Design Codes and Standards for CANDU-Specific Requirements

Julian Millard, Manager of Reactor & Fuel Handling

Marc Leger, Director, Materials Engineering

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AECL TECHNOLOGIES INC.

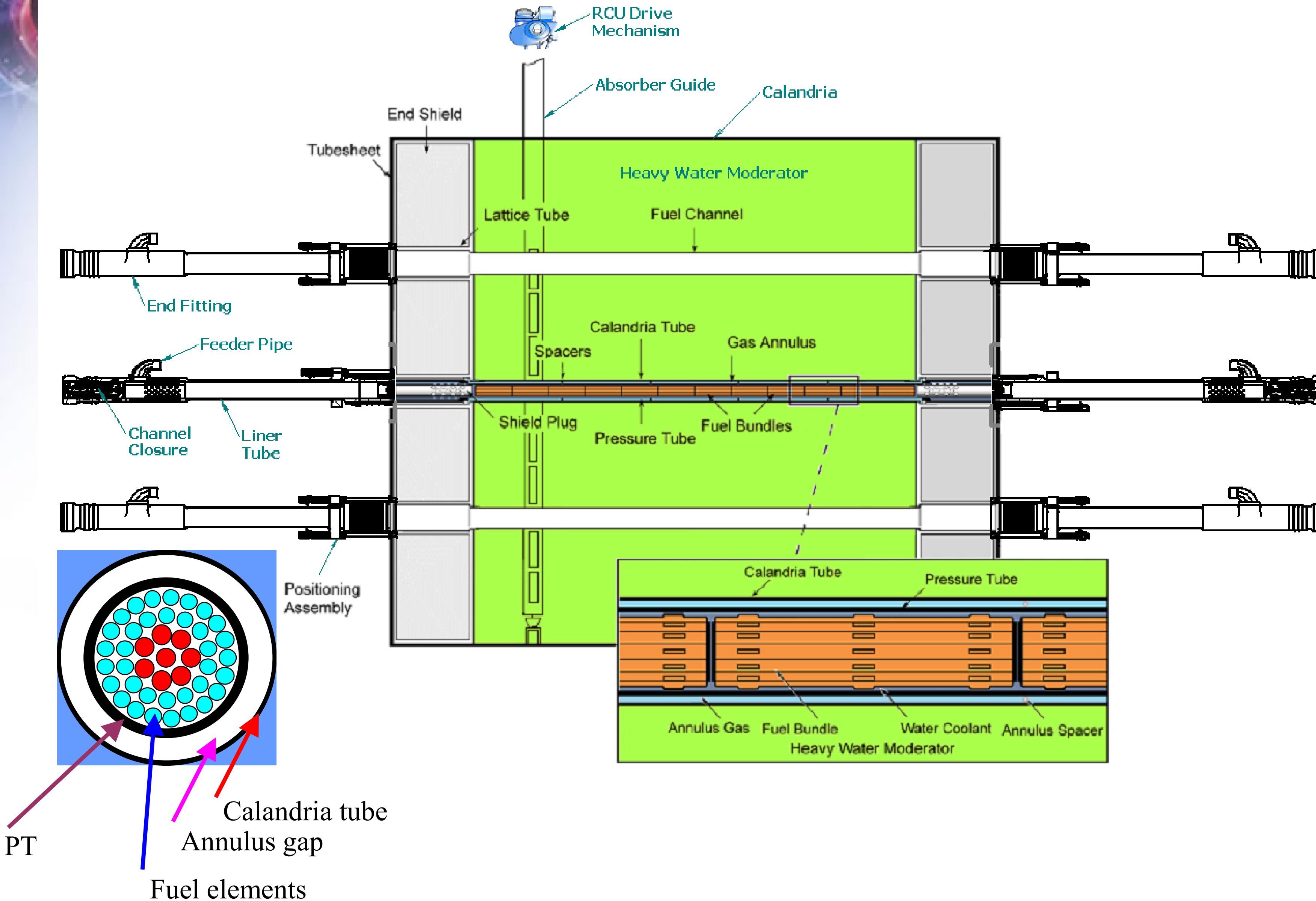
Overview

- CANDU-Specific Design Features
- Codes and Standards applied in design
- Need for additional requirements to address CANDU-specific aspects of the ACR-700 design
- Summary

CANDU – Specific Features

- Fuel channels with zirconium alloy tubes as the in-core RCPB
- On-power refueling requiring extensions of the RCPB to the fueling machine
- Reactivity control units in low pressure vessel
  - Control rod drive housings not part of RCPB

Reactor Assembly Arrangement



Codes and Standards Applied to Design

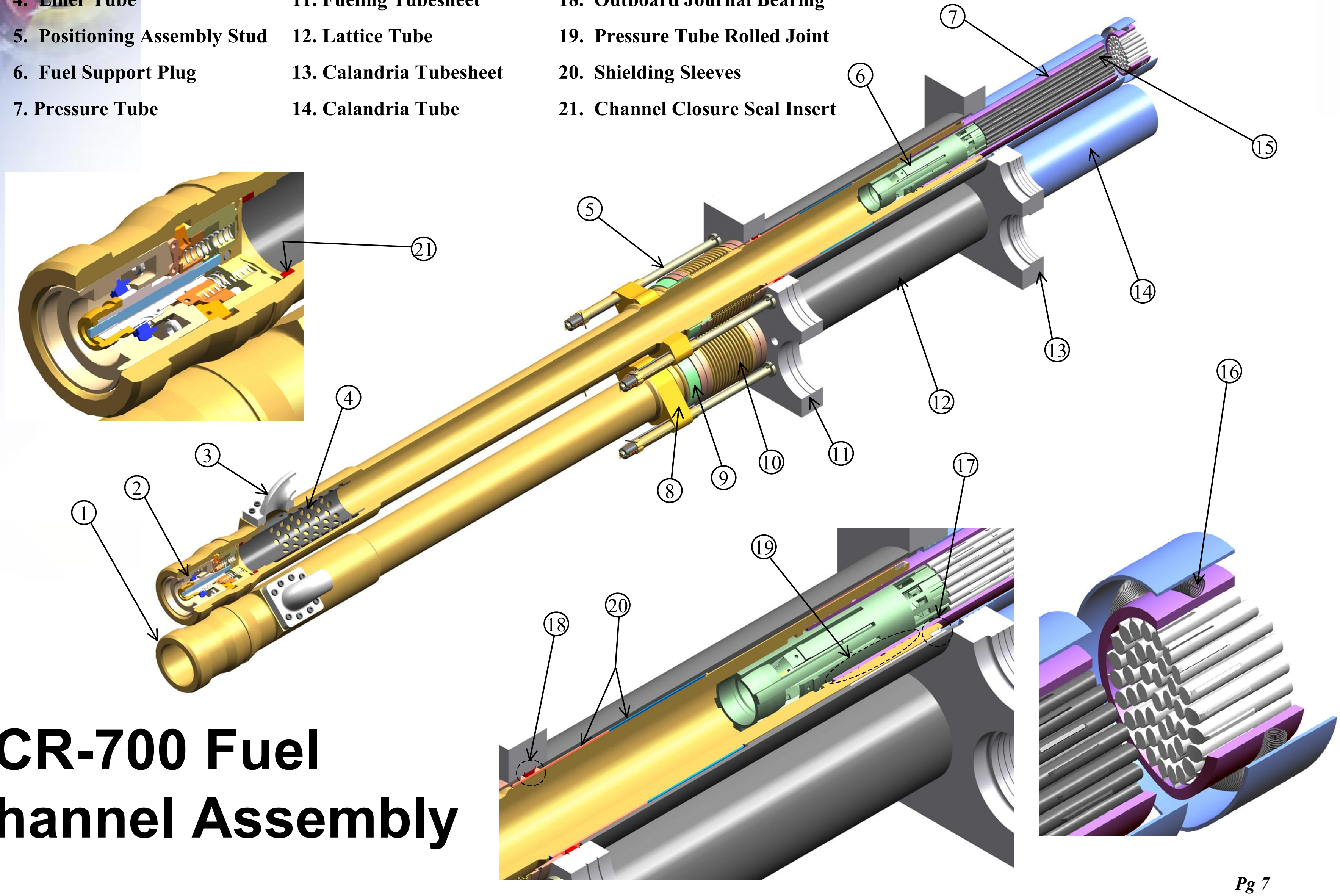
- The ASME Boiler and Pressure Vessel Code is applied to the design of CANDU reactor components
  - ASME B&PV addresses primarily pressure vessel reactor features
  - Additional elements required for CANDU-specific features
  - Canadian Standards currently form the necessary complement
    - Standards reflect design intent of ASME for CANDU-specific items and refer to ASME design requirements
    - Materials standards specific to CANDU defined

Fuel Channel Components

RCPB Components

- Components
  - Pressure tube
  - End fittings
    - Joint between pressure tube and end fitting
    - Feeder connections
  - Channel Closure Plug
  - Fuel Support Plug
  - Spacers in annulus between pressure tube and calandria tube
  - Calandria tube
  - Positioning assembly
  - Bellows and connection to annulus gas system

1. End Fitting
2. Channel Closure
3. Feeder Connection
4. Liner Tube
5. Positioning Assembly Stud
6. Fuel Support Plug
7. Pressure Tube
8. Position Assembly Yoke
9. Bellows Attachment Ring
10. Bellows Assembly
11. Fueling Tubesheet
12. Lattice Tube
13. Calandria Tubesheet
14. Calandria Tube
15. Fuel Bundle
16. Channel Annulus Spacer
17. Inboard Journal Bearing
18. Outboard Journal Bearing
19. Pressure Tube Rolled Joint
20. Shielding Sleeves
21. Channel Closure Seal Insert



ACR-700 Fuel Channel Assembly

Pressure Tube – Additional Requirements

- In addition to satisfying the ASME Class 1 design / analysis rules, pressure tubes must also satisfy additional requirements, such as:
  - Pressure tubes shall be protected against delayed hydride cracking by ensuring that the maximum tensile stress, under design level A and level B conditions, plus the maximum initial residual stress, shall at no time exceed 67% of the tensile stress required to initiate delayed hydride cracking as determined in the laboratory by tests on unnotched specimens
  - Pressure tubes shall be supported such that they will not contact the calandria tube during the life of the channel
  - A system capable of detecting leaks before through-wall cracks grow to unstable lengths shall be provided

Pressure Tube Material Requirements

- Special requirements for the fabrication and properties of seamless zirconium alloy tubing suitable for use as the in-core portions of fuel channels (pressure tubes)
- ASTM-B353 (UNS R60901) now also specifies similar fabrication and properties requirements for zirconium alloy pressure tubes
- The peak allowable design stresses are defined in the same way as ASME (the lowest of two-thirds YS or one-third UTS)
- In addition, AECL has material specifications that define additional requirements for pressure tubes

Pressure Tube to End Fitting Rolled Joint – Additional Requirements

- The joints are designed in accordance with the rules of Section III, paragraph NB-3200, of the ASME Code
- Prototype joints are subjected to performance tests to determine the structural integrity of the joints under simulated service conditions
- Production joints are produced using the same tooling design and procedures that have been qualified in the manufacture of prototype joints
- The joints are accessible for inspection through the inside of the fuel channel
  - The integrity of the joints monitored continuously using the annulus gas system

End Fitting Material

- The EF is designed in accordance with the ASME Code Section III, Subsection NB requirements with additional material requirements
- Special requirements are defined for a modified type 403 stainless steel, including its inspection and design data
  - The requirements restrict the chemical composition limits to ensure good corrosion resistance (to prevent deterioration of the various seal faces) and to provide high strength (required for the pressure tube rolled joint area to assure a strong, leak-tight connection)

Channel Closure Plug – Additional Requirements

- **Removable pressure boundary component to permit fuel changing, designed in accordance with the ASME Code Section III, Subsection NB and additional requirements to provide for the safe extension of RCPB to the fueling machine:**
  - **Secondary mechanical lock to prevent accidental release**
  - **Limited leakage in the event of seal failure**
  - **Leak test performed during each use**
  - **Make installation fail safe**

Fuel Channel Positioning Assembly

- **Classified as a Class 1 component support, designed to ASME Code Section III, Subsection NF**
  - **Provides reaction to axial positioning loads from the fueling machine**

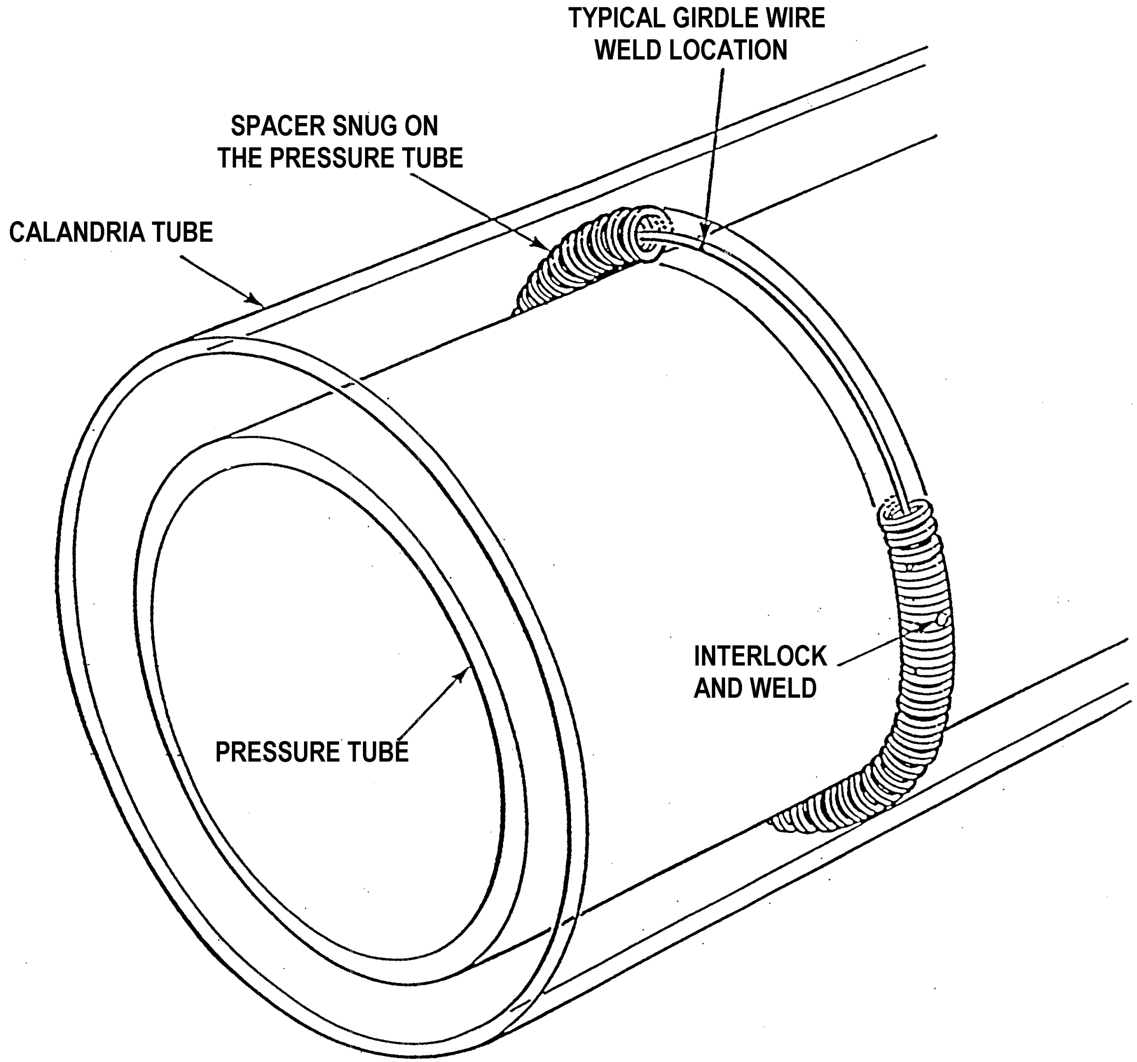
Annulus Bellows

- They are not part of RCPB, but form part of the annulus gas system pressure boundary and are not safety related.
- The Annulus Bellows are designed to B31.1

Annulus Spacer

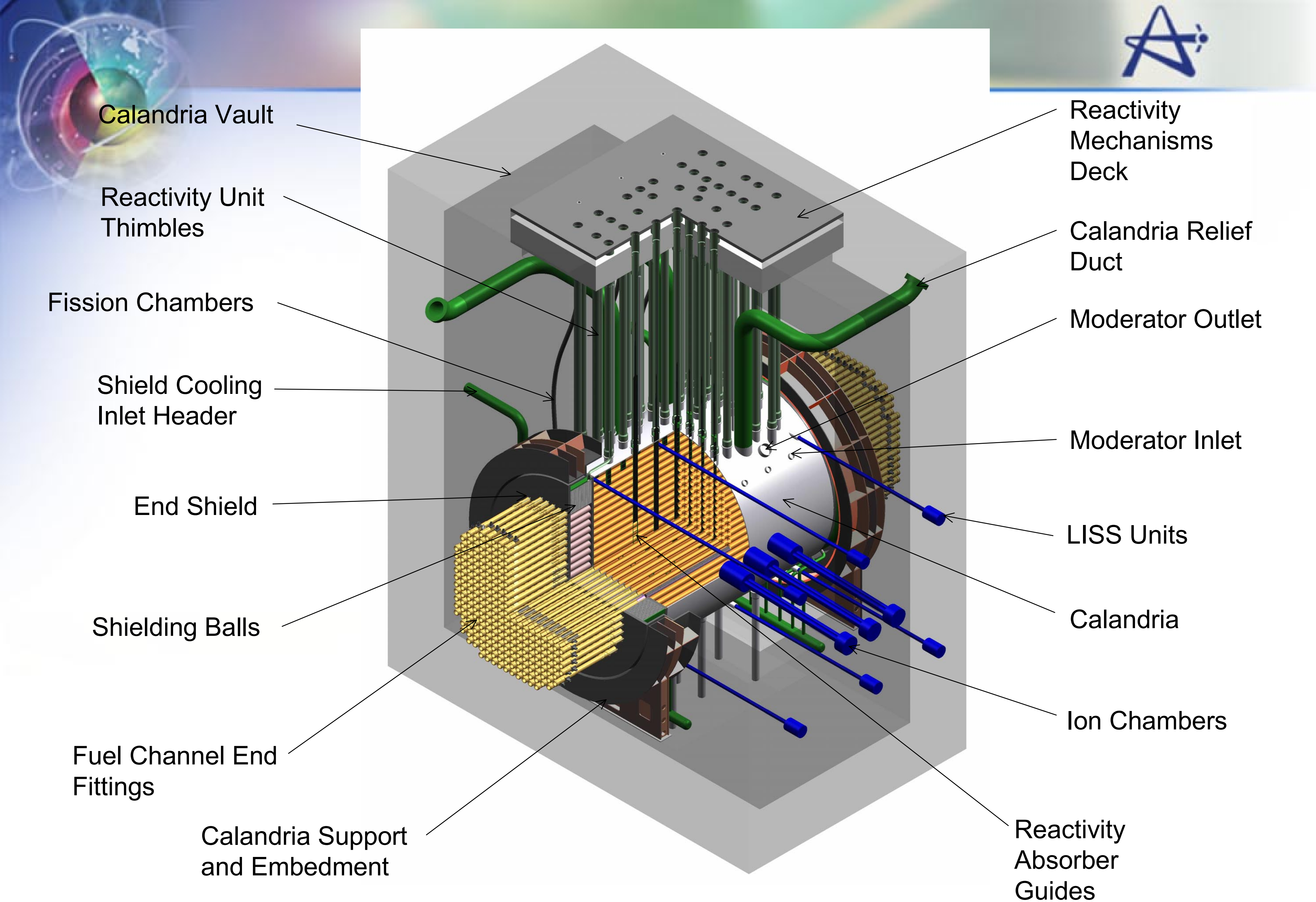
- The pressure tubes have to be supported such that they will not contact the calandria tube during the life of the fuel channel.
- Four annulus spacers keep each pressure tube separated from the calandria tube, preventing direct contact between the tubes during all operating conditions.
- The spacers allow the calandria tube to provide support for the pressure tube.
- The spacers are positioned about a meter apart so that the pressure tube sag will not result in contact with the calandria tube surrounding it.
- ACR-700 design uses a tight-fitting garter spring.
- The material is the same as recent CANDU designs — Inconel X-750 for the coil and Zircaloy-4 for the girdle wire.

Annulus Spacer



Calandria Assembly

- Not part of RCPB
- The calandria assembly is designed, analyzed, and fabricated in accordance with the requirements of the ASME Boiler and Pressure Vessel Code, Section III, Subsection NC.
- The calandria assembly is a multi-compartment vessel comprising the calandria vessel, two end shield vessels and calandria tubes.
- The calandria assembly includes integral supports and embedment structures to connect it to the building structure.



ACR –700 Reactor Assembly

Calandria Assembly Supports

- The calandria assembly supports are classified as component supports, and shall meet the Class 1 requirements of the ASME Boiler and Pressure Vessel Code, Section III, Subsection NF
- The calandria assembly supports anchor the calandria vessel and the two end shields
  - Also in the support load path from the fuel channels to the building structure

Calandria Tubes – Additional Requirements

- Designed to ASME Code Section III Subsection NC requirements
- Not part of the RCPB, but form part of the calandria vessel (moderator) pressure boundary, made from zirconium alloy grade R60804
- Additional requirements have to be met for the calandria tube to tubesheet joints, such as:
  - provisions to prevent separation of the joints under all specified service loadings
  - joints are inspected on installation, integrity monitored by annulus gas system
  - prototype joints shall be subjected to qualification tests to determine the structural integrity of the joints under simulated service conditions
  - production joints produced using the same tooling design and procedures that have been qualified in the manufacture of prototype joints
- The ends of the calandria tubes are roll expanded into the calandria tubesheets forming high-integrity joints

External Pressure Design of the Calandria Tube

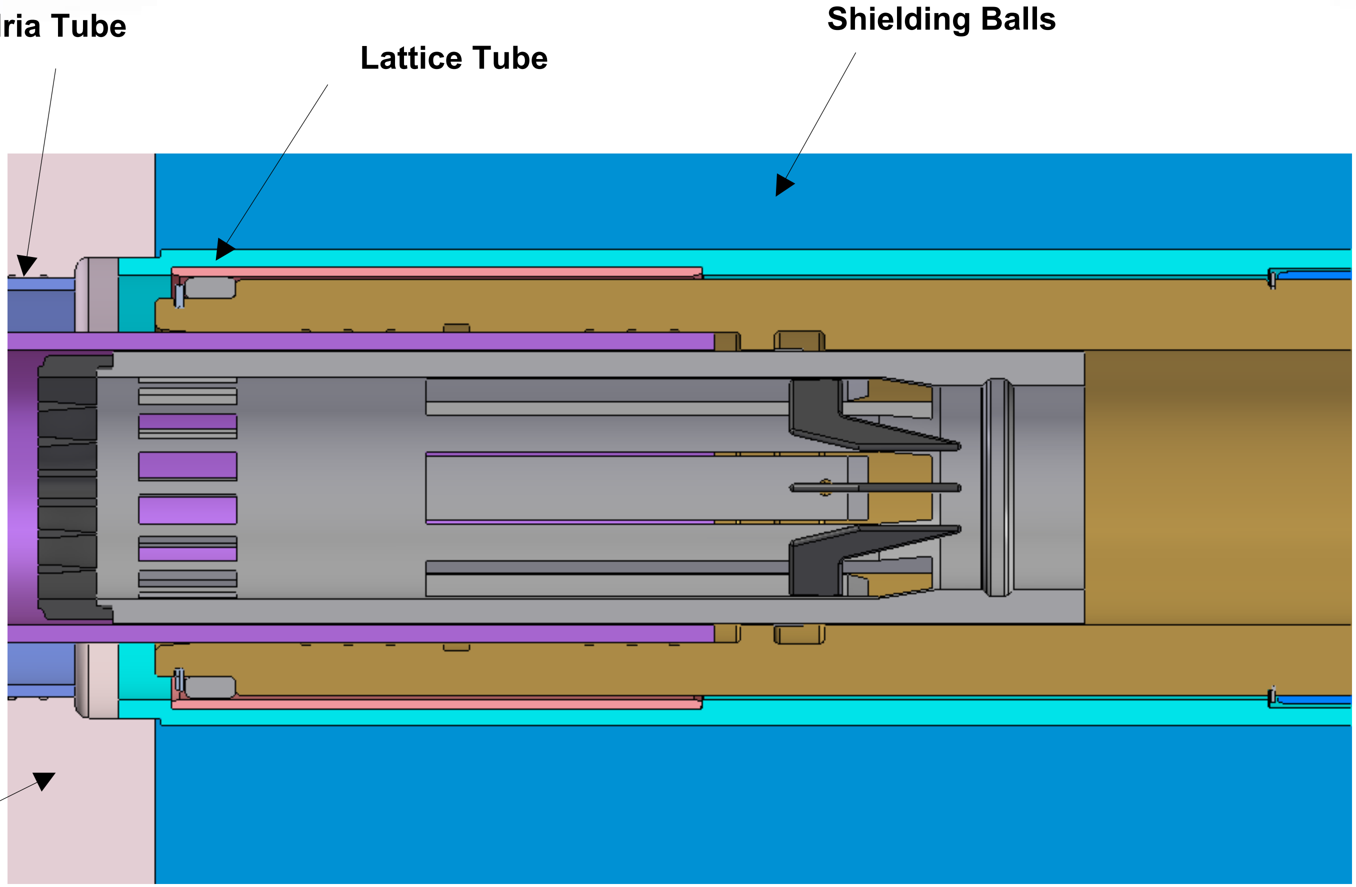
- It shall be shown by test or analysis that deformation of the calandria tube onto the pressure tube, due to external pressure under all service conditions, will not cause rupture of the calandria tube, in lieu of the requirements of the ASME Section III, paragraph NC-3133.3

Lattice Tubes

- Not part of the RCPB, form part of the end shield pressure boundary.
- The lattice tube to tubesheet joint strength shall be demonstrated by analysis to be adequate for imposed service loading. The stress in the lattice tube to tubesheet joints satisfies the stress intensity limits of the ASME Code.
- Additional requirements include:
  - The tube shall have an interference fit with the tubesheet bore after fabrication is completed to eliminate crevices, which might be sites for corrosion.
  - The lattice tube to tubesheet joints in the end shields are formed by welding. The root and final pass of each weld shall be examined by the liquid-penetrant method.

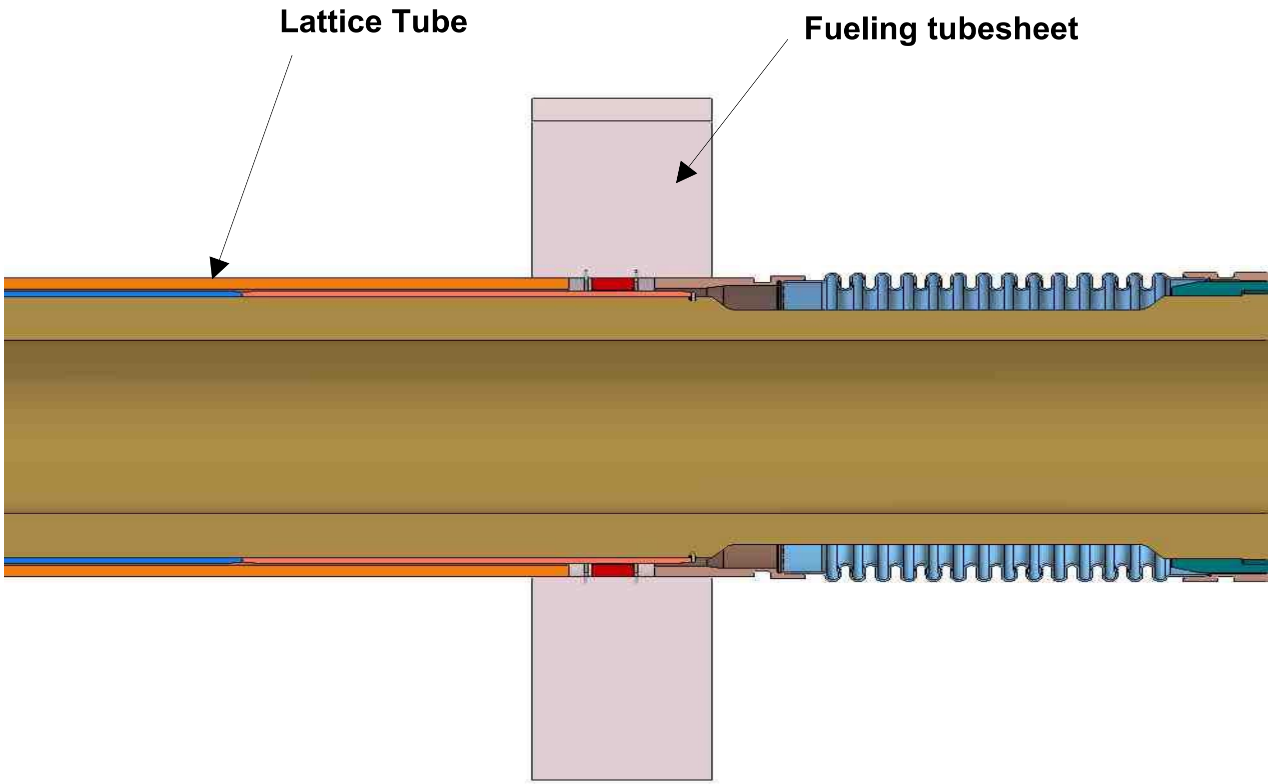
Lattice Tube (inboard end)

- Shrink fit in the calandria tubesheet and welded



Lattice Tube (outboard end)

- Slightly rolled for interference in the fueling tubesheet and welded



Reactivity Control Units

- Designed to ASME requirements
- Requirements of the SRP 3.9.4 (Control Rods Drive Systems) related to RCPB are not applicable to Reactivity Control Units in ACR-700, because they are not part of RCPB
- The control rods and shutoff rods thimble and the drive mechanism housing form part of the (low pressure) moderator boundary, and meet the requirements of a Class 3 fitting as per Section III, Subsection ND of the ASME Code

Fueling Machine

- Fueling machine snout attachment lock
  - 2 diverse locks including 1 positive mechanical lock
  - Engaged prior to removing channel closure
  - Regular tests
- Fueling machine catenary hoses
  - Qualification tests
  - Defined life
- Fueling machine supports
  - Analyse supporting mechanism using NF rules
  - Interlock to prevent motion that could affect pressure boundary
- Threaded connections
  - Rules for threaded connections for small diameter lines in Class 1 applications defined

Fuel Handling Nuclear Safety Functions - Summary

- RCS pressure boundary integrity
- Channel flow blockage detection
- Cooling and shielding of spent fuel
- Containment boundary integrity preservation
- Defective fuel bundles removal
- Criticality safety
- Fuel Handling System contributes to:
  - reactor core reactivity management
  - fuel bundle power management in channel

Design Features to Enhance Safety During Fueling - Summary

- Diverse mechanical and electrical safety interlocks prevent unintentional or unsafe release from a fuel channel to maintain RCS integrity
- Controls and instrumentation that are required to operate during and following a SSE, LOCA or MSLB are seismically and environmentally qualified
- A seismically and environmentally qualified emergency water system is included to maintain fuel cooling when the Fueling Machine is off reactor during and following a SSE, LOCA or MSLB or if the normal system becomes unavailable
- Stainless steel tubes arranged in a basket format guarantee sub-criticality of the fuel in all mediums

Design Features to Enhance Safety During Fueling - Redundancy

- All controls on uninterruptible power. Redundant motors on different buses of diesel generator backed ac power
- Redundant normal cooling circulation pump sets
- Redundant emergency water system pump sets
- Emergency water system HX can be supplied with from either division of RCW
- Redundant FM magazine cooling supply and return hoses with isolation
- Emergency cooling supply and return hoses, separate from the normal hoses
- Nuclear Class 1 valves on the FM head can be closed to isolate the FM head. Additional MVs, SVs, excess flow valves or check valves are provided.
- A dual redundant seismic trip system removes power from selected motors, brakes and valves prior to the destructive wave of a seismic event
- Redundant interlocks and multiple brakes protect against potential damage to the fuel channel end fitting by inadvertent FM movement.
- All containment penetrations have dual containment isolation valves

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