CONSIDERATIONS FOR THE DEVELOPMENT OF A DEVICE FOR THE DECOMMISSIONING OF THE FUEL CHANNELS IN THE CANDU NUCLEAR REACTOR

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Abstract: *As many nuclear power plants are reaching their end of lifecycle, the decommissioning of these installations has become one of the 21st century's great challenges. Each project may be managed differently, depending on the country, development policies, financial considerations, and the availability of qualified engineers or specialized companies to handle such projects. The principle objective of decommissioning is to place a facility into such a condition that there is no unacceptable risk from the decommissioned facility to public health and safety of the environment. In order to ensure that at the end of its life the risk from a facility is within acceptable bounds, action is normally required. The overall decommissioning strategy is to deliver a timely, cost-effective program while maintaining high standards of safety, security and environmental protection. If facilities were not decommissioned, they could degrade and potentially present an environmental radiological hazard in the future. Simply abandoning or leaving a facility after ceasing operations is not considered to be an acceptable alternative to decommissioning. The final aim of decommissioning is to recover the geographic site to its original condition.*

Keywords: fuel, reactor, reactivity

1. INTRODUCTION

In Canada, AECL (Atomic Energy of Canada Ltd.) continues to evolve the basic CANDU design, focusing on improvements in economics, inherent safety characteristics and performance, while retaining the features of the earlier family of PHWR nuclear power plants. The stated goals include lower plant capital and oparating costs, plus reduced project schedules, through the use of improved design and construction methodes and operatonal improvements. The PHWR (Pressurized Heavy Water Reactor) concept is primarily represented by the CANDU design wicth is an acronym for CANada Deuterium Uranium. The CANDU system uses pressurised heavy water D2O as moderator and coolant and natural uranium as fuel in the form of uranium dioxide UO2.

The CANDU reactor design offers:

- Natural uranium fuel with on-line fuelling;
- High localization potential;
- Suitability for small and medium sized electric grids;
- Superior safety performance and economics;
- A proven design based on the highly successful CANDU 6 reactors.

While retaining the basic features of the CANDU 6 design, the reactor incorporates innovative features and stateof-the-art technologies that enhance safety, operation and performance.

2. NUCLEAR SYSTEMS OF THE CANDU REACTOR

The nuclear systems are located in the Reactor Building and the Service Building. These buildings are robust and shielded for added safety and security. Shielding is a protective barrier that reduces or eliminates the transfer of radiation from radioactive materials. The nuclear systems are comprised of:

- A heat transport system with reactor coolant, four steam generators, four heat transport pumps, four reactor outlet headers, and four reactors inlet headers. This configuration is standard on all CANDU 6 reactors;
- A heavy water moderator system;
- A reactor assembly that consists of a calandria installed in a concrete vault;
- A fuel handling system that consists of two fuelling machine heads, each mounted on a fuelling machine bridge that is supported by columns, which are located at each end of the reactor;
- Two independent shutdown systems, emergency core cooling system, containment system, emergency heat removal system and associated safety support systems.

3. BASIC DESCRIPTION OF THE CANDU REACTOR UNIT

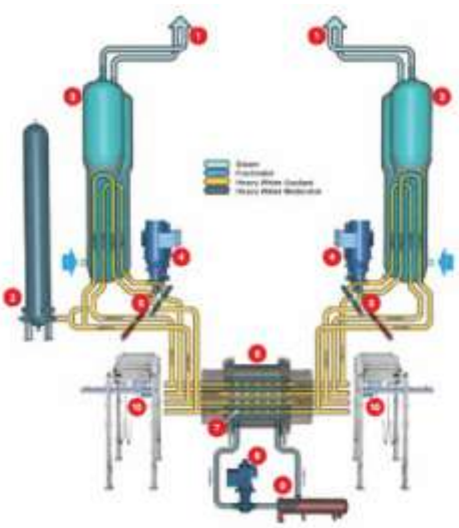

Figure 1 - Schematic illustration of a CANDU reactor core

1. Main steam pipes; 2. Pressurizer; 3. Steam generators; 4. Heat transport pumpes; 5. Headers;
6. Calandria; 7. Fuel; 8. Moderator pumpes; 9. Moderator heat exchangers; 10. Fueling machines.

A CANDU reactor utilizes controlled fission in the reactor core as a heat source to supply steam and electrical power.

The core of the nuclear steam supply system of a CANDU 6 power plant is a large cylindrical vessel called calandria. This vessel is filled with cool, low-pressure D_2O.

The vessel house has 380 horizontal tubes, loaded with natural uranium fuel bundles. That is shown schematically in Figure 1.

3.1. Reactor

The reactor comprises a stainless steel horizontal cylinder, the calandria, closed at each end by end shields, which support the horizontal fuel channels that span the calandria and provide personnel shielding. That is shown schematically in Figure 2. The calandria is housed in and supported by a light water-filled, steel lined concrete structure (the reactor vault) which provides thermal shielding. The calandria contains heavy water (D2O) moderator at low temperature and pressure, reactivity control mechanisms.

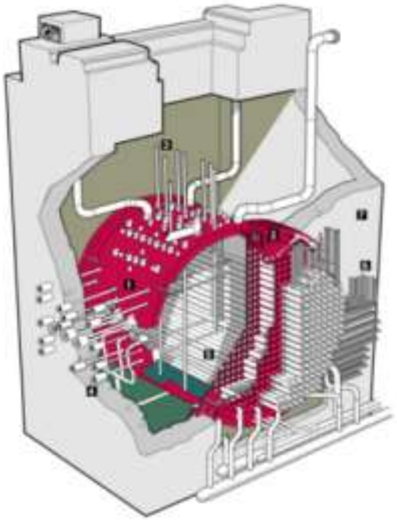

Figure 2 - Calandria and End Shield Assembly in Reactor Vault
1. Calandria; 2. Calandria end shield; 3. Shut-off and control rods; 4. Poison injection; 5. Fuel channel assemblies; 6. Feeder pipes; 7. Vault.

The CANDU is fuelled with natural uranium fuel that is distributed among 380 fuel channels. Each fuel channel with 6 meter long contains 12 fuel bundles.

General characteristics:
- Reactor type: PHWR;
- Moderator and Reflector: D2O;
- Coolant: Pressurized D2O;
- Fuel: Natural UO2;
- Refueling: On-power, bidirectional in adiacent fuel channel;
- Refueling direction: Coolant flow direction;
- Fuel cycle: Non recycle;
- Calandria length: 7,82 m;
- Calandria core length: 5,94 m;
- No. of fuel channels: 380.

3.2. Fuel channel

Fuel channels are one of the major distinguishing features of a CANDU reactor, and their reliability is crucial to the performance of the reactor. The following gives an outline of the key characteristics for CANDU fuel channels.

Each fuel channel consists of four major components: the pressure tube, the calandria tube, the annulus spacers and the end fittings (Figure 3).

The most important component of each fuel channel assembly is its 6 m long, 10 cm diameter zirconium alloy pressure tube that has a wall thickness of about 4 mm. As these tubes contain the high pressure and high temperature primary coolant, they must be adequately resistant to corrosion/erosion as well as to creep/growth under neutron bombardment.

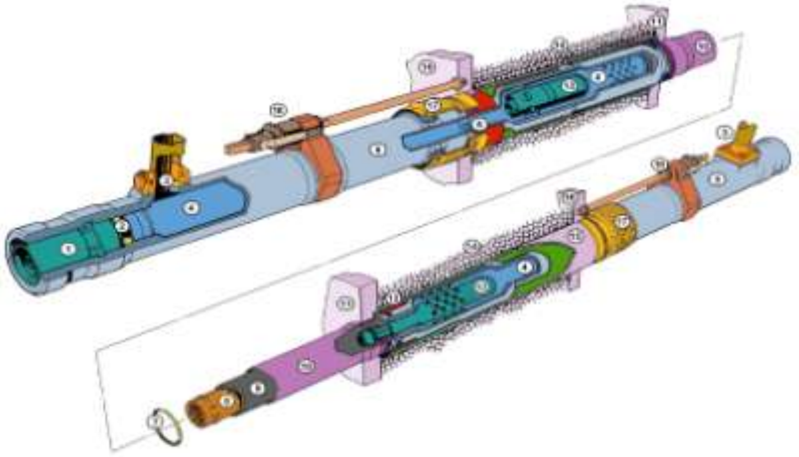

Figure 3 - Schematic illustration of a CANDU fuel channel

1. Channel closure - removable plug; 2. Closure seal insert - metal seal face for sealing the plug; 3. Feeder coupling - Grayloc seal, removable for channel replacement; 4. Liner tube - to guide fuel and shield plug into channel; 5. End fitting body - steel support tube for channel components; 6. Outboard bearings - end fitting assembly slides axially at one end, to allow for expansion; 7. Annulus spacer - separates pressure tube and calandria tube; 8. Fuel bundle - slides inside pressure tube, on bearing pads mounted on each bundle; 9. Pressure tube - holds pressurized coolant, and contains fuel bundles. (30-40 year life); 10. Calandria tube - supports the pressure tube, separates the moderator water from the pressure tube. Annulus between P/T and C/T contains low-pressure CO2; 11. Calandria tubesheet - supports and seals each calandria tube; 12. Inboard bearings - second of the two bearings which support the end fitting; 13. Shield plug - to reduce axial gamma and neutron streaming from the channel; 14. Endshield shielding balls - carbon steel balls and water for axial radiation shielding; 15. Endshield lattice tube - separates shield balls and water from end fitting, and carries annulus gas; 16. Fuelling tubesheet - supports end fittings, positioning assembly, bellows, and lattice tubes; 17. Channel annulus bellows - seals CO2 gas in annulus, allows for channel expansion; 18. Positioning assembly - holds one end of each channel in a fixed position. Position is adjustable.

Each pressure tube is located inside a calandria tube with the gas filled annulus between these two tubes insulating the high temperature primary coolant inside the pressure tube from the low temperature moderator outside the calandria tube that surrounds each pressure tube.

Four annulus spacers (spaced about a meter apart) keep each pressure tube separated from the calandria tube which surrounds it, while also allowing the calandria tube to provide sag support for the pressure tube. The annular space around the fuel channel, which is filled with dry CO2 gas, is connected to an annulus gas system that incorporates moisture detecting instrumentation to warn of leaks from either the pressure tube or the calandria tube.

The ends of each pressure tube are rolled into stainless steel end fittings to form a pressure tight, high strength joint. These end fittings provide a flow path for primary coolant between the fuel channel pressure tube and the rest of the primary heat transport system by having a feeder pipe attached to each end fitting.

General characteristics:
- Fuel channel lenght: 10,8 m (including end fitting);
- Reactor core coolant flow: 7,7 Mg/s;
- Reactor inlet/Outlet header temp: 266/312 °C;
- Reactor inlet/Outlet header press: 11,04/10,3 MPa;
- Calandria tube material: Zr-2;
- Calandria tube outside diameter: 132,3 mm;
- Calandria tube inside diameter: 129 mm.

3.3. Pressure tube

The pressure tube is located inside eath calandria tube. The pressure tube acts as a horisontal beam supported at each end by its attachement to end fitting, and at intermediate points by the surrounding calandria tube, via the annulus spacers (Figure 4). The principle functions of these pressure tubes, which are the major component of each fuel channel assembly, is to suport and locate the fuel in the reactor core and allow the pressurized heavy water primary coolant to be pumped through the fuel and remove its heat.

The design of the pressure tube is quite simple, consisting primarily of determination of its length, inside diameter and wall thickness. As the high pressure/temperature primary coolant is slightly alkaline, the prssure tubes must be adequately resistant to corrosion, as well as to creep and growth. For the temperature and pressure of the coolant, which vary along the length of the operating pressure tube, the following aspects are considered during the calculation of stresses and assessment of the fatigue life for the pressure tube:
- weight of fuel channel components, fuel and coolant;
- feeder pipe loads and torques;
- fueling machine loads;
- axial loads due to the fuel channel belows, fuel movement and end fitting bearing friction;
- annulus spacer loads;
- loads imposed during a seismic event; effects of tube initial bow, misalignment and end of design life sag and elongation.

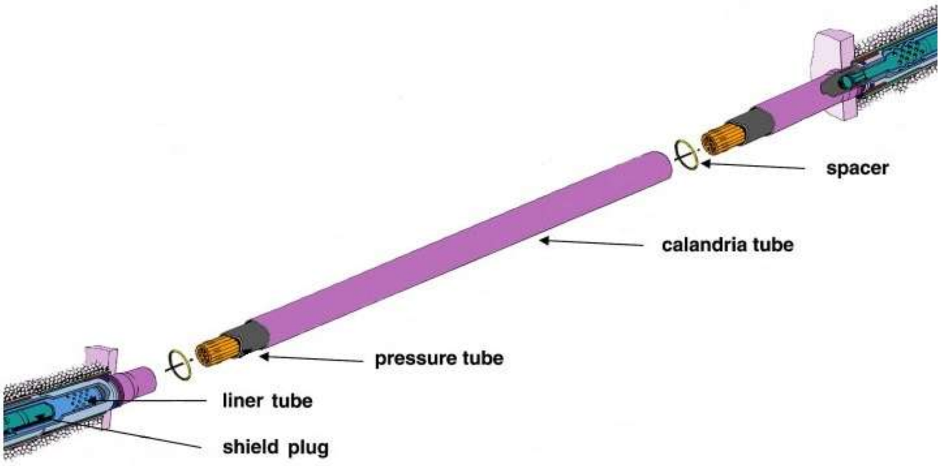

Figure 4 - Schematic illustration of a CANDU pressure tube

General characteristics:
- Material: Zirconium - 2,5% Niobium Alloy;
- Length: 6 m;
- Minimum inside diameter: 103 mm;
- Wall thickness: 4 mm;
- Maximum channel power: 6,5 MWt;
- Reactor outlet header quality: 3%.

3.4. Fuel bundle

The fuel channels are housed in a horizontal cylindrical tank (called a calandria) that contains cool heavy water (D2O) moderator near atmospheric pressure (Figure 5).

The reactor uses the proven 37-element natural uranium (NU) fuel bundle design. Each fuel element consists of a column of sintered NU fuel pellets inside a sealed zirconium alloy tube. The ends of a circular array of 37 fuel elements are welded to zirconium alloy support plates to form an integral fuel bundle assembly. Each fuel bundle is approximately 0.5 metres long and 10 centimetres in diameter, and weighs about 24 kilograms. Its compact size and weight facilitates fuel handling. There are no criticality concerns associated with the handling and transportation of fuel.

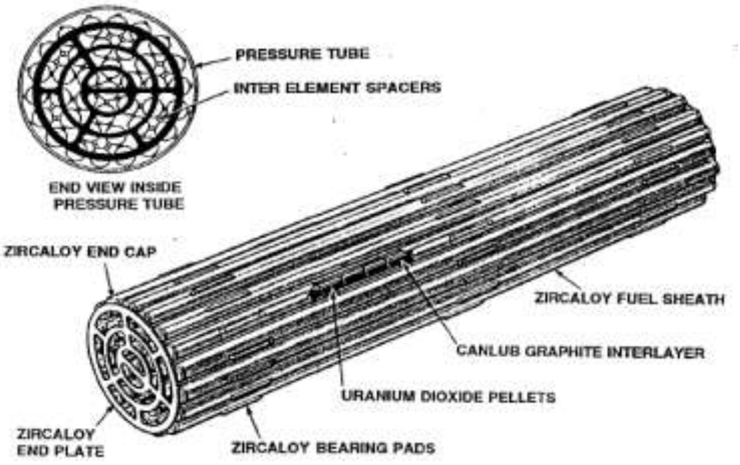

Figure 5 - Schematic illustration of a CANDU fuel bundle

General characteristics:

- Material:	Sintered and compacted pallets of natural UO2;
- No. fuel pellets/fuel pin:	36;
- No. fuel bundles/fuel channel:	12;
- No. fuel bundles/reactor core:	4560;
- Structure:	37 fuel pins bundle;
- Bundle lengh:	495,3 mm;
- Bundle diameter:	102,4 mm;
- Pin bundle diameter:	12 mm;
- Fuel bundle nominal power:	800 kW.

4. CONCLUSIONS

The design and the cofiguration characteristics of the fuel channel have to be considered in the design of the decommissioning device.

The geometrical sizes, configuration moving features, appropiates radiations protection materials which will be used were assesed.

As well a list of some ancilary equipments for the decommissioning device, subject of the project, ware drafted.

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