6th International Conference
ðComputational Mechanics and Virtual Engineering ð
COMEC 2015
15-16 October 2015, Braşov, Romania

CONSIDERATIONS REGARDING THE HORIZONTAL FUEL CHANNELS IN THE CANDU 6 NUCLEAR REACTOR. PART 1 - PRESENTATION OF THE FUEL CHANNEL

Constantin D. Stănescu [1], Gabi Roșca-Fârtat [2], Constantin Popescu [3]
[1]Polytechnic University, Bucharest, ROMANIA, prof_cstanescu@yahoo.com.
[2,3]Polytechnic University, Bucharest, ROMANIA, rosca_gabi@yahoo.com, puiu_2001uss@yahoo.com.

Abstract: *The aim of this study is to identify the fuel channel components based on which is made the installation into calandria of CANDU 6 nuclear reactor. The CANDU 6 is a 740 MW pressure tube reactor designed by Atomic Energy of Canada Limited (AECL) to provide safe and reliable nuclear power. The CANDU reactor design is based on the experience derived from preceding CANDU reactors and virtually every design feature of the latest CANDU reactor by ensuring its compliance with the latest Canadian nuclear regulations and the fundamental safety principles of the International Atomic Energy Agency (IAEA) Safety Standards. The design of the CANDU fuel channel is accordingly the result of continuing intensive engineering development of its major components. The fuel channel is designed to ensure a radiation exposure protection of workers and public, during the reactor operation. The reactor assembly of the CANDU 6 nuclear reactor consists of the horizontal, cylindrical, low-pressure calandria and the end-shield assembly. This enclosed assembly contains the heavy water moderator, the 380 fuel channels assemblies and the reactivity mechanisms. The fuel channels are one of the major distinguishing features of a CANDU reactor and their reliability is crucial to the performance of the reactor. Each fuel channel consists of four major components: the pressure tube, the calandria tube, the annulus spacers and the end fittings. Fuel bundles are enclosed in the fuel channels that pass through the calandria and the end-shield assembly. The fuel channels are assembled and installed into the calandria vessel at the reactor site following installation of the calandria. The fuel channel assembly is made according with the specific requirements of the tools and equipments, installation procedures and the quality assurance program.*
Keywords: *Candu reactor, Zirconium alloy, calandria tube, fuel channel, pressure tube, fuel bundle, end fitting, annulus spacer.*

1. INTRODUCTION

The CANDU 6 is a 740 MW pressure tube reactor designed by Atomic Energy of Canada Limited (AECL) to provide safe and reliable nuclear power.
The nuclear reactors are designed and manufactured with respect of the specific requirements of codes and standards for the manufacture of components, equipment and systems required for the construction and operation of CANDU nuclear power plant.
The requirements for CANDU reactor design must comply with the codes of Canada Standards Association (CSA), Atomic Energy Control Board (AECB) of Canada and International Energy Agency (IAEA) which specify the specific and regulatory requirements.
The fuel channels, in number of 380, pressure tubes made of zirconium-niobium alloy, located inside the calandria tubes, chuck in the end fitting, are connected by the network pipes to the cooling system.
Each fuel channel consists of four major components: the pressure tube, the calandria tube, the annulus spacers and the end fittings. Fuel bundles are enclosed in the fuel channels that pass through the calandria and the end-shield assembly.

2. FUEL CHANNEL COMPONENTS

The CANDU reactor design is based on the experience derived from preceding CANDU reactors and virtually every design feature of the latest CANDU reactor is identical to, or is an evolutionary improvement of, an earlier proven design.

The CANDU 6 reactors are the following general features of the fuel channels:
- 380 fuel channels;
- pressure tube made of Zi 2,5% NB, diameter 103,4 mm, thickness 4,19 mm;
- calandria tube made of Zircaloy 2, diameter 129,0 mm, thickness 1,37 mm;
- annulus spacers made of Incon.X750, coil diameter 4,83 mm, 4 pieces;

The time life of the fuel channel is for 30 years at 80% of its capacity and 24 years for full capacity functioning.

2.1. General presentation

The 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 components of the fuel channel design are illustrated in Figure 1.

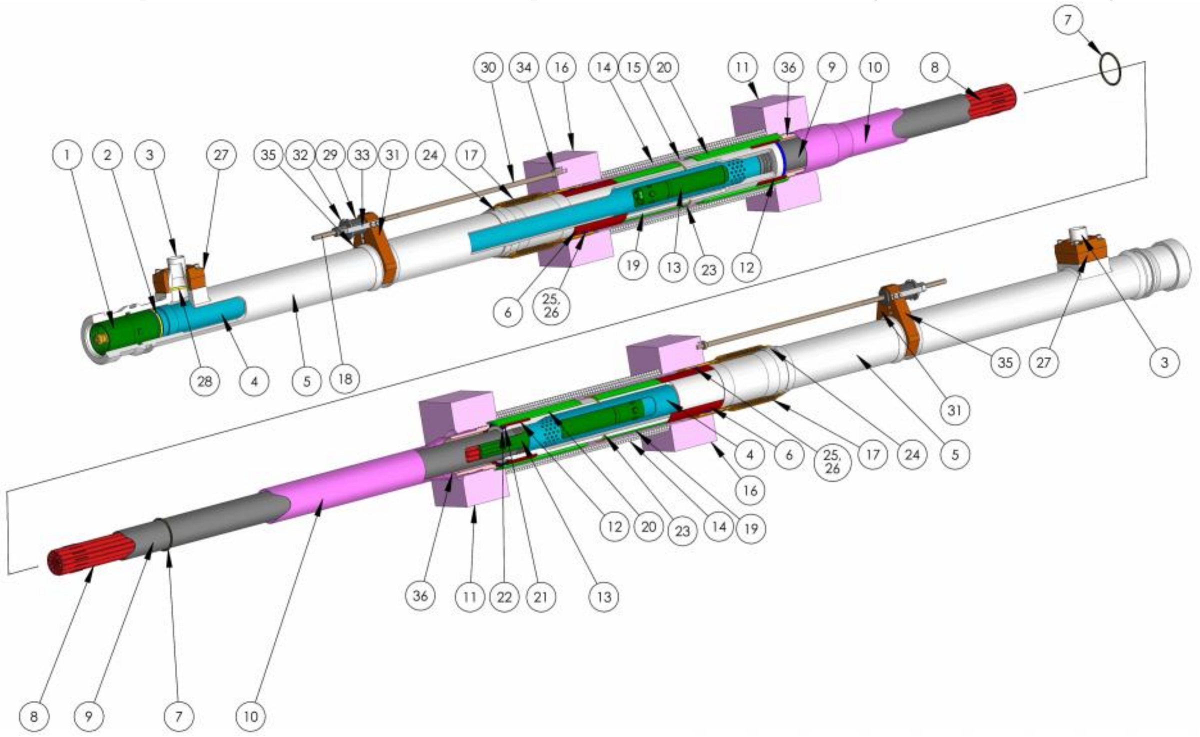

Figure 1: Representation of a CANDU fuel channel

1. Channel closure; 2. Closure seal insert; 3. Feeder coupling; 4. Liner tube; 5. End fitting body; 6. Outboard bearings; 7. Annulus spacer; 8. Fuel bundle; 9. Pressure tube; 10. Calandria tube; 11. Calandria tubesheet; 12. Inboard bearings; 13. Shield plug; 14. Endshield shielding balls; 15. Endshield lattice tube; 16. Fuelling tubesheet; 17. Channel annulus bellows; 18. Positioning assembly; 19. End fitting shielding sleeve; 20. Lattice tube shielding sleeve; 21. End fitting inner ring seal; 22. Elastic safety lock for end fitting inner ring seal; 23. Elastic safety lock for end fitting shielding sleeve; 24. Support ring for annulus bellows; 25. Annulus bellows outer ring seal; 26. Elastic safety lock for Annulus bellows outer ring seal; 27. Feeder coupling attachment; 28. Feeder gasket; 29. Rod positioning threaded part; 30. Rod positioning; 31. Right fastening piece for rod positioning; 32. Counter nut locking; 33. Safety lock for counter nut; 34. Lock pin for rod positioning; 35. Left fastening piece for rod positioning; 36. Crimping ring for calandria tube;

2.2. Calandria tube

A calandria tube surrounds each pressure tube. Calandria tubes have an internal diameter of about 129 mm and span the calandria vessel between the two end shields. The calandria tube is illustrated in Figure 2.

Figure 2: Representation of the calandria tube

These tubes provide access through the calandria for the pressure tube/end fitting assemblies. The calandria tubes help to support the fuel channel pressure tubes by means of four spacers per channel, as is illustrated in Figure 3.

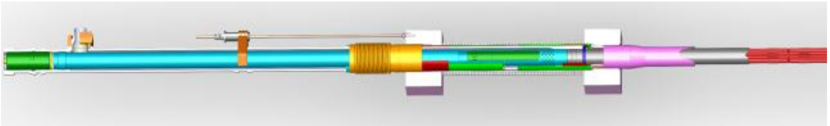

Figure 3: Representation of calandria tube with pressure tube, end fitting and fuel bundle

2.3. Pressure tube

The pressure tubes are the most important part of the fuel channel as they pass through the calandria and contain the fuel bundles. They are zirconium alloy tubes (Zr-2.5% Nb) that are about 6 meters long, about 11 cm in diameter and have a wall thickness of about 4 mm.
The design of the pressure tube consists primarily of the determination of the length, the inside diameter and the wall thickness of a simple thin-walled cylinder which is illustrated in Figure 4.

Figure 4: Representation of pressure tube

One of the main requirements of the pressure tube design is to optimize wall thickness and to minimize neutron absorption for radiation exposure protection of workers.
The product specification requires that the following tests and examinations also be carried out on each pressure tube before it can be accepted: hydrostatic pressure test, chemical analysis, tensile testing and corrosion testing.

2.4. End fitting

The end fitting, manufactured from a modified AISI 403 stainless steel, is an out of core extension of the pressure tube that provides the connection for on power fuelling, the connection to the feeders coupling and the connection with the pressure tube, which is illustrated in Figure 5.

Figure 5: Representation of end fitting

The outboard end contains a removable closure plug and provides facilities on which a fuelling machine can clamp and make a high pressure seal to allow on-power refuelling. Near the outer end of each end fitting is a side port for connection of a feeder pipe connection.
The inboard end of each end fitting is connected to one end of a pressure tube by a rolled joint, which is illustrated in Figure 6.

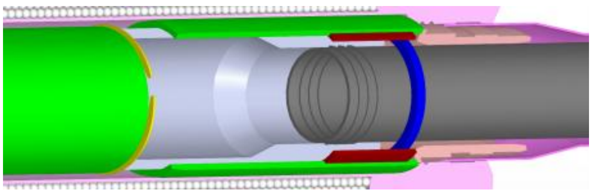

Figure 6: Representation of pressure tube rolled joint

2.5. Annulus spacer

Each pressure tube is separated from a calandria tube by means of four spacers. These spacers are positioned so that pressure tube sag will not allow the contact with the calandria tube. That is illustrated in Figure 7.

Figure 7: Representation of annulus spacers positioning on pressure tube

The spacers are made by forming Inconel wire into a close coiled helical spring, which is illustrated in Figure 8.

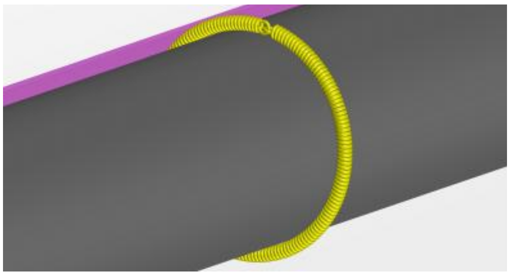

Figure 8: Representation of annulus spacer

The axial movement of the pressure tubes is allowed by a rolling motion of the annulus spacers, which results in almost no wear on the pressure and calandria tubes where they contract the spacers.

2.6. Feeder coupling

The feeder pipe connection located on the side of each end fitting is necessary for cooling system connection. The bolted feeder pipe connection has a metallic seal, as is illustrated in Figure 9.

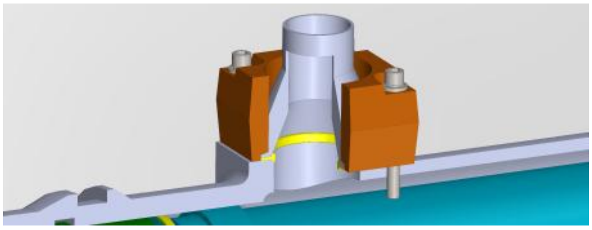

Figure 9: Representation of feeder coupling

Four bolts pass thorough a flange into holes tapped into the end fitting body to tighten this connection. The flange holds a hub welded to each feeder pipe tightly against the metal seal ring.

2.7. Positioning assembly

Each fuel channel is located axially within the reactor by a positioning assembly which is connected to one end shield, as is illustrated in Figure 10.

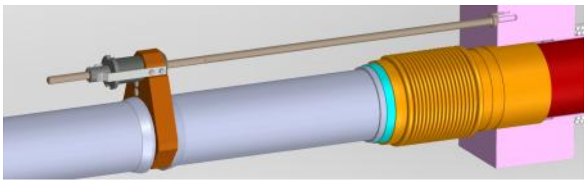

Figure 10: Representation of position assembly

A second positioning assembly is installed at the other end of the fuel channel but it is not attached to the end shield so axial motion resulting from thermal expansion, so that the pressure tube elongation to be permitted.

2.8. Annulus bellows

The annulus bellows, which is illustrated in Figure 11, connects between an end fitting and the reactor end shield, allows axial motion of the channels and also limits the torque imparted to the end fitting by the feeder piping. Each end of the bellows is welded to an end ring. One end ring is attached to the lattice tube/calandria tubesheet by welding and another is a shrink-fit onto the end fitting.

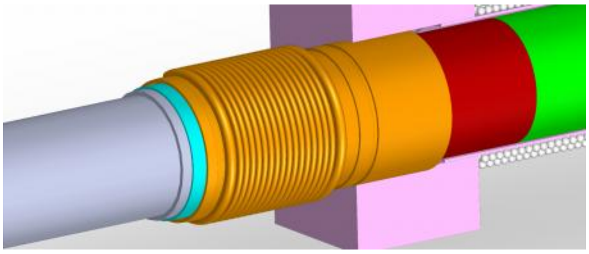

Figure 11: Representation of annulus bellows

2.9. Channel closure plug

The channel closures, illustrated in Figure 12, are located in each end fitting of a fuel channel to seal the primary coolant and to permit on-power access to the fuel channel by the fuelling machines. he channel closures can be remotely removed by a fuelling machine.

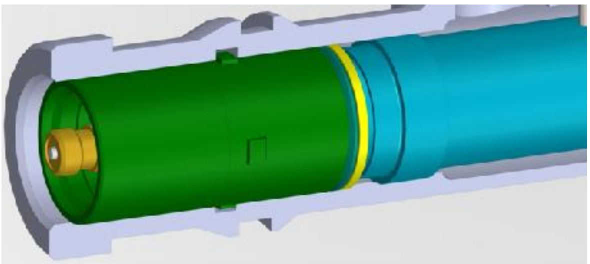

Figure 12: Representation of channel closures

2.10. Shield plug

The shield plugs, which provide shielding where the fuel channels pass through the reactor end shield, are latched into the end fitting, which is illustrated in Figure 13. They are also removed by the fuelling machine before the refueling of a channel can occur.

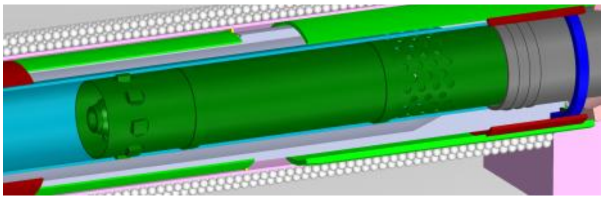

Figure 13: Representation of shield plugs

3. CONCLUSIONS

The design and the configuration characteristics of the fuel channel from the CANDU nuclear reactor are essentially in the design of device components. The fuel channel design has increased margins with extended operating life and is considered a fundamental part in the CANDU system.
The install operations to a new fuel channel must comply with the described requirements from the specified documents by AECL.
The current CANDU 6 reactors have a design life of 40 years at an average of 85% capacity. The pressure tube design life is 25 years at the reactor's 85% capacity factor.

The fuel channels from CANDU reactors, which use thin-walled zirconium alloy pressure tubes, represent a specialized application of pressure vessel design.
The fuel channels have made a significant contribution to the very high capacity factors attained in CANDU reactors since they allow on-power refueling.

REFERENCES

[1] Cheadle B.A., Price E.G., *"Operating performance of CANDU pressure tubes"*, presented at IAEA Techn. Comm. Mtg on the Exchange of Operational Safety Experience of Heavy Water Reactors, Vienna, 1989.
[2] Roger G. Steed, *"Nuclear Power in Canada and Beyond"*, Ontario, Canada, 2003.
[3] Venkatapathi S., Mehmi A., Wong H., *"Pressure tube to end fitting roll expanded joints in CANDU PHWRS"*, presented at Int. Conf. on Expanded and Rolled Joint Technology, Toronto, Canada, 1993.
[4] AECB, *"Fundamentals of Power Reactors"*, Training Center, Canada.
[5] AECL, *"CANDU Nuclear Generating Station"*, Engineering Company, Canada.
[6] ANSTO, *"SAR CH19 Decommissioning"*, RRRP-7225-EBEAN-002-REV0, 2004.
[7] CANDU, *"EC6 Enhanced CANDU 6 - Technical Summary"*, 1003/05.2012.
[8] CNCAN, *"Law no. 111/1996 on the safe deployment, regulation, authorization and control of nuclear activities"*, 1996.
[9] CNCAN, *"Rules for the decommissioning of objectives and nuclear installations"*, 2002.
[10] IAEA, *"Assessment and management of ageing of major nuclear power plant components important to safety: CANDU pressure tube"*, IAEA-TEDOC-1037, Vienna 1998.
[11] IAEA, *"Assessment and management of ageing of major nuclear power plant components important to safety: CANDU reactor assemblies"*, IAEA-TEDOC-1197, Vienna 2001.
[12] IAEA, *"Decommissioning of Nuclear Power Plants and Research Reactors"* Safety Standard Series No. WS-G-2.1, Vienna 1999.
[13] IAEA, *"Nuclear Power Plant Design Characteristics, Structure of Power Plant Design Characteristics in the IAEA Power Reactor Information System (PRIS)"*, IAEA-TECDOC-1544, Vienna 2007.
[14] IAEA, *"Organization and Management for Decommissioning of Nuclear Facilities"*, IAEA-TRS-399, Vienna 2000.
[15] IAEA, *"Selection of Decommissioning Strategy: Issues and Factors"*, IAEA-TECDOC-1478, Vienna 2005.
[16] IAEA, *"State of the Art Technology for Decontamination and Dismantling of Nuclear Facilities"*, IAEA-TRS-395, Vienna 1999.
[17] IAEA, *"Water channel reactor fuels and fuel channels: Design, performance, research and development"*, IAEA-TEDOC-997, Vienna 1996.
[18] IAEA, *"Heavy Water Reactor: Status and Projected Development"*, IAEA-TEREP-407, Vienna 1996.
[19] Nuclearelectrica SA, *"Cernavoda NPP Unit 1&2, Safety features of Candu 6 design and stress test summary report"*, 2012.
[20] UNENE, Basma A. Shalaby, *"AECL and HWR Experience"*, 2010;