The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

2291-10

Joint ICTP-IAEA Course on Science and Technology of Supercritical Water Cooled Reactors

27 June - 1 July, 2011

SCWR CORE DESIGN - HWR TYPE

Laurence LEUNG

Atomic Energy of Canada Ltd. (AECL)
Stn. 87, Chalk River Laboratories
Chalk River K0J 1J0
Ontario
CANADA

SCWR Core Design – HWR Type (SC09)

Laurence Leung
Manager, Advanced Concepts and Collaboration

Joint ICTP-IAEA Course on Science and Technology of SCWRs, Trieste, Italy
June 27 – July 1, 2011

AECL EACL

Objectives

- To present specific of heavy-water reactor (HWR) core designs

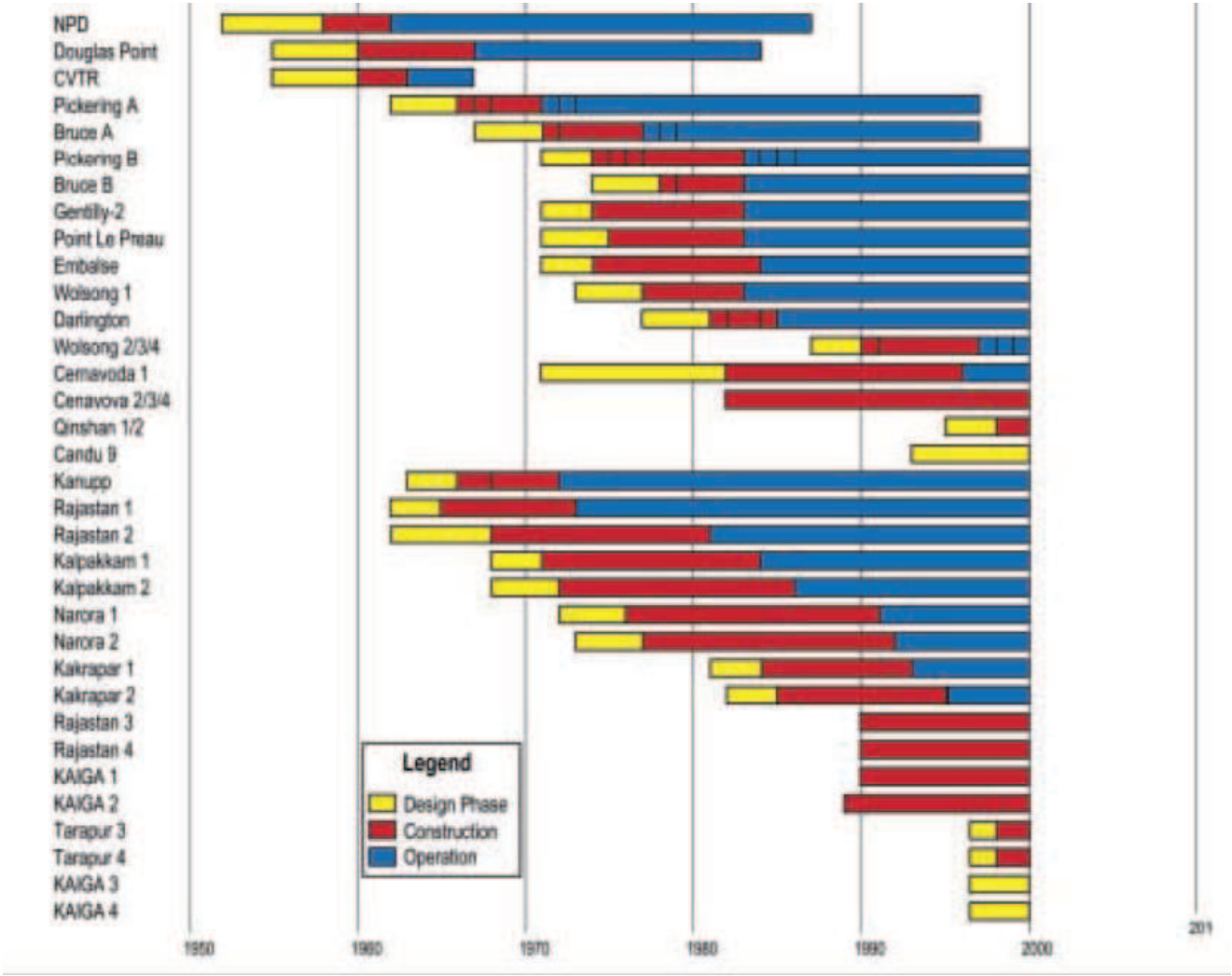
- To highlight similarity and differences between Canadian SCWR and existing HWR designs

Introduction

- Canada started the heavy-water reactor program in 1950s
- The Nuclear Power Demonstration is the first prototype
- A number of heavy-water reactors have been designed and constructed
  - Power generation or research
  - Horizontal or vertical fuel channels
  - All heavy-water moderated (high or low pressures)
  - Heavy-water, light-water, organic, or gas cooled
- Advanced heavy-water reactor program
  - Canada
  - India
- Generation IV SCWR program
  - Canada

AECL EACL

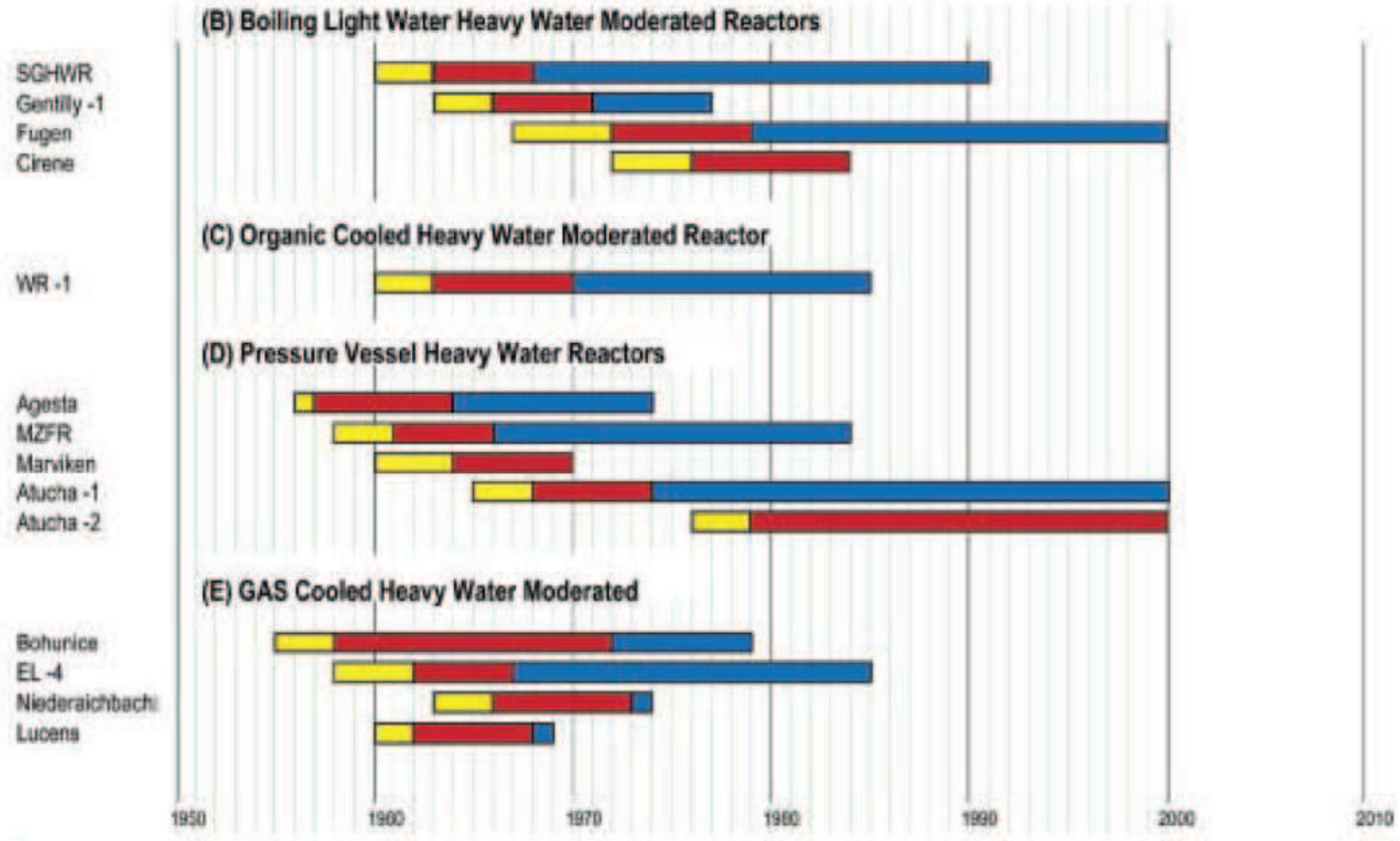
Heavy-Water Cooled Reactors



IAEA Technical Reports Series No. 407, 2002

AECL EACL

Other Heavy-Water Reactors



IAEA Technical Reports Series No. 407, 2002

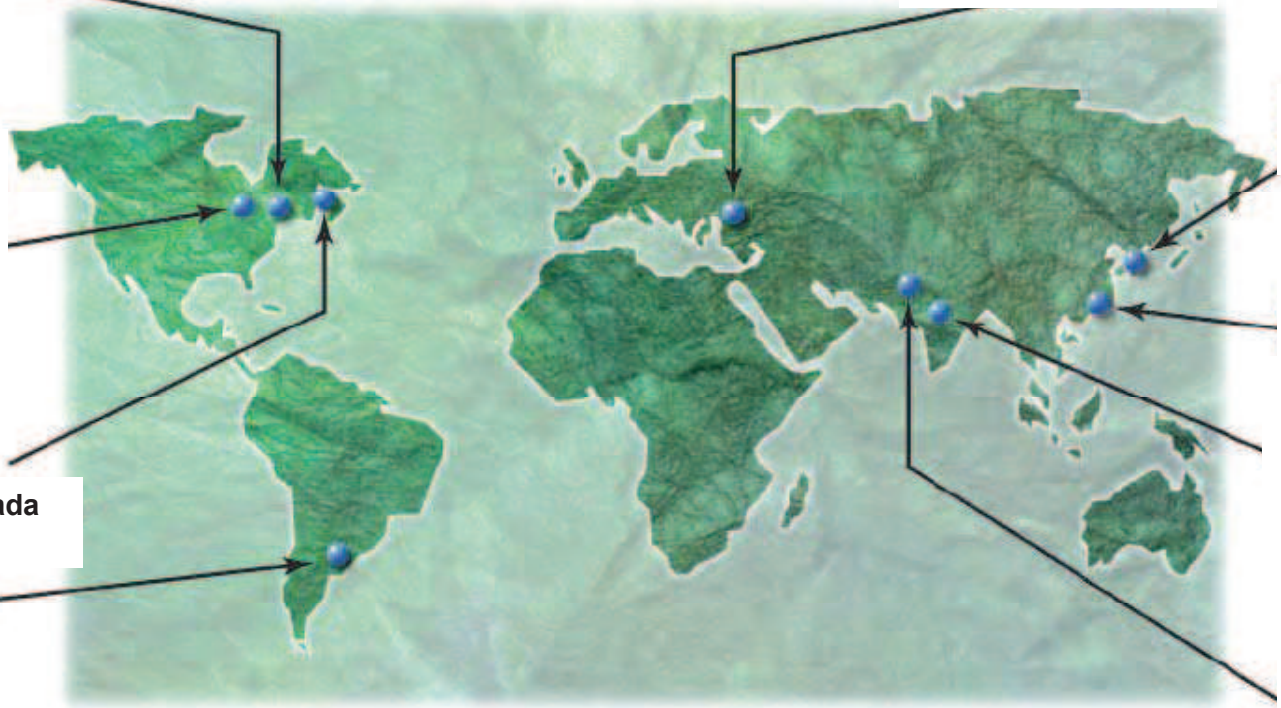
Global HWRs for Power Generation

Quebec, Canada
Gentilly 2 – 1 Unit

Ontario, Canada
Darlington – 4 Units
Pickering – 8 Units
Bruce – 8 Units

New Brunswick, Canada
Point Lepreau – 1 Unit

Argentina
Embalse – 1 Unit
Atucha – 2 Units



Romania
Cernavoda – 2 Units

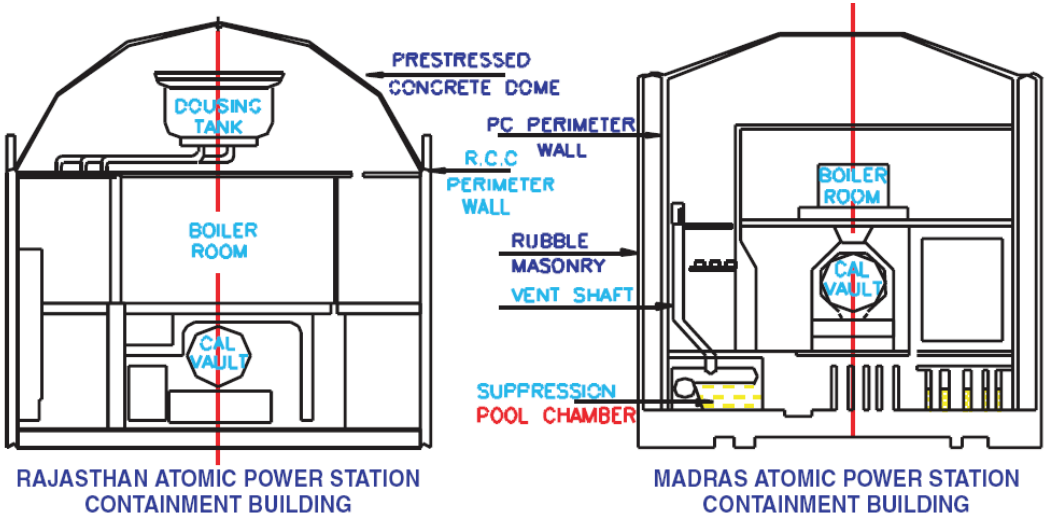
South Korea
Wolsong – 4 Units

China
Qinshan – 2 Units

India
Rajasthan – 4 Units
Kalpakkam – 2 Units
Narora – 2 Units
Kakrapar – 2 Units
Kaiga – 4 Units
Tarapur – 4 Units
Rawatbhata – 6 Units

Pakistan
KANUPP – 1 Unit

HWR Plants in India

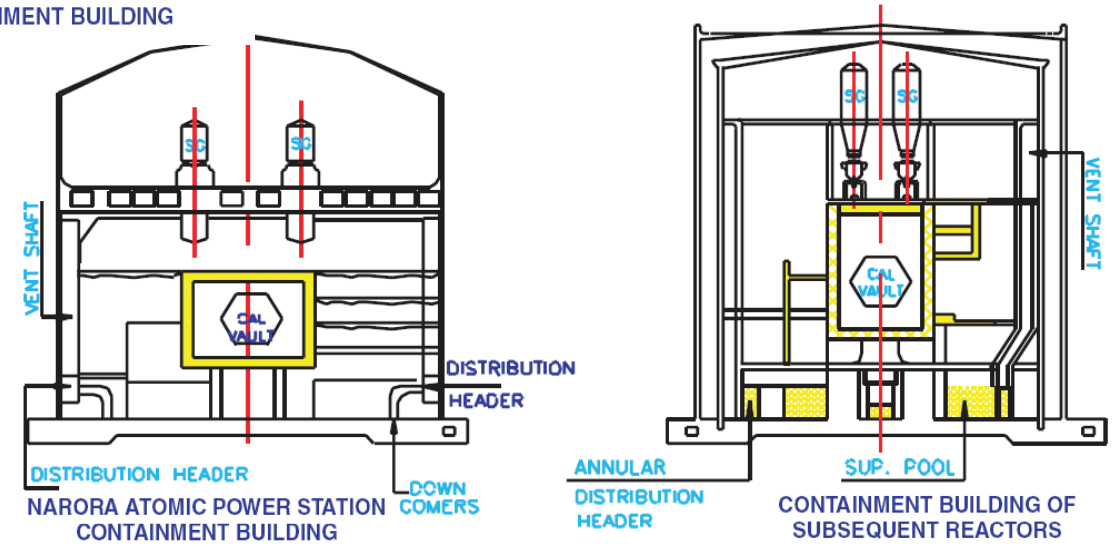


Tarapur 3/4

- Heavy-water cooled, heavy-water moderated
- Horizontal channel
- Two loops
- 37-element UO2 fuel bundle
- Net electric output of 450 MW

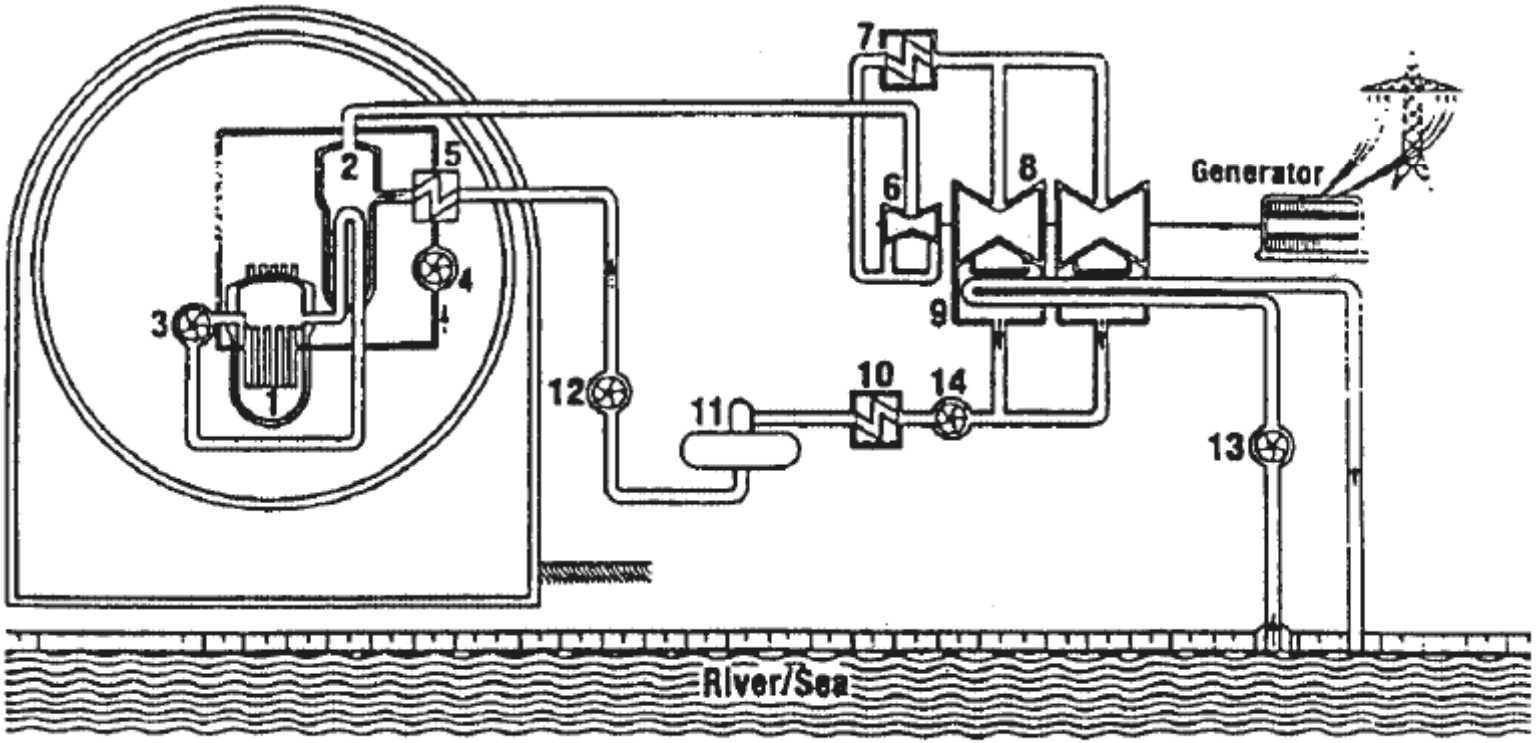
Rajasthan, Madras, Narora, Rawatbhata and Kaiga

- Heavy-water cooled, heavy-water moderated
- Horizontal channel
- Single loop
- 19-element UO2 fuel bundle
- Net electric output of ~200 MW



IAEA Technical Reports Series No. 407, 2002

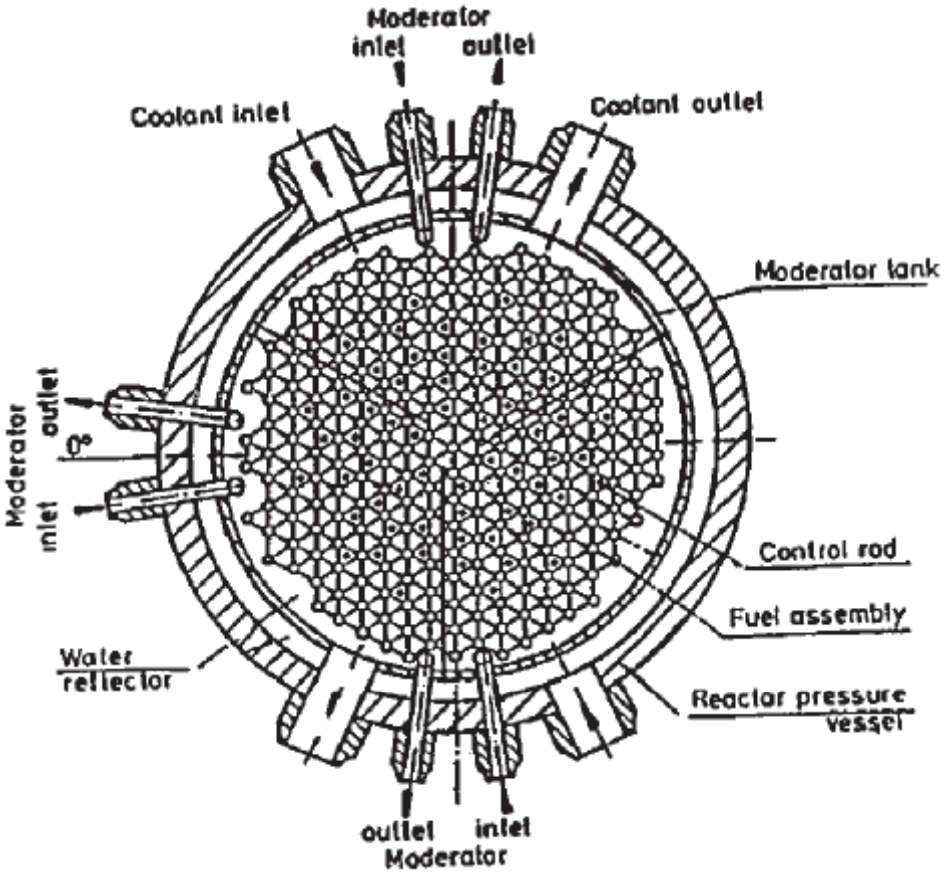
Atucha-I Plant Flow Diagram

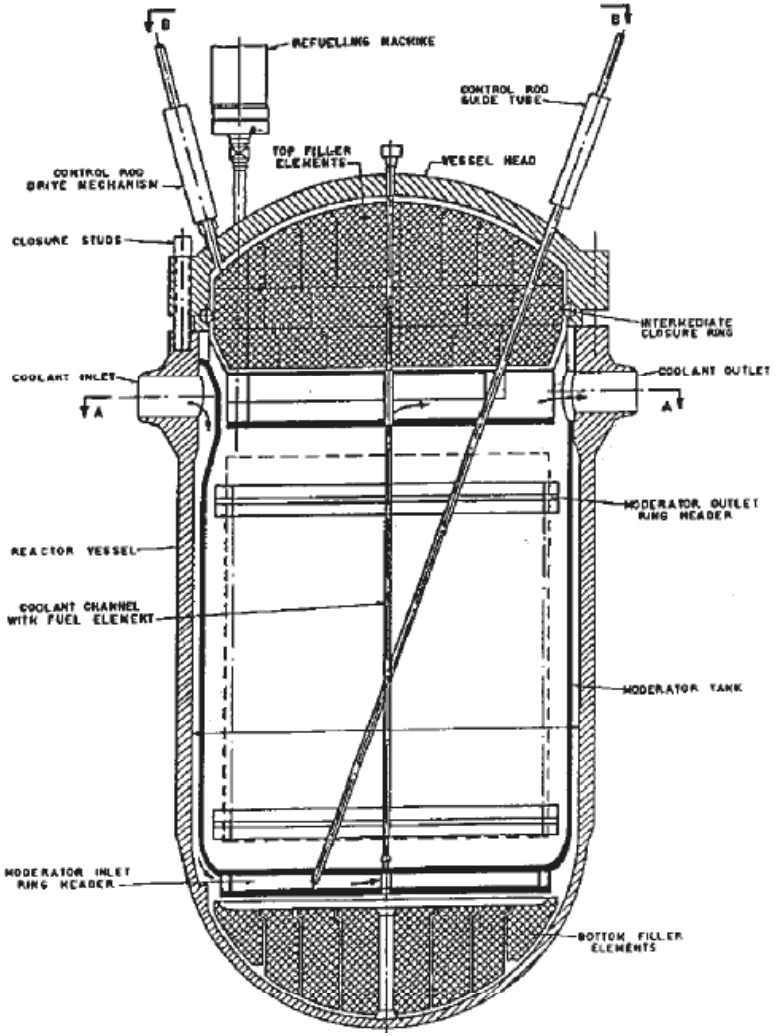


1 Reactor
2 Steam generator
3 Reactor coolant pump
4 Moderator pump
5 Moderator cooler
6 HP turbine
7 Moisture separator
8 LP turbine
9 Condenser
10 LP preheater
11 Feedwater tank
12 Feedwater pump
13 Main cooling water pump
14 Main condensate pump

IAEA Technical Reports Series No. 407, 2002

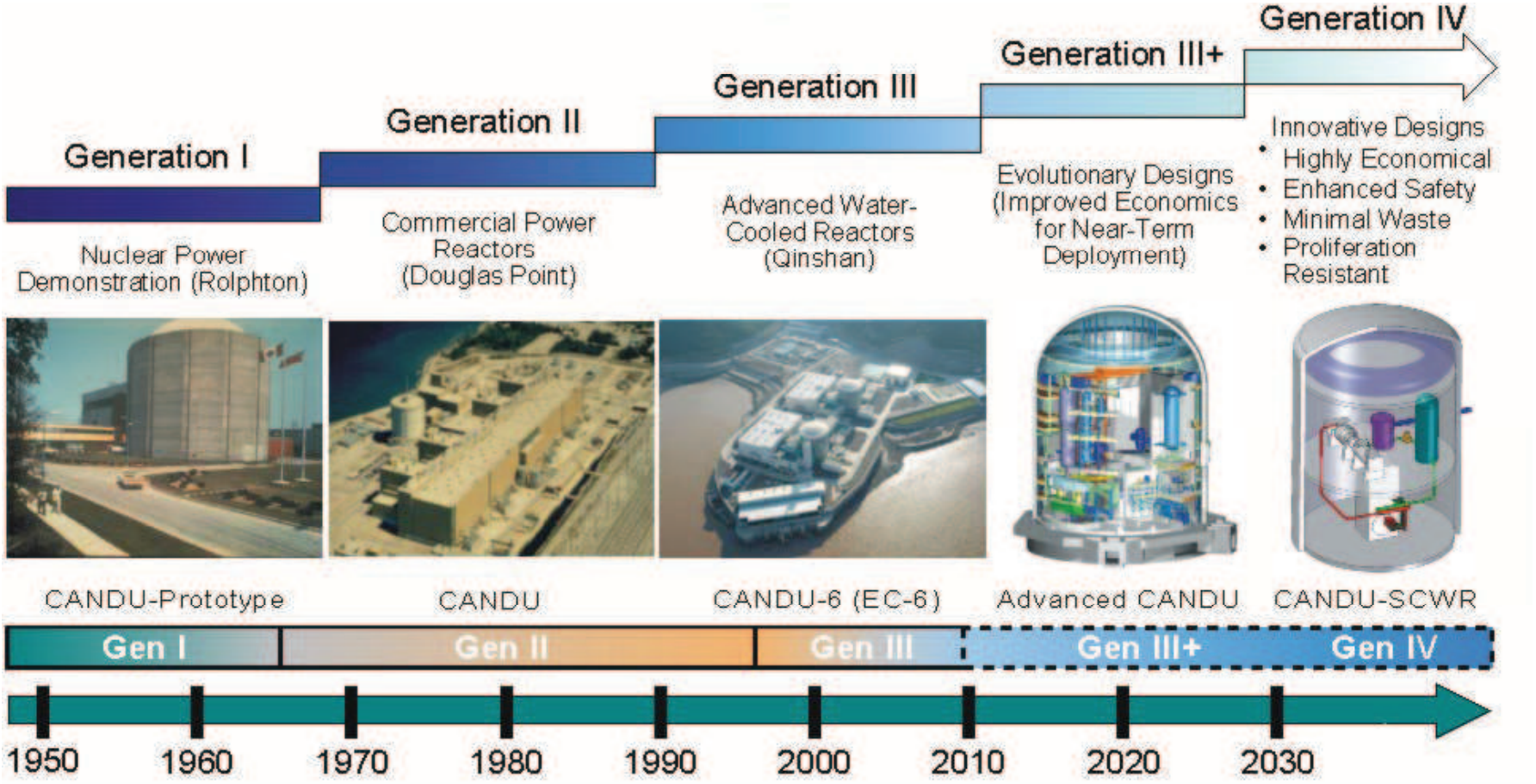
Atucha-I Reactor Core





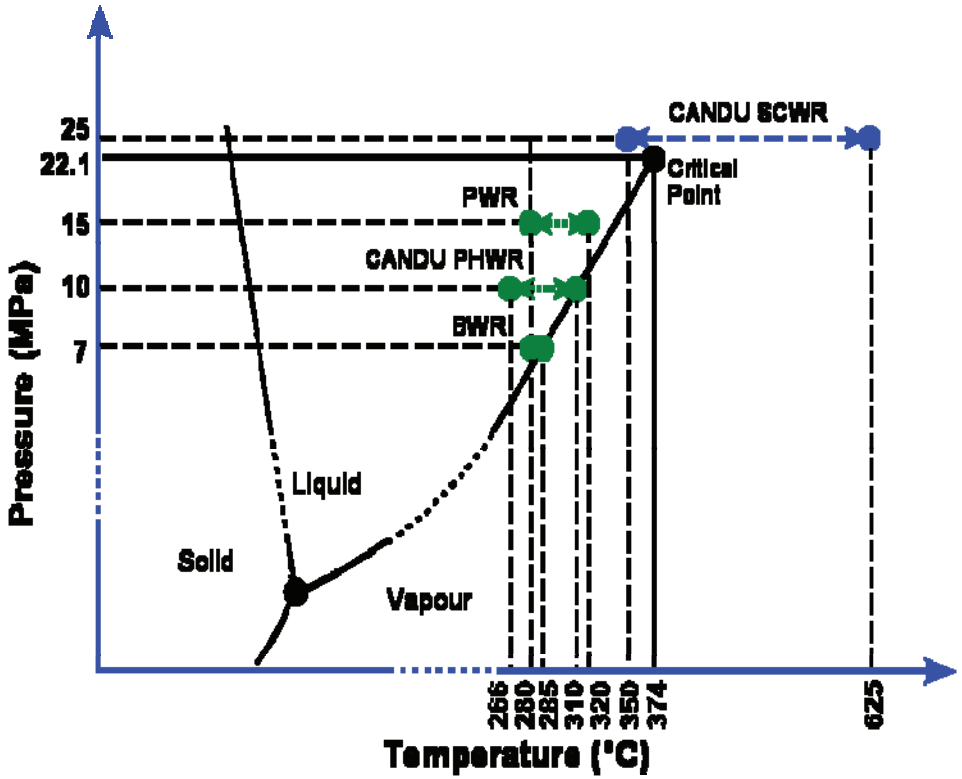
IAEA Technical Reports Series No. 407, 2002

CANDU Design Evolution



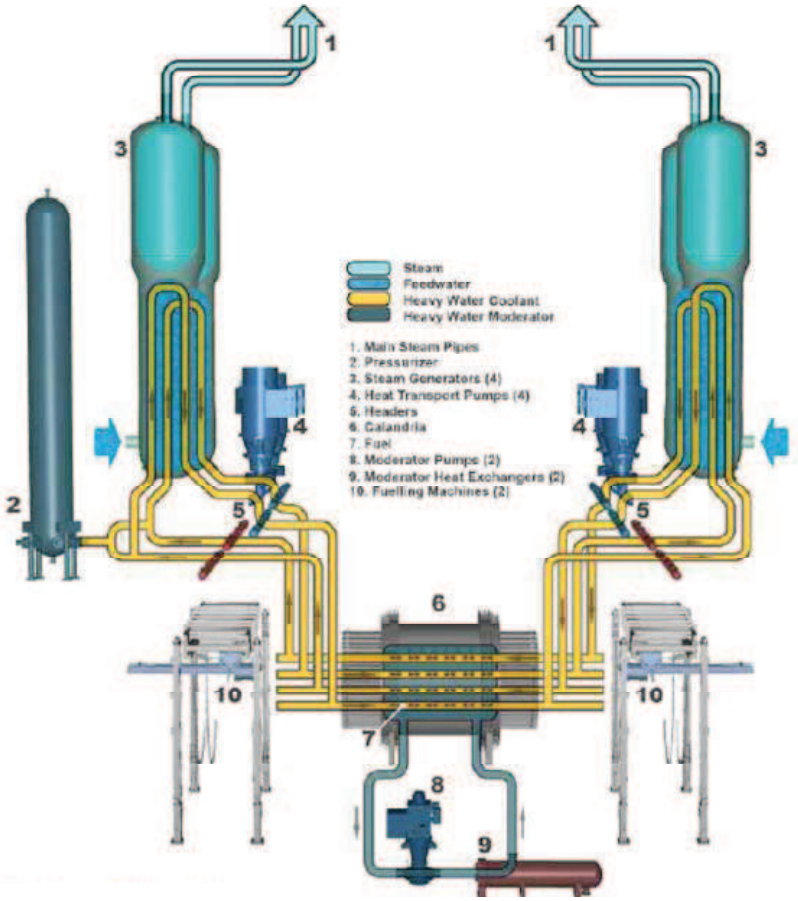
Operating Conditions

- CANDU-6 Reactor
  - Heavy-water cooled, heavy-water moderated
  - Outlet header pressure at 10 MPa(g)
  - Outlet header temperature at 310ºC
  - Thermal efficiency at 35.3%
- Advanced CANDU Reactor
  - Light-water cooled, heavy-water moderated
  - Outlet header pressure at 11.1 MPa(g)
  - Outlet header temperature at 319ºC
  - Thermal efficiency at 36.6%
- Canadian SCWR
  - Light-water cooled, heavy-water moderated
  - Pressure at 25 MPa
  - Outlet temperature up to 625ºC
  - Thermal efficiency up to 48%
    - Further improvement using the reheat-channel option



Nuclear and Fuelling Systems

- CANDU-6 Schematic

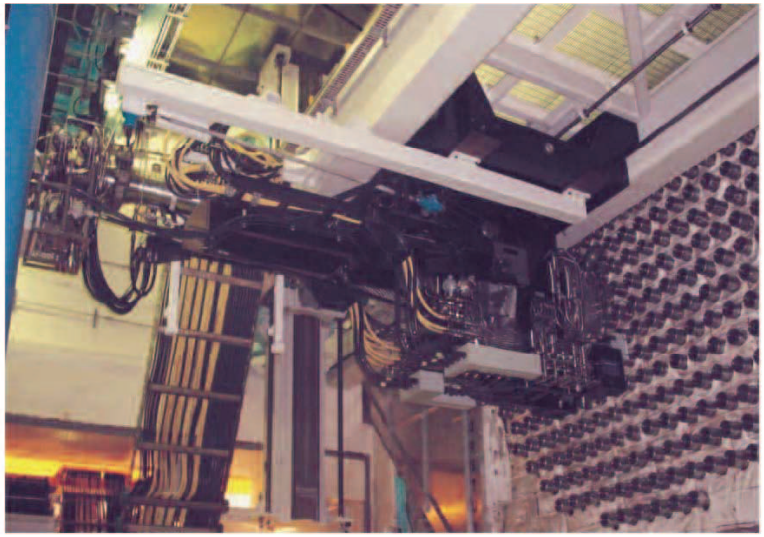


AECL Publication, 2009

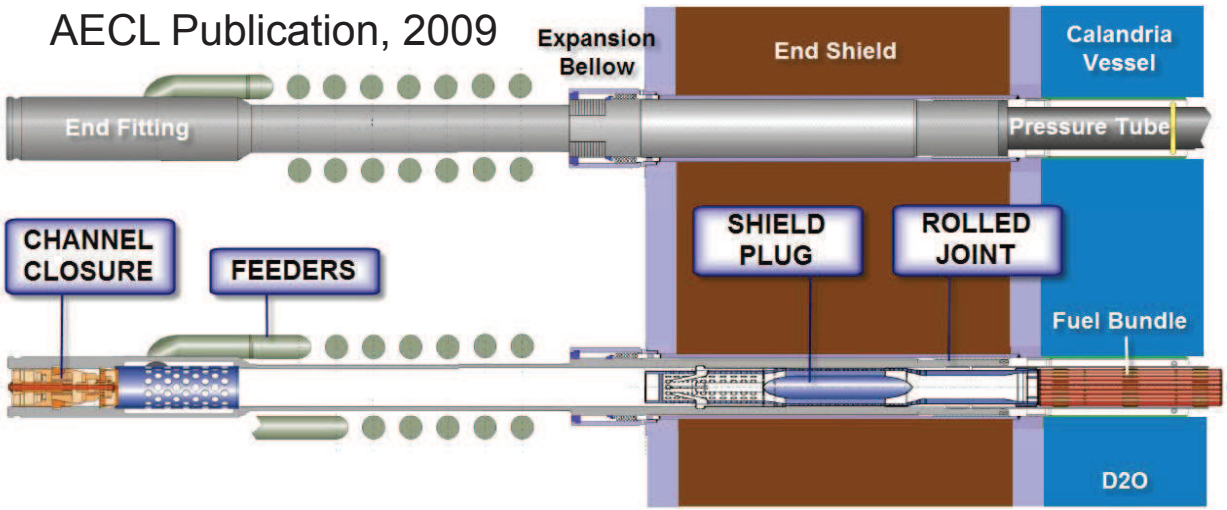
- Canadian SCWR
  - Direct cycle
    - Eliminating steam generators
    - Reducing containment size
    - Reducing capital cost
  - Batch refueling
    - On-line refueling challenging
      - Large fuelling machine
      - Large channel closure plug
    - Horizontal channels become unnecessary
      - Vertical channels core
      - Simplified refueling scheme

Fuelling Machine and End Fitting Components

- Out-of-Core
  - Fuel Channel Hardware
  - Channel closure (seals end of fuel channel)
  - Shield plug (holds fuel bundles and provides shielding)
  - Feeders (connect E/F to headers)
- Interface
  - (Rolled) joint technology

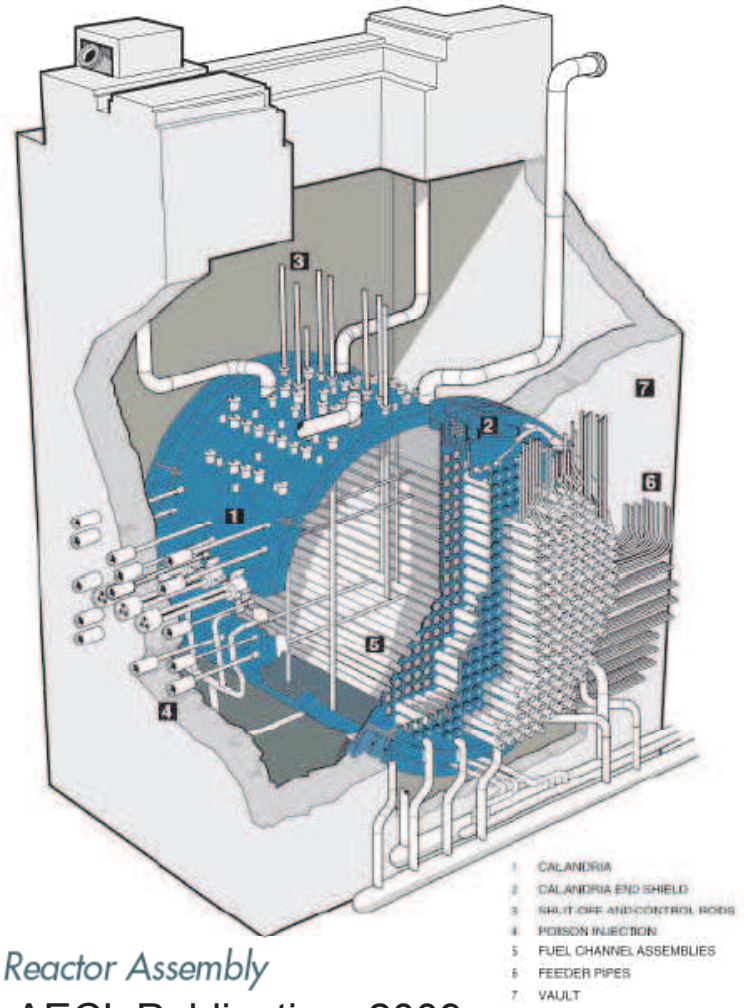


AECL Publication, 2009



CANDU-6 and Canadian SCWR Cores

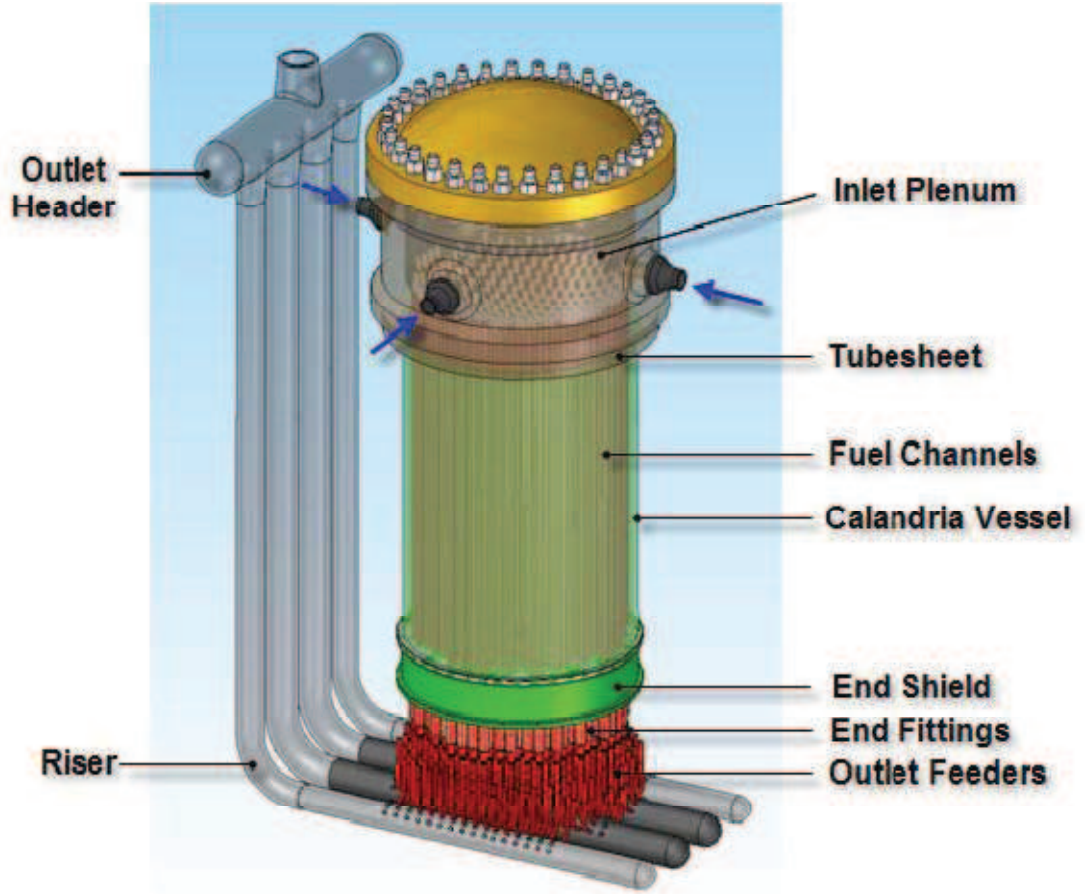
CANDU-6



Reactor Assembly

AECL Publication, 2009

Canadian SCWR



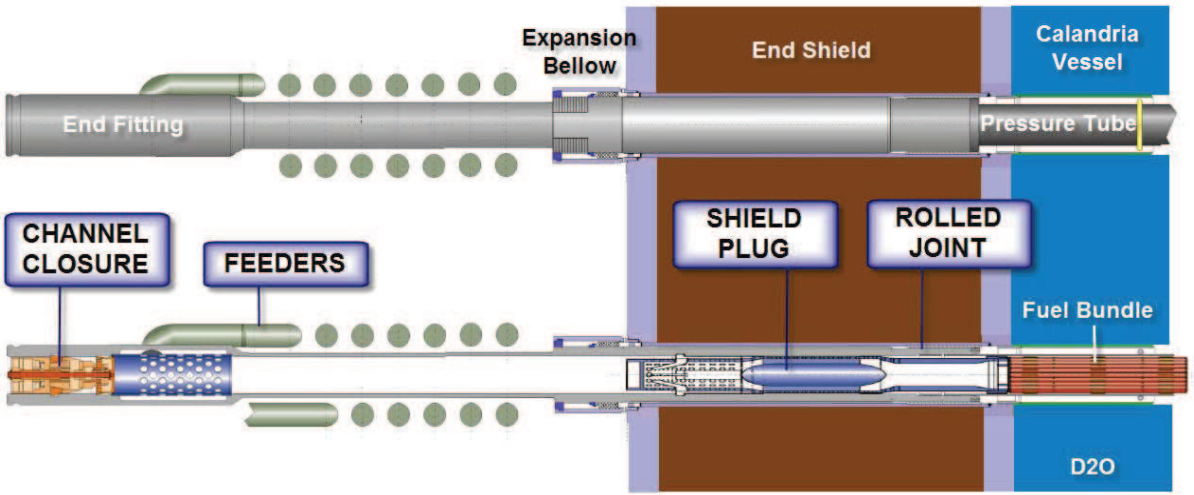
M. Yetisir et al., 2011

Comparison of Core Parameters

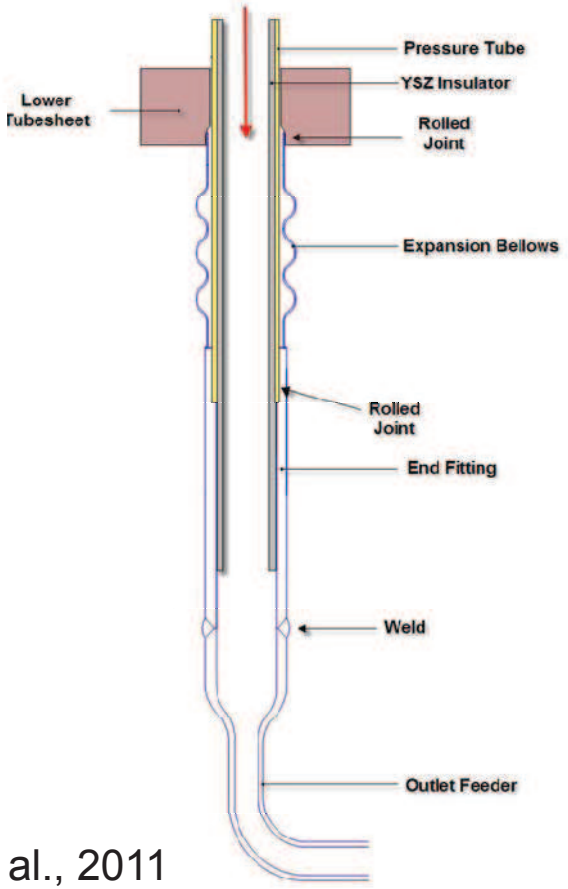
- CANDU-6
  - Calandria vessel ID: ~7.5 m
  - 380 channels
  - Lattice pitch: 286 mm
  - Fuel channel ID: 103.4 mm
  - Active length: 5.94 m
  - Inlet header pressure: 11.8MPa
  - Inlet plenum temperature: 266°C
  - Outlet header pressure: 10MPa
  - Outlet header temperature: 310°C
  - Moderator: heavy water
- Canadian SCWR
  - Calandria vessel ID: ~5.5 m
  - 336 channels
  - Lattice pitch: 250 mm
  - Fuel channel ID: 136 mm
  - Active length: 5 m
  - Inlet plenum pressure: ~26MPa
  - Inlet plenum temperature: 350°C
  - Outlet header pressure: 25MPa
  - Outlet header temperature: 625°C
  - Moderator: heavy water

Outlet End Fitting Configurations

- CANDU-6



- Canadian SCWR

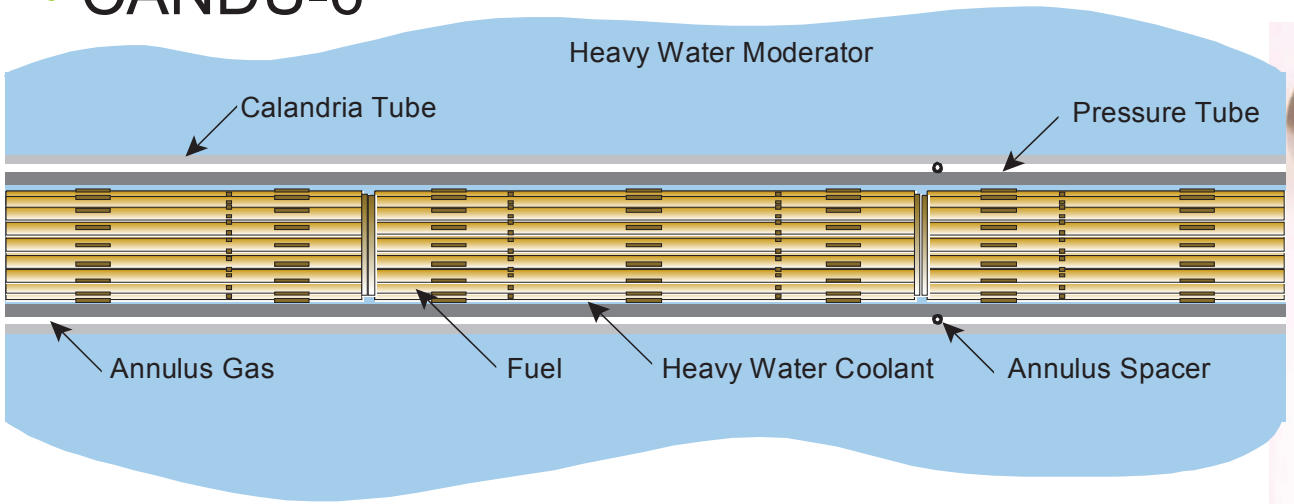


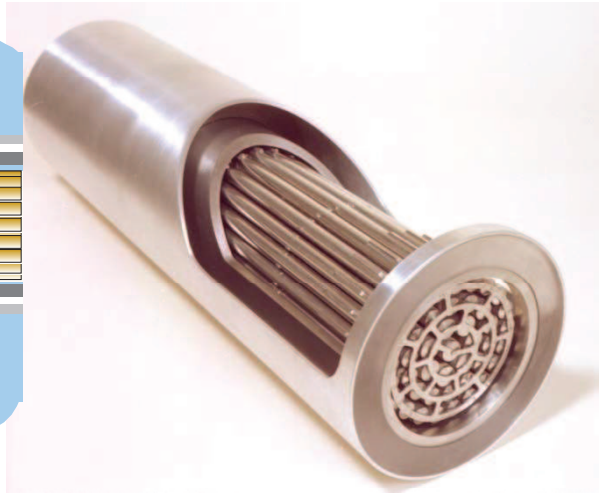
M. Yetisir et al., 2011

AECL EACL

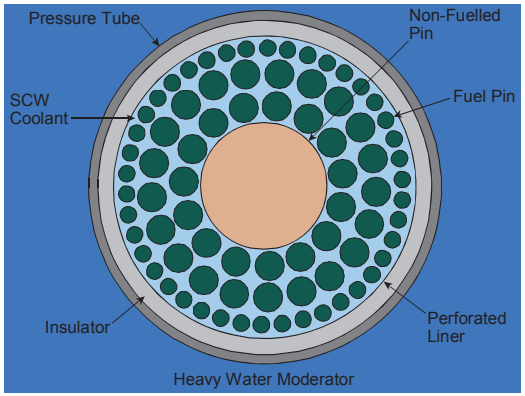
Fuel Channel Configuration

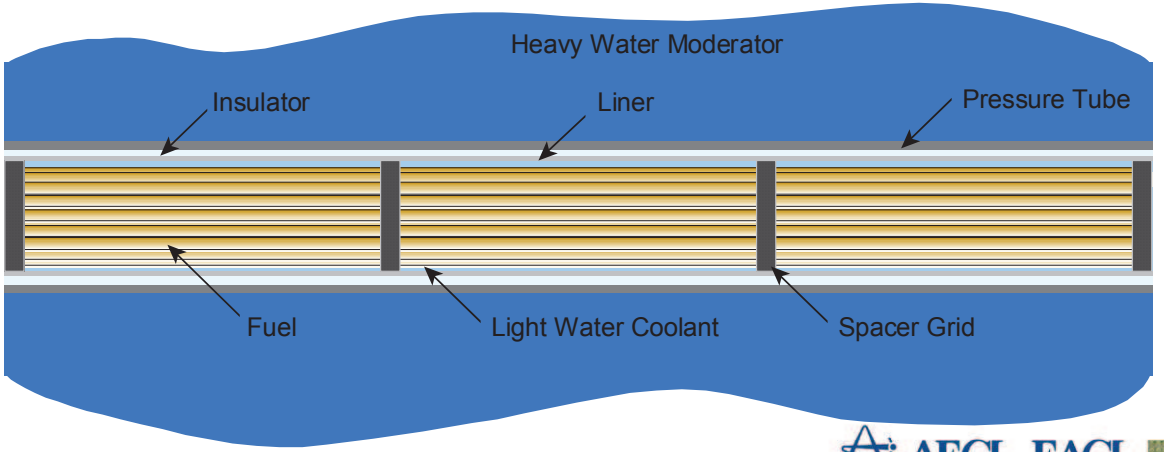
- CANDU-6





- Canadian SCWR

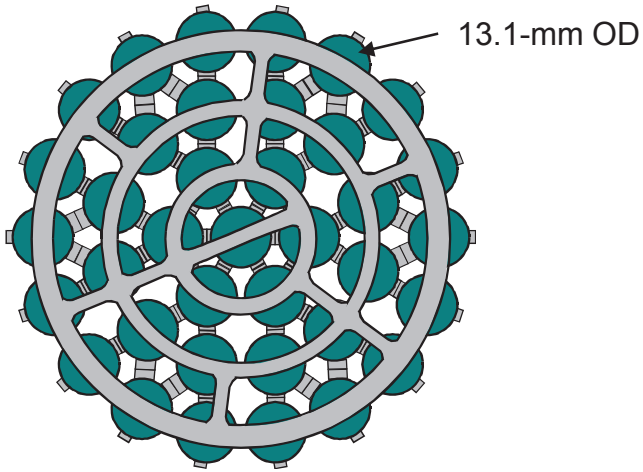




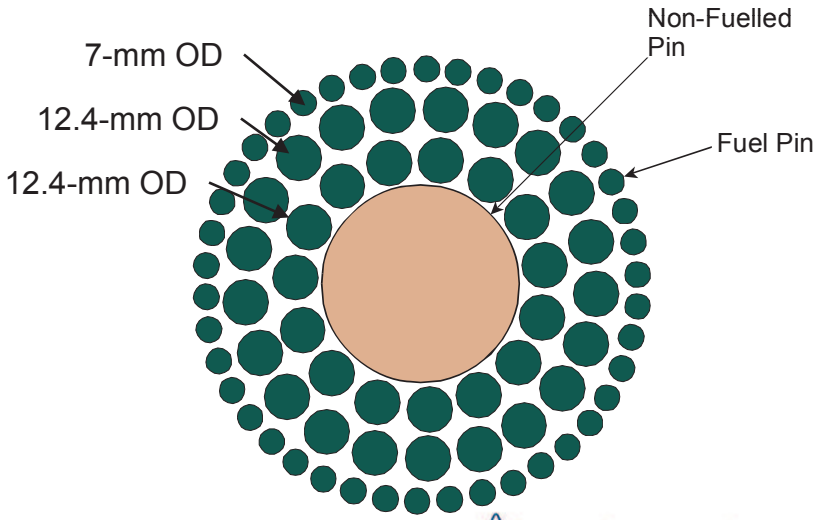
AECL EACL

Fuel Cycle and Fuel

- CANDU-6
  - Natural uranium
  - Exit burnup 7.5 MWd/kg
  - 0.495-m 37-element bundle
  - Zircaloy-4 cladding
  - Appendages: spacer pads, bearing pads, endplates



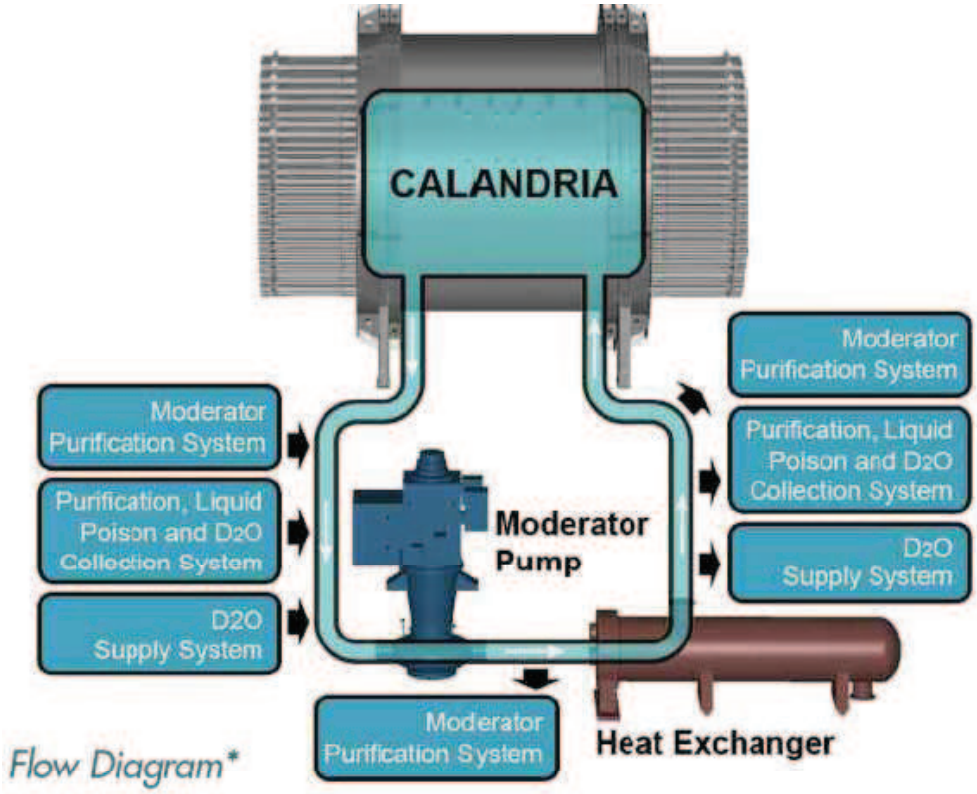
- Canadian SCWR
  - 13%Pu-Thorium
  - Exit burnup 43.1 MWd/kg
  - 5-m 78-element bundle
  - Modified Stainless Steel cladding
  - Appendages: wrapped wires/grids



AECL EACL

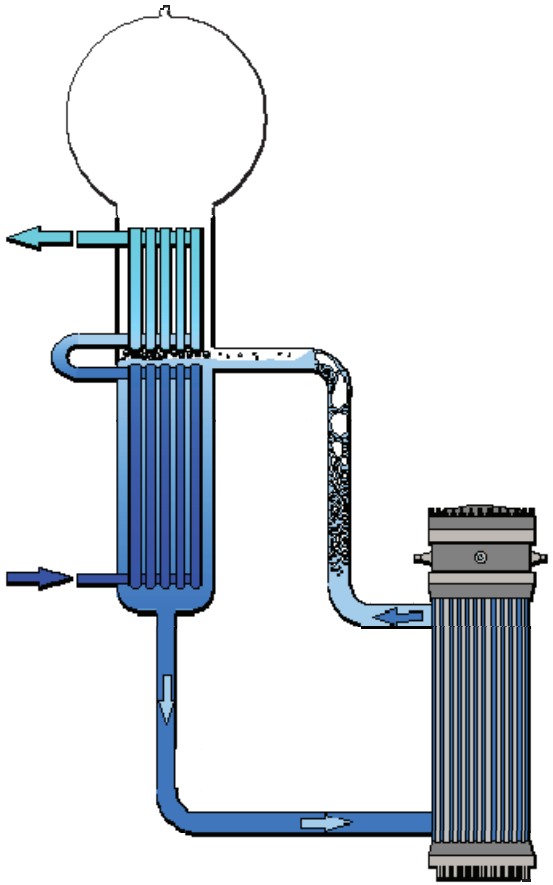
Moderator Cooling System

- CANDU-6



AECL Publication, 2009

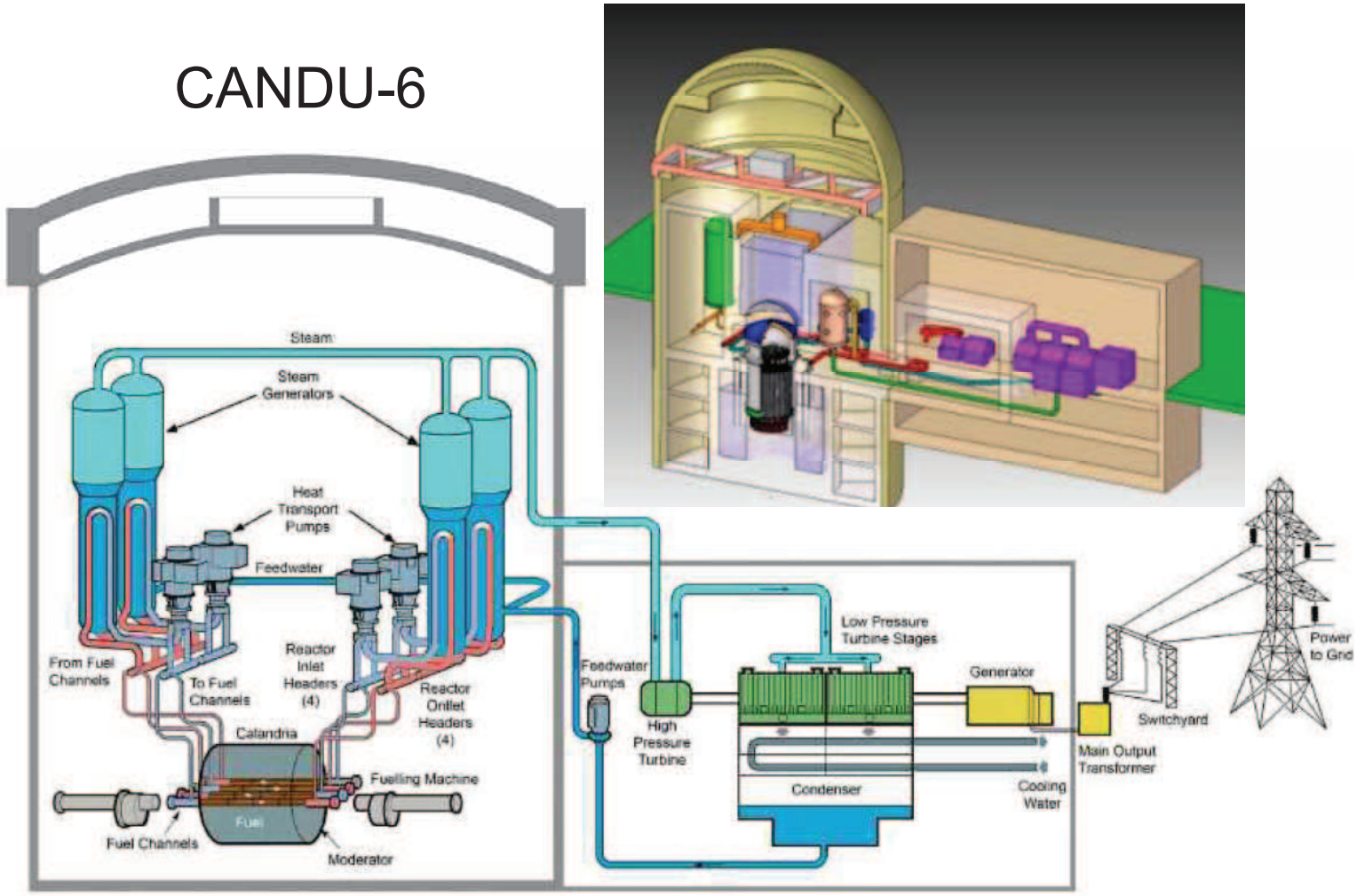
- Canadian SCWR



Plant Layout

Canadian SCWR

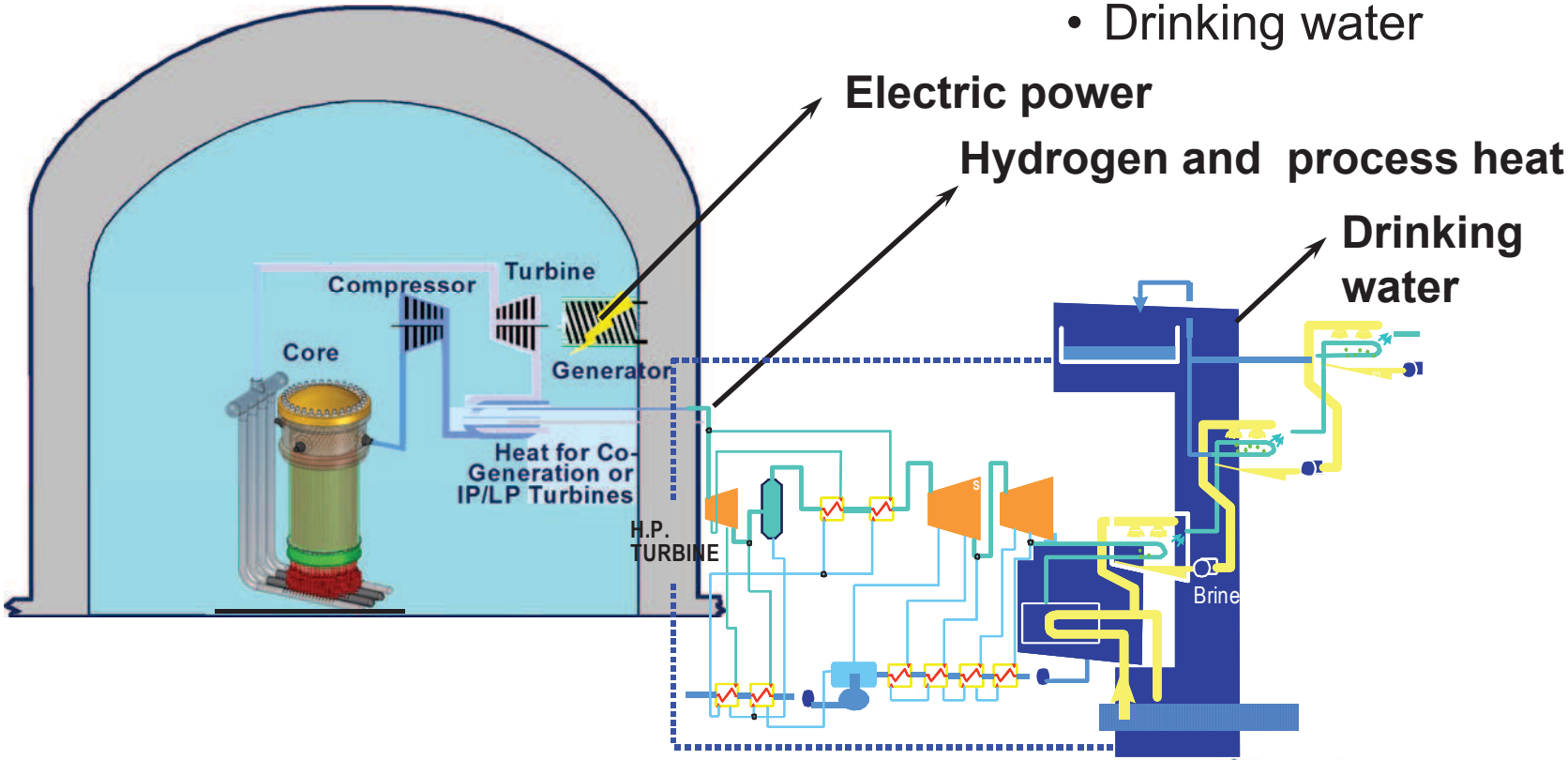
CANDU-6



AECL Publication, 2009

Applications

- Current fleet of HWRs
  - Electrical energy
  - Isotope production
- Canadian SCWR
  - Electrical energy
  - Process heat
  - Hydrogen production
  - Industrial isotopes
  - Drinking water



Conclusions

- 53 heavy-water reactors in operation around the world
- SCWR design concept evolved from the CANDU heavy-water-moderated reactors
  - Modular design with separated light-water coolant and heavy-water moderator
- Major differences from CANDU reactors
  - >48% thermal efficiency
  - Direct cycle
  - Vertical-channel core with batch refueling
  - High-efficiency fuel channel
  - Pu-Thorium fuel cycle
  - 5-m long 78-element bundle
  - Passive moderator cooling
  - Multiple applications

References

- "Heavy Water Reactors: Status and Projected Development", IAEA Technical Reports Series No. 407, 2002.
- "CANDU 6 – Technical Summary", AECL Publication, 2005 June.
- "Enhanced CANDU 6 – Technical Summary", AECL Publication, 2009 November.
- "Advanced CANDU Reactor (ACR1000) – Technical Summary", AECL Publication, 2010 January.
- M. Yetisir et al., "Conceptual Mechanical Design for A Pressure-Tube Type Supercritical Water-Cooled Reactor", Proc. 5th International Symposium on Supercritical Water-cooled Reactors, Vancouver, Canada, March 13-17, 2011.
- M. McDonald et al., "Pre-Conceptual Fuel Design Concepts For The Canadian Supercritical Water-Cooled Reactor", Proc. 5th International Symposium on Supercritical Water-cooled Reactors, Vancouver, Canada, March 13-17, 2011.
- IAEA, "Description of SCWR Design Concepts", Chapter 2 of Heat Transfer Behaviour and Thermohydraulics Codes Testing for SCWRs, IAEA Technical Document, (in draft)


AECL EACL