CANDU 6, plus a comprehensive understanding of the operation of the RRS.

Part I – Procedure for Mature Reactor Core (Equilibrium Fuel Burnup)

The Part I startup procedure will be used during most of the reactor's operating life. This procedure requires several hours to execute because of the limited rate at which neutron poison can be removed from the moderator water.

Startup Steps – Part I

0. **State of system:** returning from Guaranteed Shutdown State after long outage, with reactor regulating system (RRS) in-service. Process systems available to support startup.
1. Check SDS1 and SDS2 in 'poised' state
2. Measure moderator poison concentration
3. Apply to Technical Unit for estimated plot of poison concentration vs power.
4. Verify RRS control action – request small power increase, note correct response of reactivity devices (ZCR, adjusters). Reduce power setpoint to its previous level
5. Request Shift Supervisor's permission to begin moderator poison removal (using the moderator ion exchange system) and power raising.
6. Start poison removal.
7. RRS will raise average zone level (AZL) to hold set power. When AZL reaches 65%, request a new power setpoint at double the current level. AZL will drop; when it reaches 20%, request RRS to 'Hold Power'. AZL will rise again. Repeat until power level reaches the new power setpoint.
8. Repeat Step 7 and plot actual power vs poison concentration (see data from Step 3)
9. On each repeat, the rate of rise (rate log signal) will increase. Reactor power approximately doubles its previous level at each step, so the level reached at each step increases by progressive powers of two.
10. As a self-sustaining chain reaction (criticality) is approached, at one stage the reactor power will double only by decreasing AZL from 65 to 20% once. The reactivity now is approximately 4 mk negative, less than the self-sustaining (critical) state. (When reactivity equals zero a self-sustaining state is achieved.) Request a new power setpoint at double the current level.
11. It will be seen that AZL no longer drops to 20% before the reactor power doubles.
12. Repeat Step 10 three times. Each time, the percentage decrease in AZL required to double the reactor power is less than in the previous step.
13. Stop removal of moderator poison. The reactor is now in a critical state.
14. Raise reactor power to approximately 0.1% of full power, and then carry out verifications of RRS performance, and other tests before raising power further.

$$reactor\ power = -\frac{C}{reactivity},$$

where C is a constant proportional to the external neutron source strength.

This relationship, valid when reactivity is less that zero, is used in combination with the computer-driven RRS to approach the self-sustaining (critical) state slowly and safely.

Part II – To be followed for a New Reactor, or for a Mature Reactor after Very Long Shutdown.

When the external neutron source strength is very low (in a CANDU reactor this state exists before the reactor is first started up, or after a very long reactor shutdown period. In both cases, the external neutron source strength is low because the gamma radiation level, which produces photo-neutrons by reaction with deuterium nuclei, is itself very low.

The state of "Low Neutron Source" results in the constant "*C*" in the previous equation falling to such a small value that the neutron detectors used to measure the neutron flux (proportional to "*reactor power*" in the previous equation) produce small and unreliable signals.

[Note that this is an unsafe state, because when the reactor is in this state is not possible to accurately measure the true value of the (negative) reactivity. For this reason, Canadian reactor operating procedures stipulate that a large amount of neutron poison must be dissolved in the moderator water under such conditions, to achieve the "Guaranteed Shutdown State" from which it is physically impossible to start the reactor without taking very deliberate steps to do so.]

To start up from the "Low Neutron Source" state, the plant operators must insert special "Startup Instrumentation" into the reactor, temporarily. These instruments (usually boron trifluoride proportional counters) are very sensitive, so that they can produce a reliable measurement of reactor power even at very low reactor power level. This instrumentation is connected temporarily to the SDS1 circuitry so that the startup signal will shut down the reactor rapidly, if such becomes necessary. Special arrangements are made so that the RRS will take safe action if the reactor power rises unexpectedly.

Startup Steps – Part II

0. **State of system**: RRS in "fail safe" – all process system reactivity devices in their maximum negative positions. Reactor in GSS state. Startup instrumentation installed and tested. SDS1 and SDS2 poised (**Note:** poising of these safety systems is a prerequisite step, to be complete before reactor startup is initiated). Trip setpoints (high count rate, high rate log, low count rate, loss of polarizing voltage) set correctly. Plant process systems available to support startup. All other prerequisite conditions satisfied.
1. Insert 'dummy' signal to RRS ion chambers. Verify that RRS is operational.
2. Request Shift Supervisor's permission to begin poison removal and power raising.
3. Begin poison removal and routine poison concentration sampling.
4. Plot poison concentration vs. count rate.
5. Plot count rate vs. time to estimate power-doubling time (**Note:** as the ion chamber signal increases, it will eventually predominate over the constant dummy signal.)
6. Maintain high count rate trip setpoint approximately one decade about current count rate.
7. Reduce purification flow rate as necessary to maintain power-doubling time of approximately 10 minutes.
8. When RRS ion chambers become operational (at about 10^{-7} % of full power) stop purification flow.
9. Remove "dummy" RRS signal and confirm RRS control of reactor power.
10. Disconnect startup instrumentation from SDS1, connect and test normal ion chamber signals.
11. Continue in accordance with the startup procedure as described in Part I.