Cernavoda NPP PLiM Program

in support of Unit 1 Long Term Operation

Sorin Ghelbereu, Technical Manager
CNE Cernavoda NPP, Romania

ISOE Joint Topical Session on Refurbishment and Plant Life Extension Activities 2017
Paris, France – November 8th , 2017

Content

- General background

- Early Long Term strategy and Aging Management related activities
  - Preventive Maintenance (PM)
  - Plant Life Management (PLiM)

- Cernavoda PLiM Programs Overview

- Unit 1 Project to extend Fuel Channels Operation beyond 210,000 EFPH

- Conclusions

General background

NUCLEARELECTRICA

- **CANDU 6 Nuclear Reactor**
  - ✓ **fuel: natural uranium**
  - ✓ **primary & moderator fluids: heavy water**
- **Electrical output:** **714 MW**
- **Owner:** **National Utility, S. N. Nuclearelectrica S.A**
- **Operator:** **CNE Cernavoda**
- **Start of commercial operation:**
  - **U1 – 1996 December**
  - **U2 – 2007 October**

General background

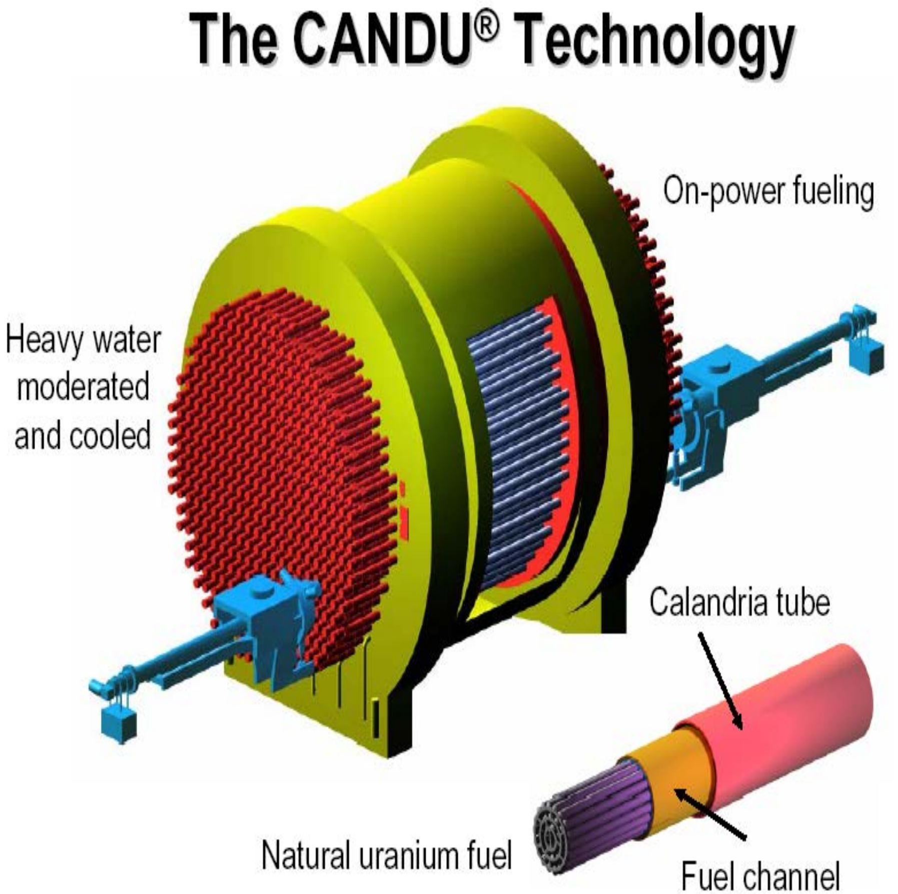
NUCLEARELECTRICA

CANDU reactor design - developed in Canada since the 1950s

Built in Canada, India, Pakistan, South Korea, Argentina, Romania and China

The D2O moderator is contained in a large tank – Calandria vessel - penetrated by several hundred horizontal pressure tubes which form the fuel channels.

CANDU fuel assembly consists of a bundle of 37 half meter long fuel rods (UO_2 fuel pellets in Zircaloy tubes) plus a support structure, with 12 bundles lying end to end in a fuel channel.



General background

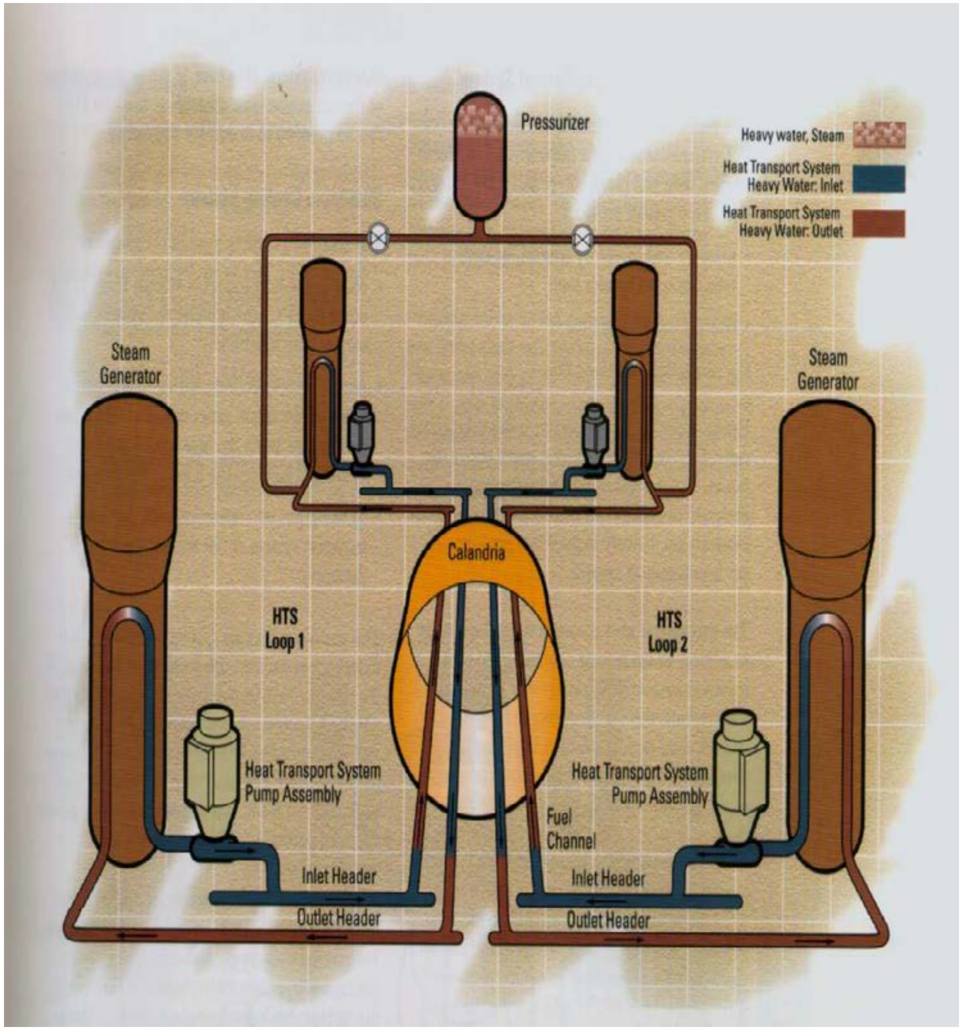
CANDU 6 design:
- medium size reactor (380 tubes)
- designed in late 1970s
- superior materials
- and enhanced safety features

Two parallel HTS coolant loops are provided in CANDU 6 design.

Each heat transport system loop is arranged in a 'Figure of 8', with the coolant making two passes, in opposite directions.

CANDU 6 units:

- Point Lepreau & Gentilly 2 (Canada)
- Wolsung 1 -4 (South Korea)
- Embalse (Argentina)
- Cernavoda 1, 2 (Romania)
- Qinshan Phase III 2 units (China)



Early Long Term strategy and current Aging Management activities

NUCLEARELECTRICA

- In 2009, based on the pilot phase experience, CNPP adopted “Continuous Equipment Reliability Process”, according to INPO-AP 913 model.
- PLiM Programs were documented for major impact components, requiring proactive control of aging effects that cannot be addressed by PM strategies.

➢ ***Specific criteria for the selection in the PLiM Program***:

- Need a plant outage longer than normal outages to Replace & Repair;
- Repair or Replacement plan cost > 1.000.000 Euro;
- High complexity with limited life (may become "obsolete" or irreplaceable);
- Significant impact on plant’s operating capacity (nuclear safety or production).

- For each PLiM component, after understanding the applicable ageing related degradation mechanisms (ARDM), long term plans were developed to mitigate the ageing degradation effects.

- In 2010 an overall implementation strategy was developed, justified by:
  - the complexity of PLiM inspection services with specialized tools required,
  - the need for continuity in the assessment of the results,
  - the extensive experience of Original Equipment Manufacturer (OEM) considered subject matter expert.

➢ It consist in **long term services** (10 years mostly) **contracted with subject matter experts**.

➢ Was approved by SNN Technical Advisory Committee (CTES), before starting the contracting process.

Early Long Term strategy and current Aging Management activities

NUCLEARELECTRICA

➢ ***Selection of PLiM components***

The major components selected in the scope of PLiM Program:

- Fuel Channels
- Steam Generators
- Feeders
- Turbogenerator
- Digital Control Computers (DCC)
- RB Concrete Structure
- Large Power Transformers
- Heat Exchangers (11 HXs, both NSP and BOP)
- Cables
- Piping Surveillance (FAC, buried piping, snubbers, supports, expansion joints)
- Stand-by Diesel Generators.

The list of PLiM components was validated with other CANDU 6 plants in Canada and South Korea and corresponds to CANDU 6 international practice.

Early Long Term strategy and current Aging Management activities

NUCLEARELECTRICA

PLiM Programs implementation

➢**Periodic inspection/ testing/ replacements activities**:

•Fuel Channels, Steam Generators, feeders: periodic inspection and material properties testing based on CAN CSA N 285.4 standard requirements

- RB Structure: Periodic Concrete Containment Leak Rate Testing CSA N 287.7, Periodic Inspection of Containment Components CSA N285.5
- Heat Exchangers periodic inspection based on ASME Code, and EPRI Guidelines
- Piping surveillance (erosion-corrosion, Buried piping): the inspection program is defined based on the risk for thinning calculated with software applications (CHECK-Works, BP-Works)

•Active components (Turbo-generator, Main Transformers, DCC): PM requirements for periodic tests, replacements, overhaul and design modifications to resolve obsolescence or SPV mitigation.

➢**Life Assessment study**:

•Perform an in-depth analysis of PLiM component current condition and life prognosis.

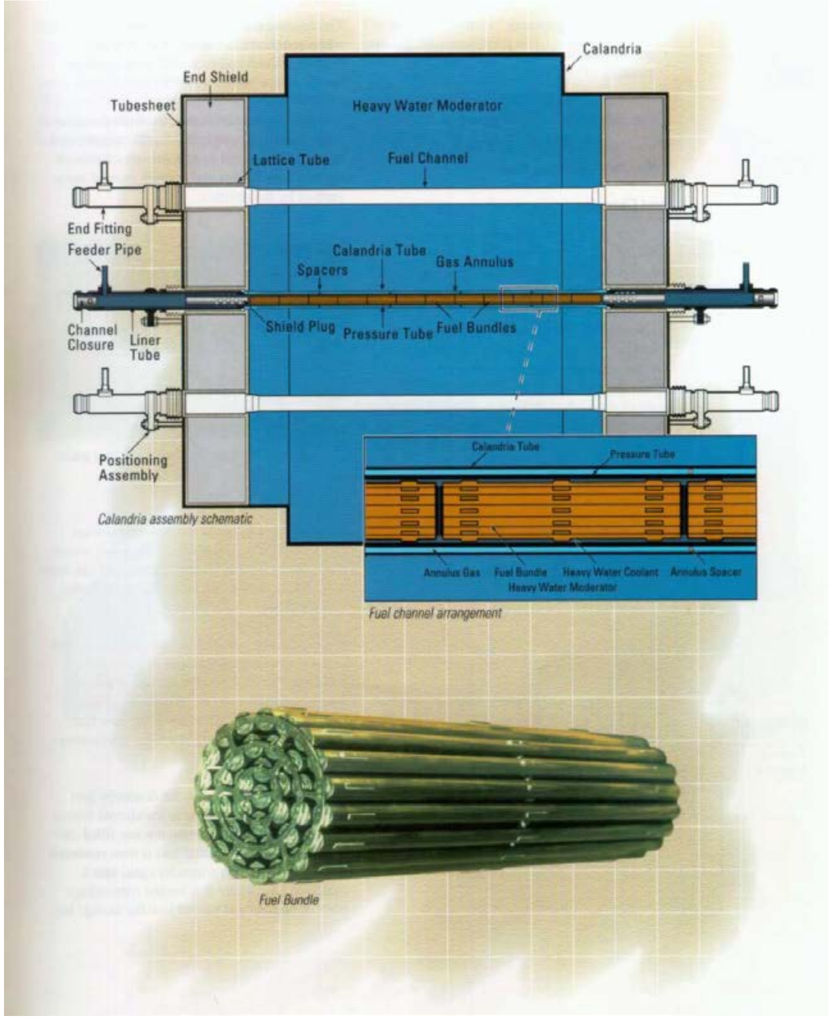
•define the Life Cycle Management Plan to attain the design life / for extended life.

•offer valuable information to be used for Refurbishment scope definition.

Cernavoda PLiM Programmes Overview

Fuel Channel Program

- **Fuel Channel inspections:**
  - were performed since 1999
  - according to CAN/CSA-N285.4-94 requirements
  - using Ultrasound (US) & Eddy Current (EC) detectors
  - assessment of inspection results in accordance with CSA 285.8- Ed. 2015.
- The inspections were performed using AFCIS (Advanced Fuel Channel Inspection System) - the latest technology developed by Atomic Energy of Canada Limited (AECL) for fuel channel non-destructive examination.
- A 10 years Framework Agreement was negotiated with Candu Energy Inc. (former AECL) to perform:
  - Mandatory inspections between 2013-2022
  - Life Assessment studies (2015, 2020).
- The first Life Assessment confirmed the actual good condition of U1 FC, as no elongation, sag, thinning, nip-up problems are foreseen before 210,000 EFPH.
- The gap measurement between calandria tubes & LISS horizontal structures performed in U1OP16 confirmed that there is no risk for fretting before 245.000 EFPH.



Cernavoda PLiM Programmes Overview

NUCLEARELECTRICA

Fuel Channel Program – cont.

- Following industry practice, FC inspection program focused on the pressure tube degradation: Elongation (creep), Diametral Expansion, Wall Thinning, Fuel Channel Sag (possible CT/LISS or PT/CT contact).
- However, CSA-N285.4 requirements contain also requirements for material property testing of pressure tubes removed from operating reactors for Deuterium uptake and irradiation. These requirements which have evolved in recent years and need to be met, to maintain the operating license.

Future challenges and SNN initiatives

1. Material property testing

- For instance, in CSA-N285.4 – Ed. 2009 the concept of CANDU lead unit is no longer available for dispositioning of pressure tube extraction. Once SNN switches to a later revision of the standard, a tube extraction or a Integrated Material Surveillance Program (IMSP) will be necessary to comply.
- Recently, OPG and Bruce Power have implemented an IMSP in order to use 2 tubes recently removed from Embalse as part of their own surveillance program and avoid pulling 1 tube each in their own reactors.
- As consequence, SNN has initiated the process to join the IMSP with OPG and Bruce Power and a report was prepared demonstrating SNN reactors are sufficiently similar to satisfy the requirements of an IMSP and can use the results from the inspection of the 2 pressure tubes removed from Embalse NPP.

Cernavoda PLiM Programmes Overview

Fuel Channel Program – cont.

NUCLEARELECTRICA

Future challenges and SNN initiatives

2. Fuel Channel Life Management

- In the last years, Operating Experience from older CANDU plants revealed that the technological advances in inspection tools, a better understanding of degradation mechanisms and updated models developed in the last decades in COG R&D specific programs can predict more accurately FC life expectancy .
- In this scope, a Fuel Channel Life Management Joint Project was launched by large utilities (OPG, BP) to benefit from recent R&D technological innovations to extend FC life from 210,000 to 247,000 EFPH.
- In this context, SNN should maintain a close contact with the operating experience of similar plants and latest COG initiatives in Joint Projects or R&D specific programs, to identify a cost-effective option.

Cernavoda PLiM Programmes Overview

NUCLEARELECTRICA

Steam Generators Program

- **SG inspection program:**

  - according to CAN/CSA-N285.4-94 requirements
  - using Eddy Current (EC) inspection method.
  - tubes, nozzles, internal supports/walls
  - since 1998 and continue every 4 years.

- Incoloy 800 tubes alleviate the concern over Stress Corrosion Cracking and Inter Granular Attack, as SG condition is very good compared to Inconel 600.

- However, tube condition is monitored and Tubesheet deposits are periodically removed to minimize issues with localized chemistry and pH.

- SGs are exposed also to deterioration of Tube Support Plates and other internals due to Flow Assisted Corrosion (FAC).

- A 10 years Framework Agreement was signed in 2011 with the OEM (Babcock & Wilcox) and the Life Assessment study for U1 was received in 2012.

- **LA conclusion**: U1 SG condition is very good after 15 years of operation and no problems are foreseen for attaining and extending the design life, if the actual operating conditions are maintained.

- In U1OP16 SG primary side cleaning was performed after a cost- benefit analysis. 2 tones of debris were extracted and an increase of ~ 3% FP was obtained, as consequence.

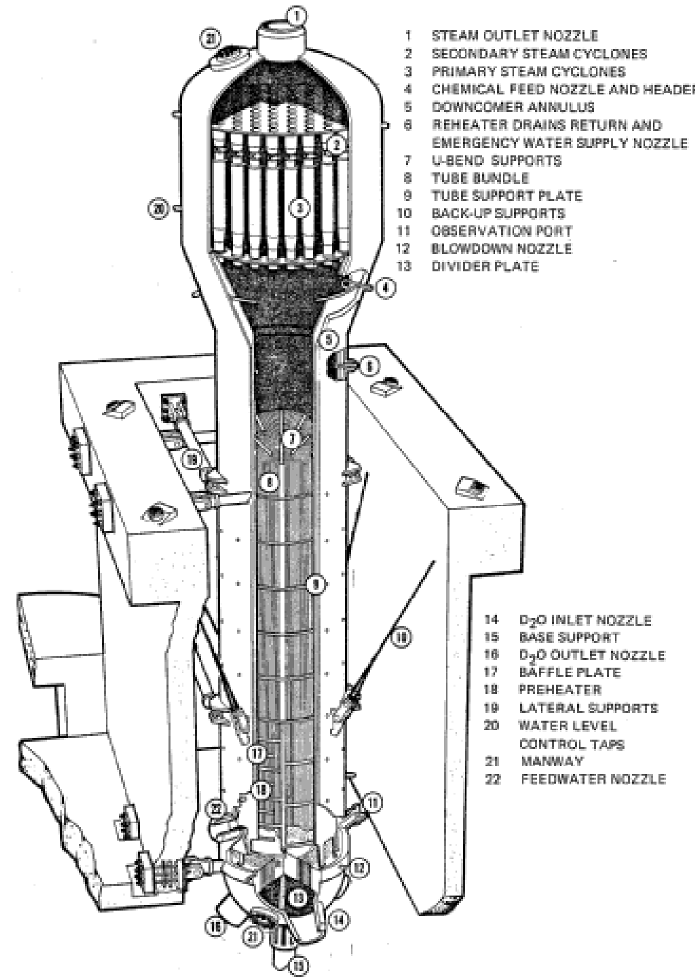


FIGURE 2.2-16 600 MW STEAM GENERATOR

Cernavoda PLiM Programmes Overview

NUCLEARELECTRICA

Feeders Program Status

- Feeder periodic inspection program started in 2003, according to CAN/CSA-N285.4-94 requirements, to determine wall thinning and to identify cracks.
- Since 2008, Cernavoda NPP adhered to COG “Feeders Integrity Program” joint project to adress external Opex issues from Point Lepreau.
- The major Ageing Related Degradation Mechanism for typical CANDU feeders is Flow Accelerated Corrosion (FAC) in the outlet feeders downstream of the Grayloc connection.
- The FAC issues identified above apply to Unit 1, depending on the particular alloy chemistry and fabrication techniques used. In Unit 2 the situation is improved, due to material higher Cr content.
- Regular monitoring of feeder wall thickness will allow:
  - to accurately determine wall thickness reduction rate
  - to optimize the specific feeder replacement during future outages (refurbishment included).
- A 10 years Framework Agreement is in place with OEM for periodic inspection and Life Assessment studies.
- The LA study and the Stress analysis based on U1OP16 inspection results concluded that feeder assemblies will achieve their required 24 EFPY of operating life.

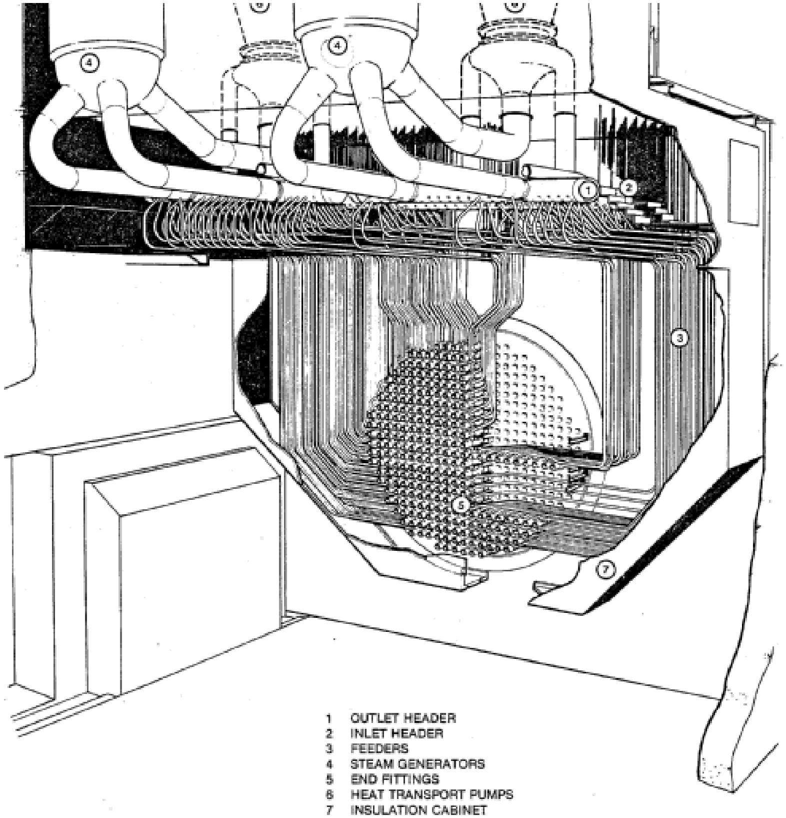


FIGURE 2.2-7 FEEDER AND HEADER ARRANGEMENT

Cernavoda PLiM Programmes Overview

NUCLEARELECTRICA

Heat Exchangers Program Status

- The main degradation mechanism discovered for HXs:
  - Stress Corrosion Cracking;
  - Pitting Corrosion;
  - Wear / Fretting in support area;
  - Dirt deposits.
- The technical basis and program manual was developed with AECL support.
- HX subject to PLiM program:
  - the majority are in nuclear side,
  - but also some important for power production (like High/ Low Pressure Heaters and Turbine Condenser).
- For the remaining critical HX's, a classical PM was adopted.
- The tube plugging criteria following Eddy Current inspection is over 80% from tube wall thickness and over 3 Volts amplitude of EC signal.
- A 10 years Framework Agreement was signed in 2012 with the experienced croatian company INETEC .
- The LA study for U1 Turbine Condenser, revised in 2015 to include the results of tube metalo-graphic testing, revealed that plugging rate is small and no concern was identified for another 21 years .

Cernavoda PLiM Programmes Overview

Turbo-Generator Program

Turbine

- Program technical basis was developed with OEM support (General Electric).
- Potential ageing issues and practices obtained from the international OPEX recommend:
  - on-line monitoring thermal performance monitoring system to detect degradation, vibration monitoring, bearing temperature monitoring,
  - regular periodic inspection (10÷12 years) and overhaul as required;
  - careful operation, ultrasonic inspection of discs for flaws, monitor blading r visually or with tensional vibration protection system, and use ultrasonic inspection for erosion and Flow Assisted Corrosion.

Generator

- The dedicated AMP , based on industry experience, include:
  - regular internal inspection, monitoring and testing, particularly insulation;
  - rotors and stators should be rewound after 25 years, so spares are recommended;
  - plan for obsolescence of the excitation system;
  - Eddy Current tests should be done on the cooler tubes and water chemistry should be maintained in the target range.

Life Assessment study, performed by OEM in 2012, concluded that if the actual inspection and testing program is continued and generator obsolescence issues are solved, the turbo-generator can operate reliably until 2047.

Cernavoda PLiM Programmes Overview

Reactor Building Program

NUCLEARELECTRICA

- The technical basis and program manual was developed with AECL support in 2009.
- Although Cernavoda NPP is a newer station, with a relatively short period of operation, Reactor Building and civil structures are older, as they were built years ago, in early1980s .
- The components selected in scope of the program are: Containment, Dousing Tank, Reactor Vault/ Reactor Building, Fuel transfer channel.
- There were no major events related to ageing of Civil Structures, the internal OPEX indicates that the main ageing issues related to Buildings and Structures at Cernavoda U1 up to date have been with the elastomeric components.
- Inspection and test results showed R/B foundation settling is less than expected in U1& 2. Also, the Pre-stressed concrete structure is in good condition.
- However, the degradation mechanisms identified in international literature for concrete are expected to apply to Cernavoda NPP Unit 1. Therefore, some improvements are necessary for monitoring and testing of civil structures.
- In 2015 a 10 years Framework Agreement was awarded to CEI (which took over AECL) and the Life Assessment studies are scheduled for end of 2016 for U1 and 2018 for U2 (to include RBLRT results from U2OP17).
- **Based on LA study for U1 RB**, received recently, an action plan shall be issued in 2018, in order to reinforce the actual RB PLiM program according to the recommendations.

Cernavoda PLiM Programmes Overview

NUCLEARELECTRICA

Piping Surveillance

- Program technical basis approved in 2009 :
  - Flow Accelerated Corrosion (FAC) subprogram;
  - Non FAC subprogram for support systems (including Microbiological Influenced Corrosion);
  - Weld inspection for Main Steam Lines;
  - Buried Pipe subprogram;
  - Pipe Supports & Shock Absorbers
- Piping condition is monitored via an inspection program plus contributors control (temperature, pressure, pH, oxigen concentration, chemical parameters, etc).
- The list of the most susceptible lines to FAC was issued, after simulation of process parameters with CHECWORKS application.
- FAC inspections are scheduled based on the Risk MATRIX: Failure probability - Impact
- **Buried Pipe subprogram** was added after 2010 WANO Peer Review Mission.
- In 2011 a Preliminary risk-ranking (by system) was completed, to prioritize BP inspections.
- Four plant systems identified as high-risk, related to the buried components: EPS, SDG, EWS and ECC. Preliminary inspections results revealed an appropriate condition of buried components after 17 years of operation mainly due to coal-tar external coating and burial conditions (clean sand).
- In 2015 a contract for complete services for BP program implementation with external support was awarded for plant mapping, detailed risk-ranking with BPWORKS software, initial assessment, inspections & evaluations of BP condition from 2017.

Cernavoda PLiM Programmes Overview

NUCLEARELECTRICA

Pipe Supports & Shock Absorbers

- Program technical basis was approved in 2009.
- The supports and shock absorbers which are subject of specific PLiM program were established taking into account:
  - different requirement derived from ASME Code,
  - local prescriptions for presurre boundary equipment (PT ISCIR)
  - and specific loading resulted from stress analysis performed for different operating scenarios (normal operation, transients and seismic conditions)
- The inspections and test requirements are addressed according to ASME-OM Standard and Snubbers User Group (SNUG) Good Practice Guides and consist of:
  - visual inspection;
  - functional test (hand-stroking & stand testing of 10% of the population).
- The supports and shock absorbers inspection is approved by the local regulatory body and is performed according to the program. All discovered deficiencies are addressed and periodic replacement was performed according to the plan.
- A long term strategy for Snubber testing and spare parts requirements was approved in 2012 and was validated in 2013 by a Technical Support Mission from north-american utilities.
- In 2015 a contract for complete services with external support was awarded to TEN-TECNATOM association for initial assessment, inspections & tests and periodic evaluation of snubbers condition.

Cernavoda PLiM Programmes Overview

Power Transformers Program

NUCLEARELECTRICA

Main Output Transformers (MOT)

- The technical basis and program manual was developed with local OEM support and so far, plant OPEX include several issues, but related mainly to system power distribution and not to the main output system.
- The main degradation mechanisms are transformer insulation failure due to ageing and insulation deterioration, due to high temperature conditions, as it operates at maximum load.
- MOTs actual condition both in U1 and U2 shows signs o degradation and measures to reduce contributors to aging of oil and isolating cellulosic paper are required.
- More than this, a project for refurbishment of all 4 MOTs has been approved and the long term contract for planned replacement will start in 2013.

Service Power Transformers

- Operate at low loads (≈ 50%) and their current condition is better than for the MOTs.
- Current Aging Management Program for both types of transformers include the tasks:
- Monitor the operating parameters and perform a Preventive Maintenance program with specialized support from manufacturer;
- Repair & Replace before failure, based on condition and performance evaluation;
- Life Assessment studies will be recived in 2017, to enhance the actual Transformers PLiM program.

Cernavoda PLiM Programmes Overview

Digital Control Computers Program

The technical basis and program manual was developed with OEM support early in the Life of Unit 1, triggered by obsolescence issue , specific to all electronic components.

Unit 1 DCC refurbishment was completed 2012 Planned Outage.

Internal OPEX on Cernavoda DCCs do not include any relevant ageing degradation issues.

DCC Aging Management Program **include current PM Program**, consisting of:

- Main parameters monitoring (No. of alarms, No. of stalls, No. of restarts)
- Perform different tests to asses aging
- Continuous monitoring of Technical obsolescence
- Condition and Performance Assessment of DCC components
- visual inspection of the spare DCCZ cables & connectors
- assessment of transfer control relays

and a PLiM component, related mainly to obsolescence management*:*

- Performance monitoring via System Health Monitoring process & Life Assessment***;***
- Participation in COG Joint Projects:
  - COG Joint Project # 4048 “DCC Replacement”;
  - COG Joint Project # 4294 “Plant Computer Working Group“
- Contracting long term services with DCC OEM & participation in COG Joint Project for:
  - Design & Obsolescence Management;
  - Spare parts Administration via COG (long term agreement for stock preservation).

Cernavoda PLiM Programmes Overview

Conclusions

- According to the Overall implementation strategy Cernavoda NPP started early in the the life of the Plant PLim Program implementation with the objectives:
  - avoid accelerated degradation;
  - avoid economic penalties;
  - sustain plant operation beyond design life limit.

- As consequence, a large amount of data, resulting from plant inspections was available for the first Life Assessment studies.

- First Life Assessments for the most important PLiM components, have been completed by 2016, as scheduled.

- The first Life Assessment studies received indicate that PLiM components do not have the same estimated End of Life.

- For some key components (Steam Generators, Turbine, Reactor Containment) Life Assessment show more than 30 years of service life, if the actual operation and maintenance strategies are continued.

- For other life–limiting components (such as Fuel Channels, feeders) more detailed analysis is necessary to attain 30 years of service life.

Fuel Channels Life extension beyond 210,000 EFPH

NUCLEARELECTRICA

Background:

- CANDU 6 was designed for 30 years operation, but Fuel Channels were verified for ageing accelerated tests only at 80% GCF (equivalent to 210,000 EFPH).
- Actual data resulting from plant inspections show preliminary reserve for FC extended operation up to 30 years in service (245,000 EFPH).
- Other key components (Steam Generators, Turbine, Containment) could have more 30 years service life, if adequately operated and maintained.
- Recent OPEX from older CANDU plants revealed that significant conservatism was included in the original design.
- In the last years, sustained by increased operational experience, evolved analytical capability and sophisticated inspection tools, R&D studies demonstrate that a better evaluation of safety margins is already possible.
- For this reason, in 2017 Cernavoda started a project to extend U1 fuel channels lifetime from 210,000 to 245,000 EFPH.

Fuel Channels Life extension beyond 210,000 EFPH

NUCLEARELECTRICA

The Project for U1 Fuel Channels Life extension beyond 210,000 EFPH has started in 2017.

- will take the benefits from our **early Plant Life Management programs implementation f**or all important components such as: fuel channels, feeders, steam generators, reactor building, turbine/generator, piping surveillance, heat exchangers, DCC, main transformers.
- will increase the service life for the life-limiting components and save premature replacement for the other ones with a life expectancy higher than 30 years of operation.

In the preliminary phase:

- important input data will be given by the Life Assessment studies obtained in the last couple of years which indicated a good performance of the life-limiting components, but also for other component important for energy production.

In the second phase:

- New technical, economical ands safety assessments are necessary to demonstrate that aging mechanisms are identified, understood and incorporated into the safety analysis, that prove adequate safety margins to prescribed acceptance criteria.
- If successful, the project will postpone Unit 1 End of Life to 2027, allowing the necessary time for refurbishment preparedness, which usually indicate 8-10 years in advance.

PLiM Program in support of Unit 1 Long Term Operation

NUCLEARELECTRICA

Conclusions:

- ✓ Early Plant Life Management programs implementation for all important components, resulted in **a large amount of data** from plant inspections **available for the Life Assessment studies**.
- ✓ First Life Assessment studies, received after the second decade of U1 design life, indicate that **PLiM components do not have the same estimated End of Life**.
- ✓ Some key components (Steam Generators, Turbine, Reactor Containment) **could operate over 30 years** of service life, if the actual PLiM strategies are continued.
- ✓ **For other life–limiting components** (fuel channels, feeders) **more detailed analysis is necessary** to attain 30 years of service life.
- ✓ However, current degradation trends combined with increased R&D capabilities to eliminate the initial conservatism, indicate that **there is sufficient reserve** to extend the operation of Unit 1 beyond 210 kEFPH with 3÷4 years.
- ✓ This will allow adequate preparedness for Cernavoda U1 refurbishment, which requires an extended activity over a long period, 10 years being considered as the most appropriate.

Thank you for your attention !

QUESTIONS ?