On Power Fueling Technology
Part 1: ACR

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AECL TECHNOLOGIES INC.

Synopsis

- This presentation explains the advantages found in the CANDU reactor design from the use of on power fueling and describes the equipment used
- On power fueling allows a low core reactivity to be maintained and provides flexibility in station maintenance outages
- CANDU reactors have been safely and successfully using on power fueling for 4 decades in 45 reactors
- The ACR design builds on that experience with a new system with improvements in safety, operability and maintainability

ACR 700

- The ACR 700 reactor is an evolutionary design building on past CANDU designs
- It uses slightly enriched fuel in a 284 channel horizontal pressure tube reactor
- On power fueling is used with a small constant staff complement
- This presentation is based on AECL report 108-35000-REPT-001

Overview

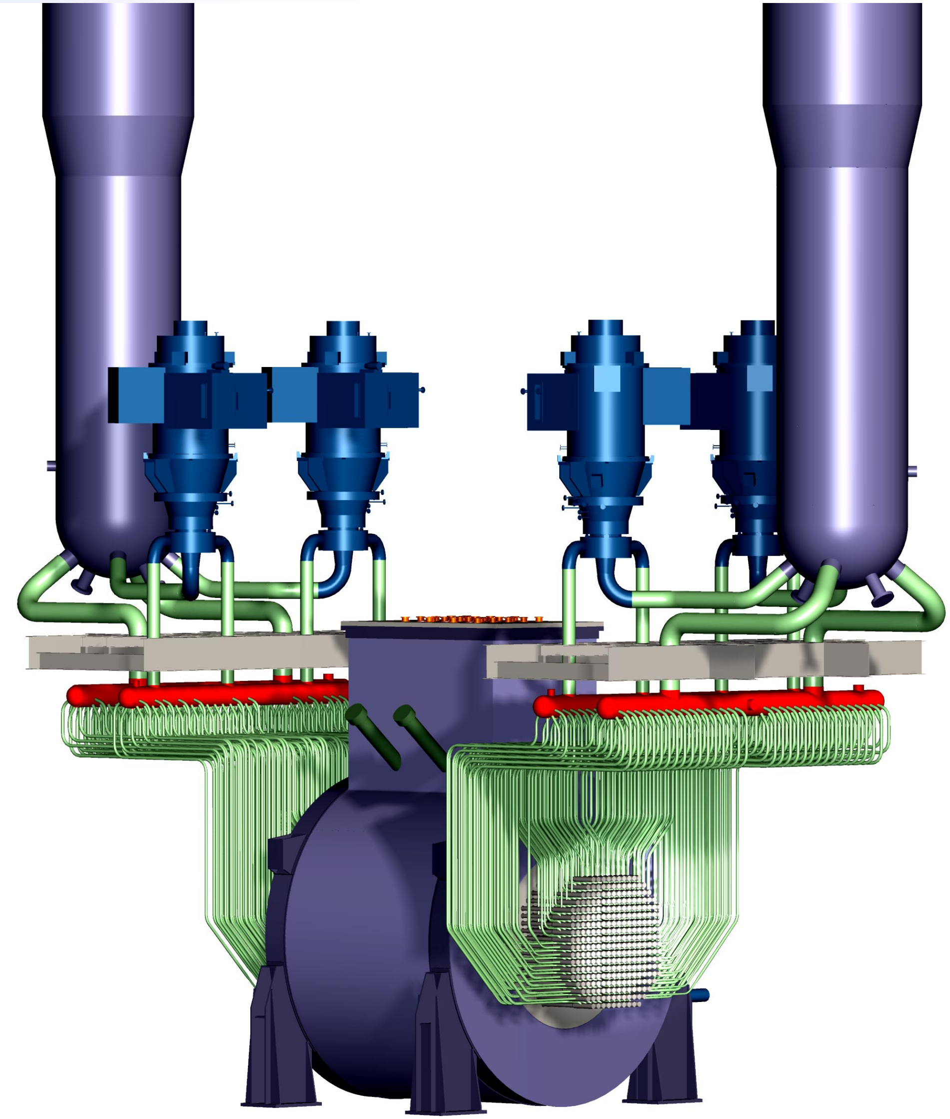
The On Power Fueling Technology presentations cover:

- **Part 1**
  - Fueling Scheme
  - Overview of Fueling Equipment and Interfaces
  - Design Features to Enhance Safety
  - ACR Fuel Handling Systems
- **Part 2**
  - Current CANDU Design & Experience

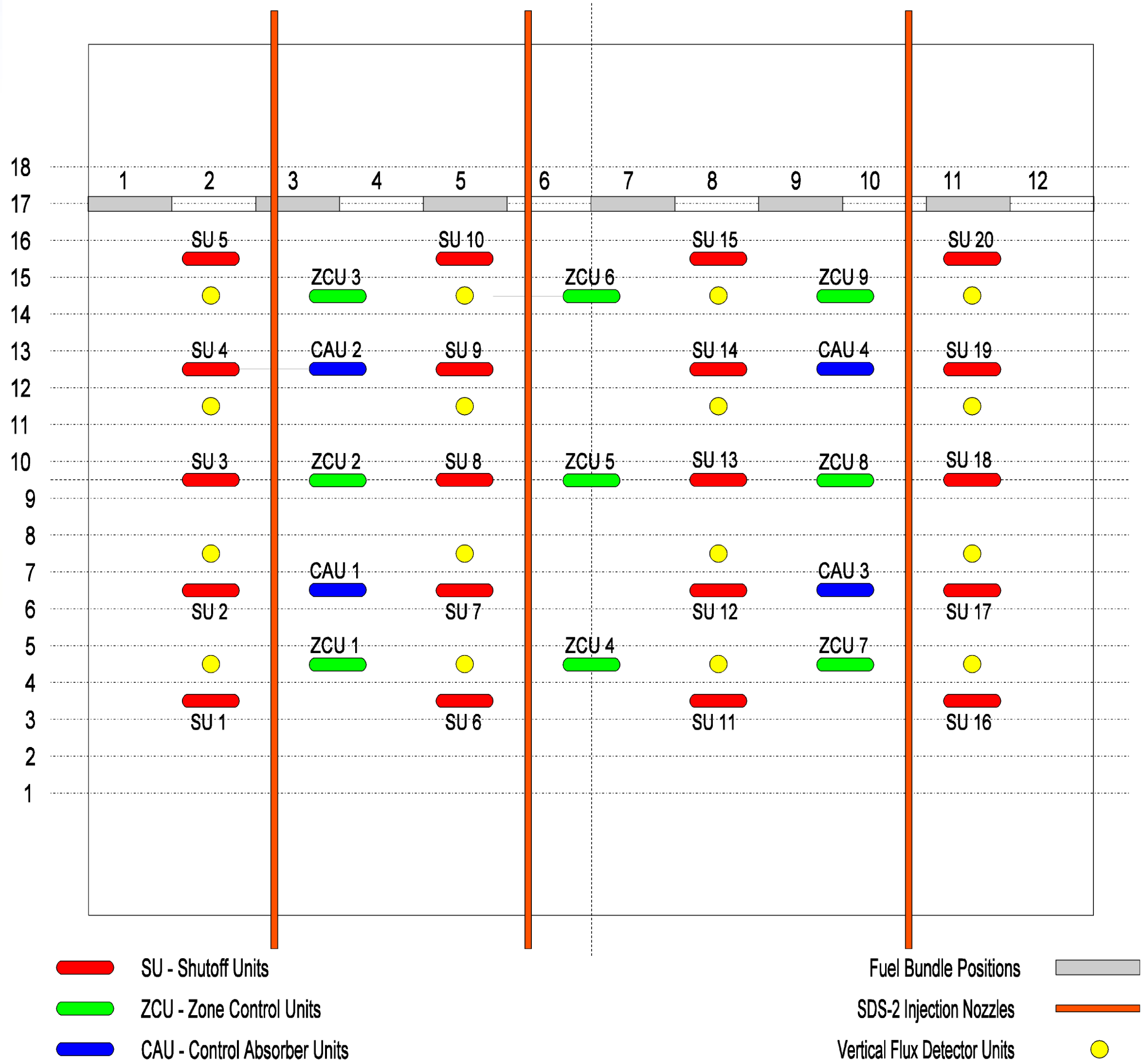
Fueling Scheme

- CANDU reactors use on power fueling to keep core reactivity at about 4.5 mk
- Fueling is carried out at a rate of 5.6 bundles per full power day (for daily fueling)
- Each 2 bundle replacement gives about 0.2 mk
- Channels are selected for fueling for overall core balance with a typical fuel residence of about 20 months
- 9 zone controllers provide a total of about 9 mk for spatial control, xenon override and fueling flexibility
- 4 control absorbers provide for power setbacks

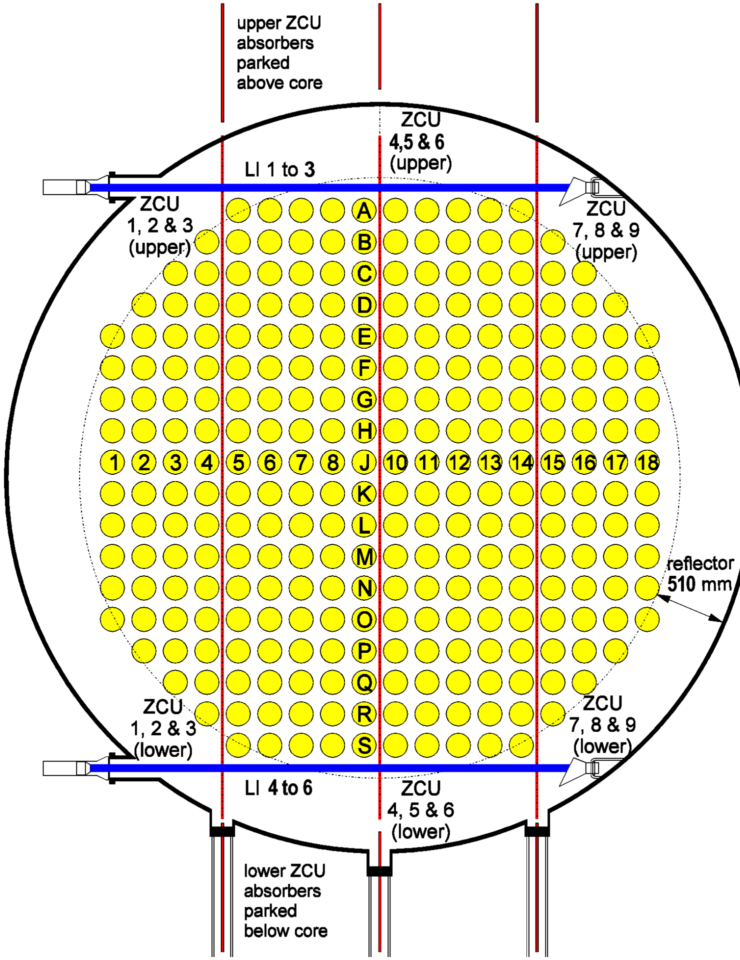
ACR 700



Reactivity Mechanisms Deck and Fuel Channels



End View of ACR 700



ACR-700 Reactor Core
284 Fuel Channels
220 mm Lattice Pitch

Fueling

- Each fuel channel contains a string of 12 fuel bundles
- Irradiated fuel is removed from the downstream end and fresh bundles are inserted at the upstream end
- Irradiated fuel is discharged via a fuel port through the containment boundary to a bay in the reactor auxiliary building
- New fuel is supplied via fuel ports also through the containment boundary
- The fueling machine has a movable class 1 pressure vessel that connects to the fuel ports and fuel channels in sequence to move the fuel around

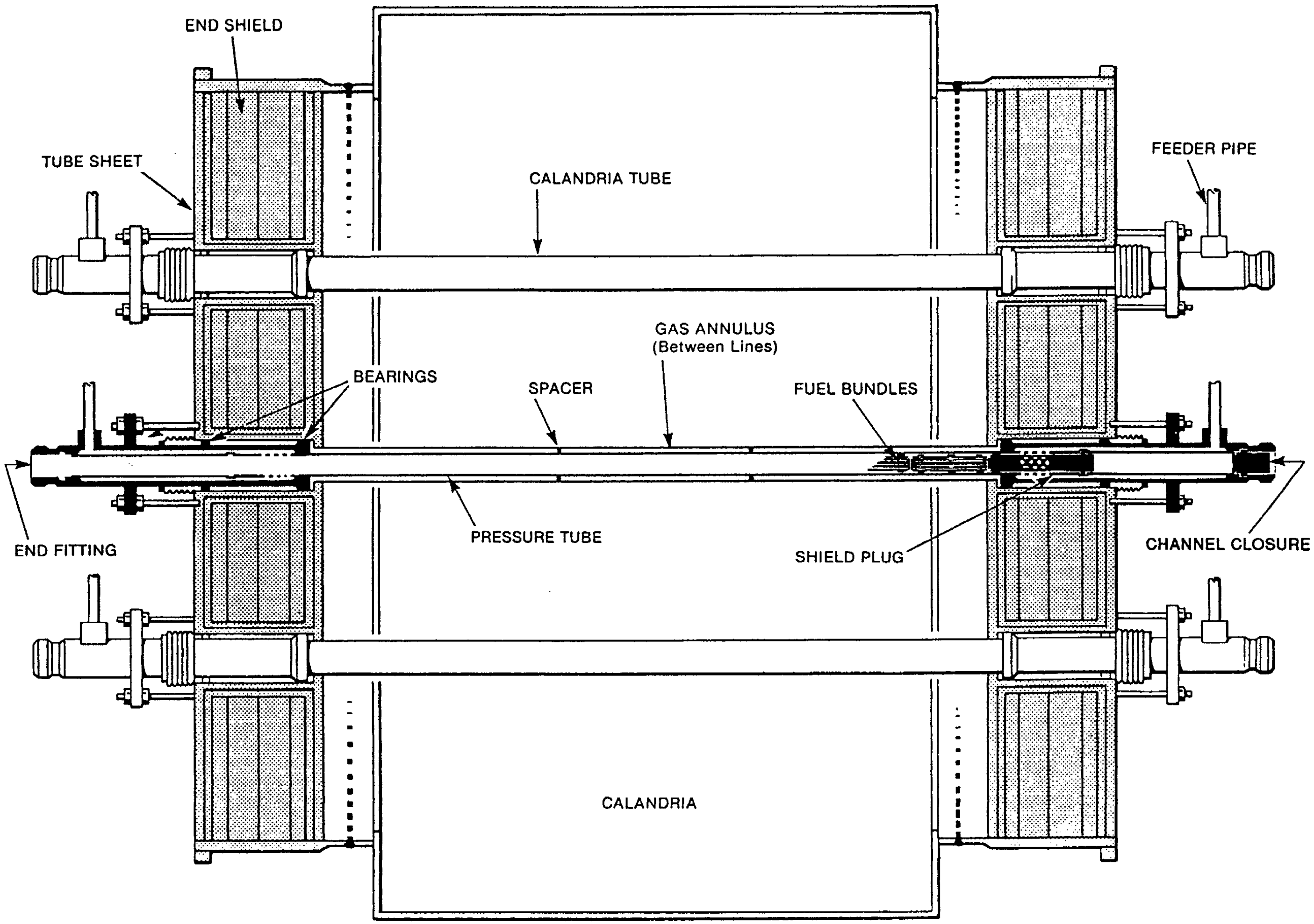
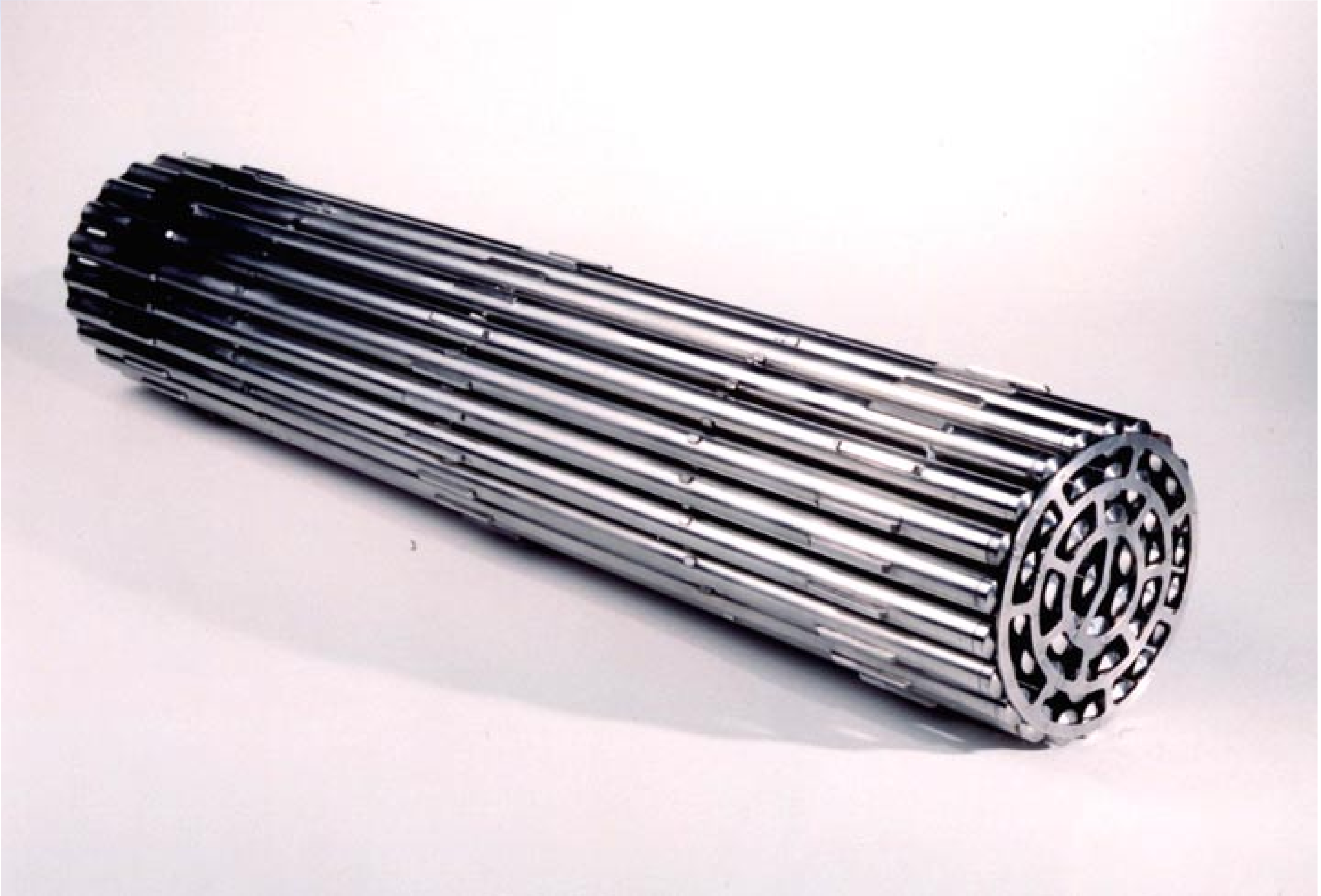
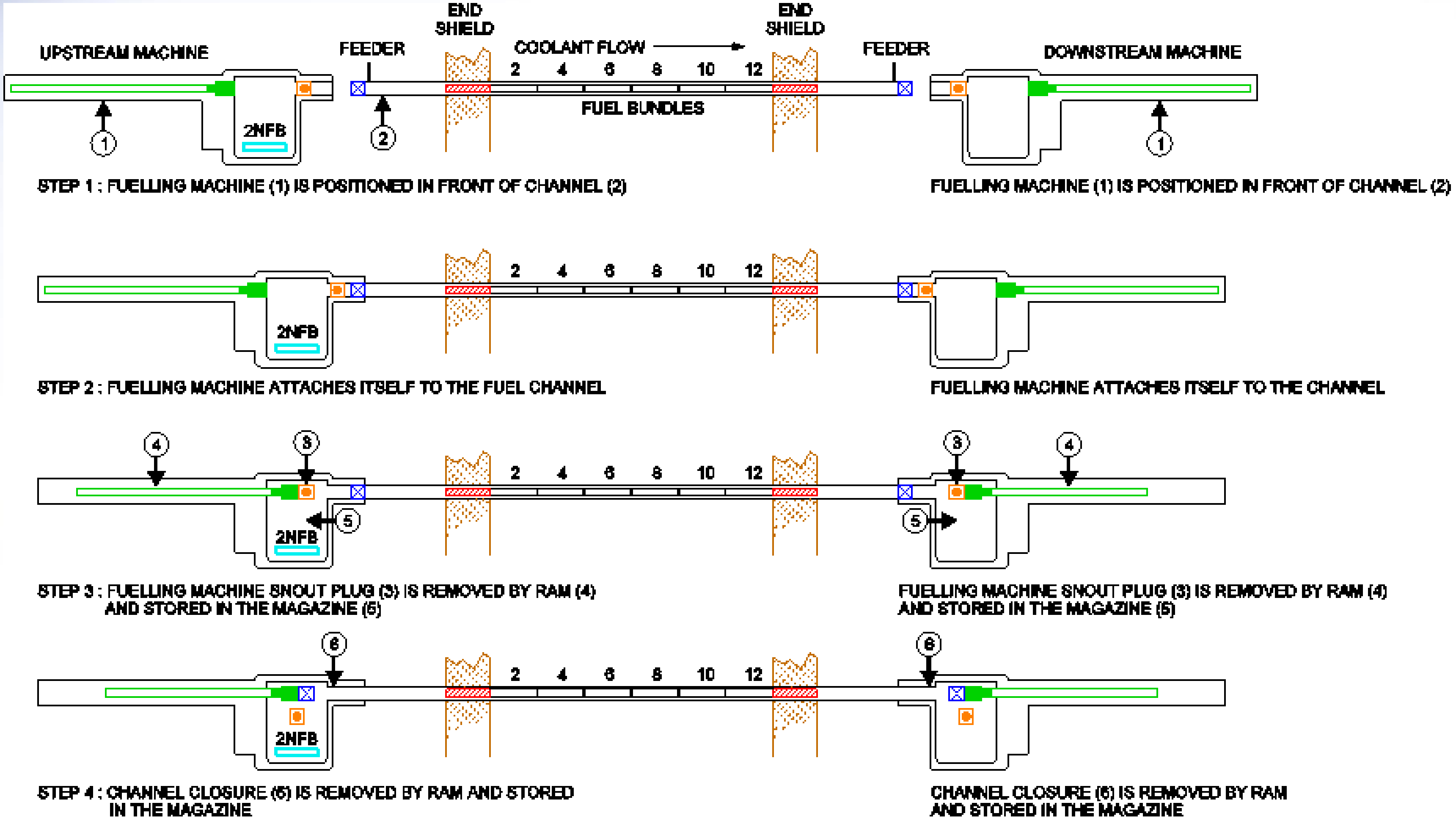


FIGURE 3-4 SIMPLIFIEr ᒣIAGRAM OF CANDU REACTOR

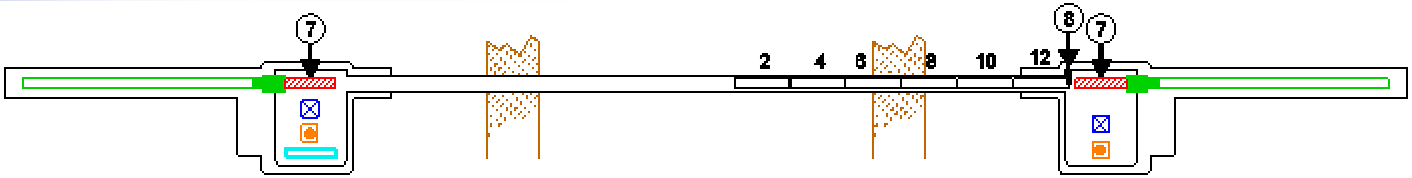
CANFLEX Fuel Bundle



Fueling Sequence - 1

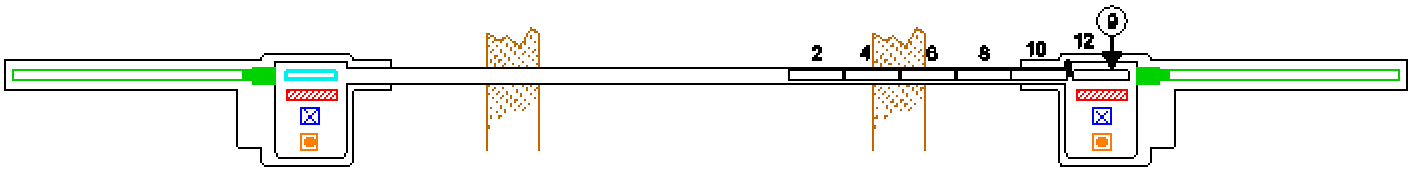


Fueling Sequence - 2

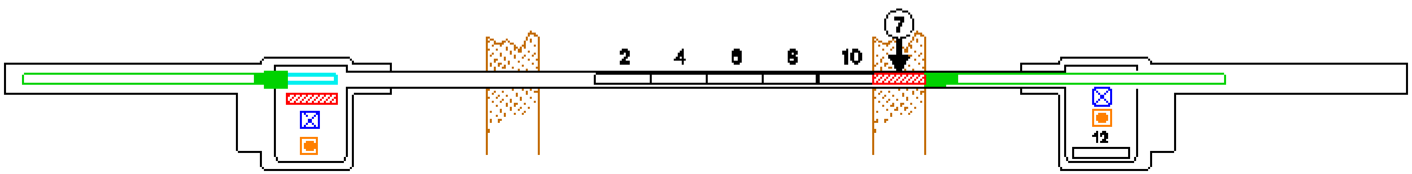


STEP 5 : CHANNEL SHIELD PLUG (7) IS REMOVED BY RAM AND STORED IN THE MAGAZINE

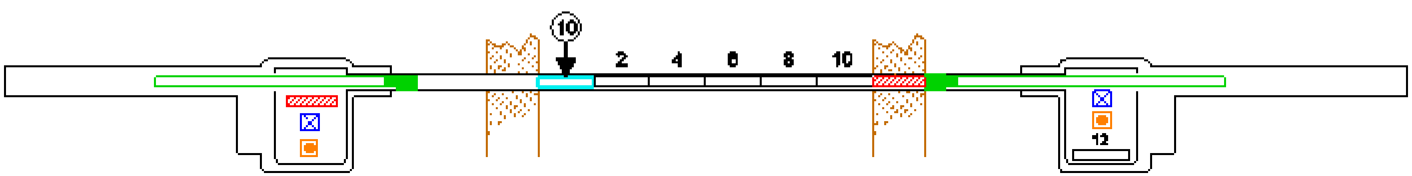
CHANNEL SHIELD PLUG (7) IS REMOVED BY RAM AND STORED IN THE MAGAZINE. FUEL STRING IS PUSHED BY COOLANT FLOW AGAINST SEPARATOR STOPS (8)



STEP 6 : TWO IRRADIATED FUEL BUNDLES (9) ARE SEPARATED FROM THE FUEL STRING AND STORED IN THE MAGAZINE

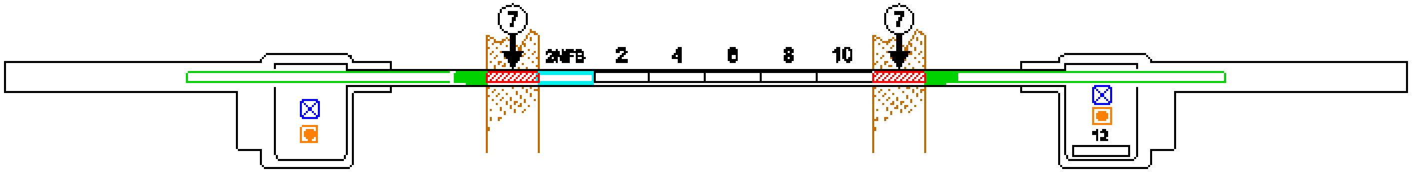


STEP 7 : RAM PUSHES THE SHIELD PLUG (7) INTO POSITION WHICH PUSHES THE FUEL STRING BACK INTO POSITION

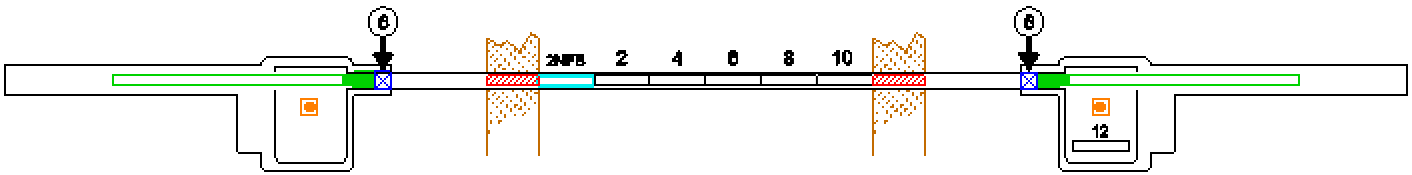


STEP 8 : RAM PUSHES TWO NEW FUEL BUNDLES (10) INTO THE FLOW

Fueling Sequence - 3

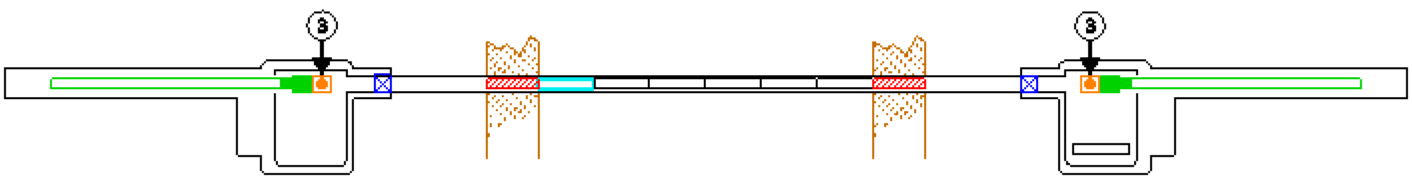


STEP 9 : EACH RAM INSTALLS THEIR RESPECTIVE SHIELD PLUGS (7)
THE PRESSURE DROP ACROSS THE CHANNEL IS MEASURED TO CHECK FLOW



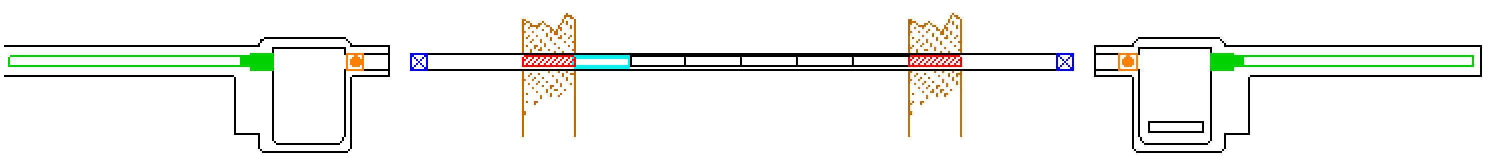
STEP 10 : RAM INSTALLS THE CHANNEL CLOSURE (6)

RAM INSTALLS THE CHANNEL CLOSURE (6)



STEP 11 : FUELLING MACHINE SNOUT PLUG (3) IS INSTALLED IN THE SNOUT
LEAK CHECKS PERFORMED

FUELLING MACHINE SNOUT PLUG (3) IS INSTALLED IN THE SNOUT



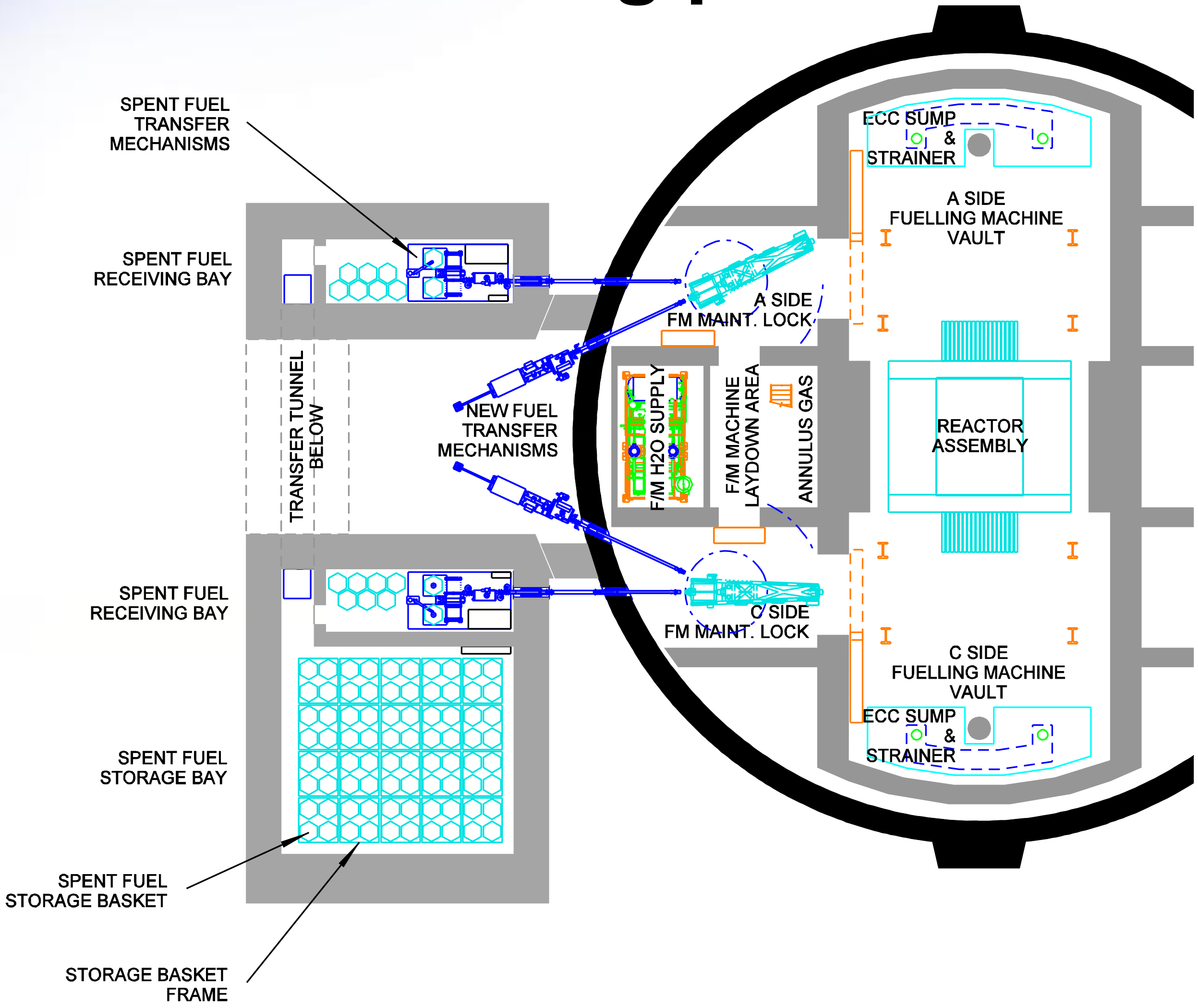
STEP 12 : FUELLING MACHINE DETACHES ITSELF FROM THE CHANNEL

FUELLING MACHINE DETACHES ITSELF FROM THE CHANNEL

Fueling equipment

- New fuel storage
- New fuel transfer
- Fueling machine
  - Head
  - Carriage
  - Bridge
  - Catenaries
  - Fluid systems
  - Controls
- Spent fuel transfer
- Spent fuel storage (bay and dry stores)

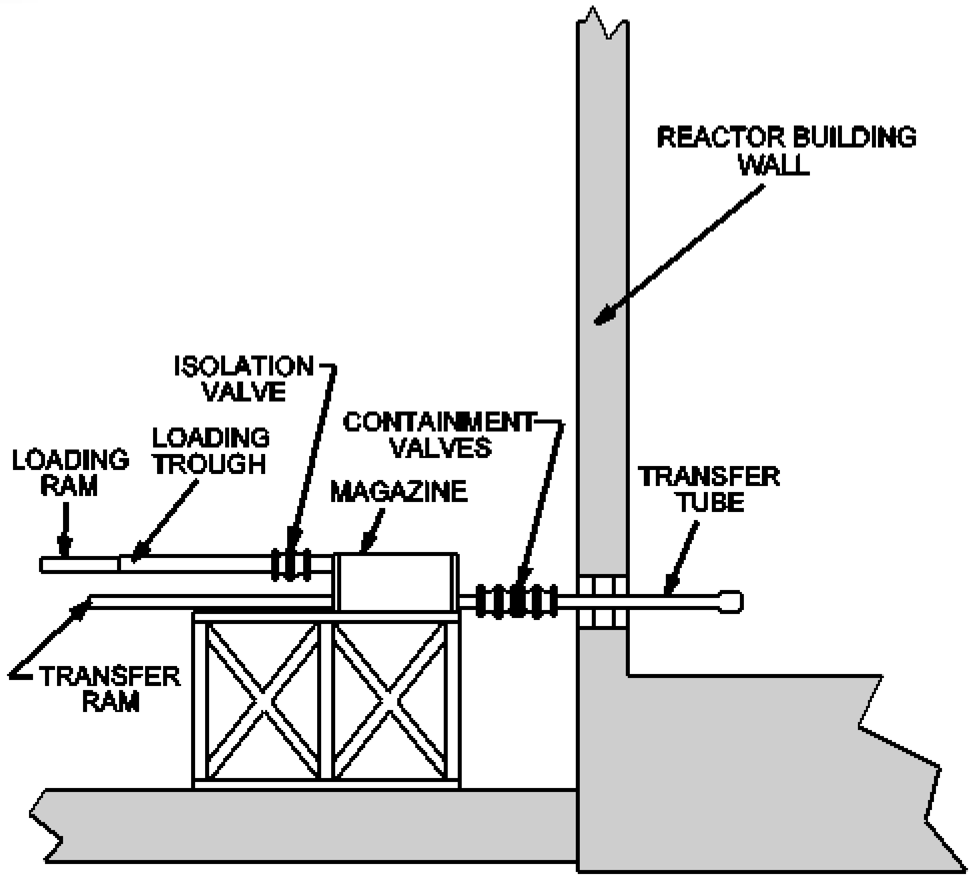
Building plan view

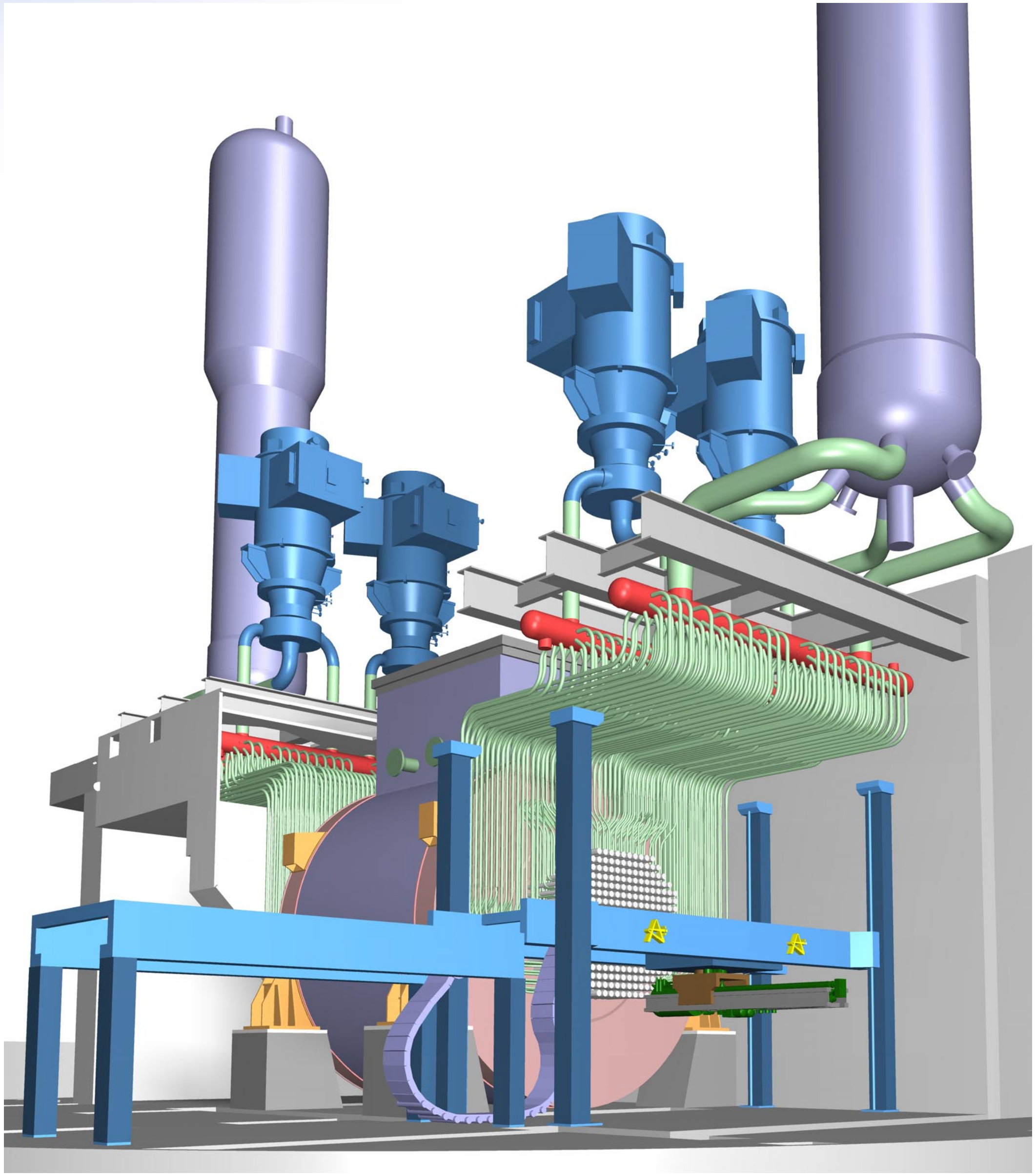


New Fuel Transfer

- New fuel is stored in a secure storage area and transported to the transfer room as required
- All fuel is stored with features to prevent inadvertent criticality
- With the containment valves closed, fuel is inspected and then loaded into the transfer mechanism magazine
- With the isolation valve closed, the containment valves are opened so the fuel can be transferred into the fueling machine head

New Fuel Transfer





Fueling Machine

- The CANDU fueling machine consists of:
  - A head encased in a class 1 pressure vessel with a snout to connect it to fuel channels and ports, separators to separate one bundle from the next, a magazine to hold fuel and hardware, and a latching ram to move fuel and hardware
  - A carriage to hold the head providing axes to align and push the head on to ports / channels
  - A bridge to lift the head and carriage around the reactor vault and support inspection and maintenance
  - A catenary system to take power and fluid to the head and connect them back to an accessible area
  - A control system with viewing and safety interlocks to allow remote control
  - A process system to provide pressure control and cooling

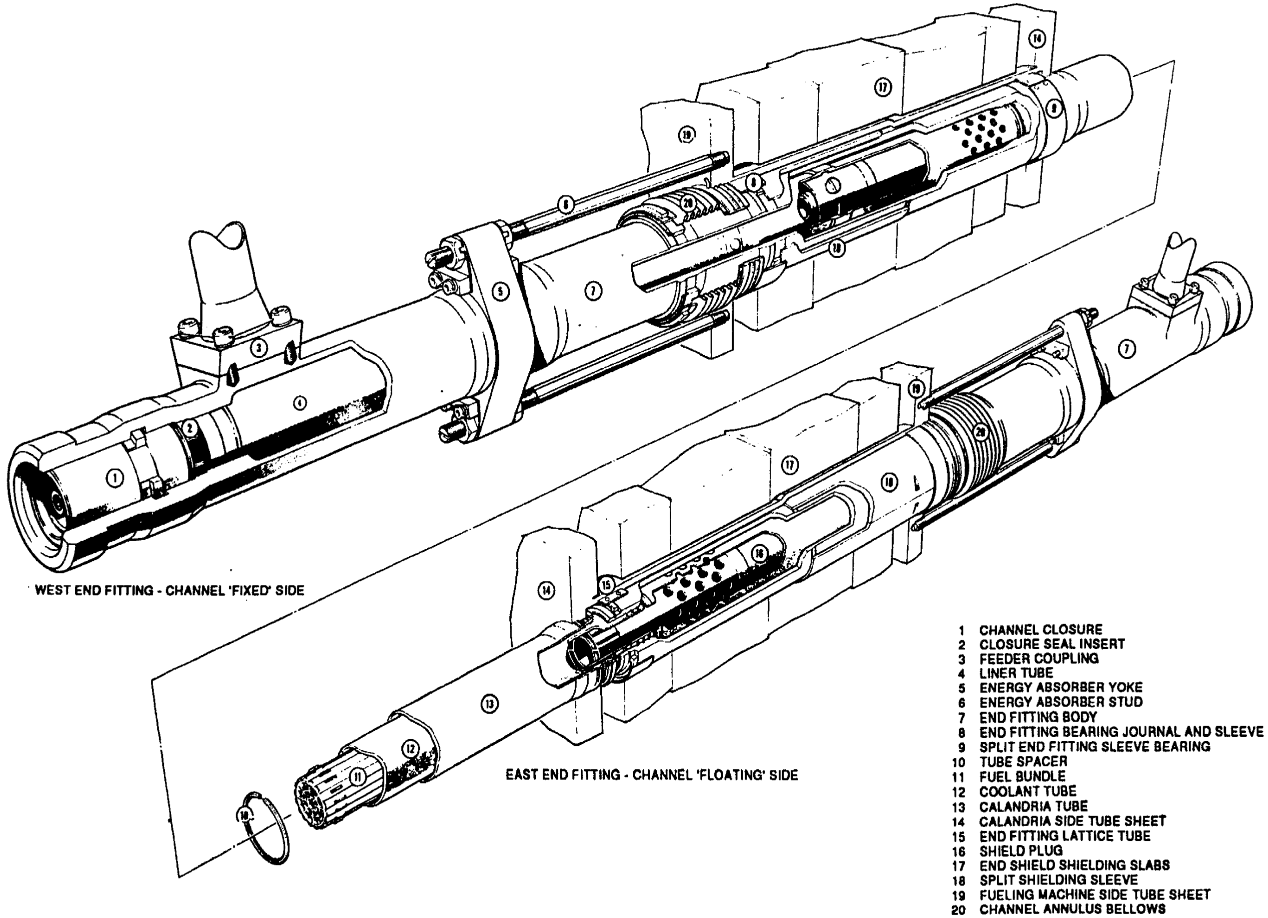
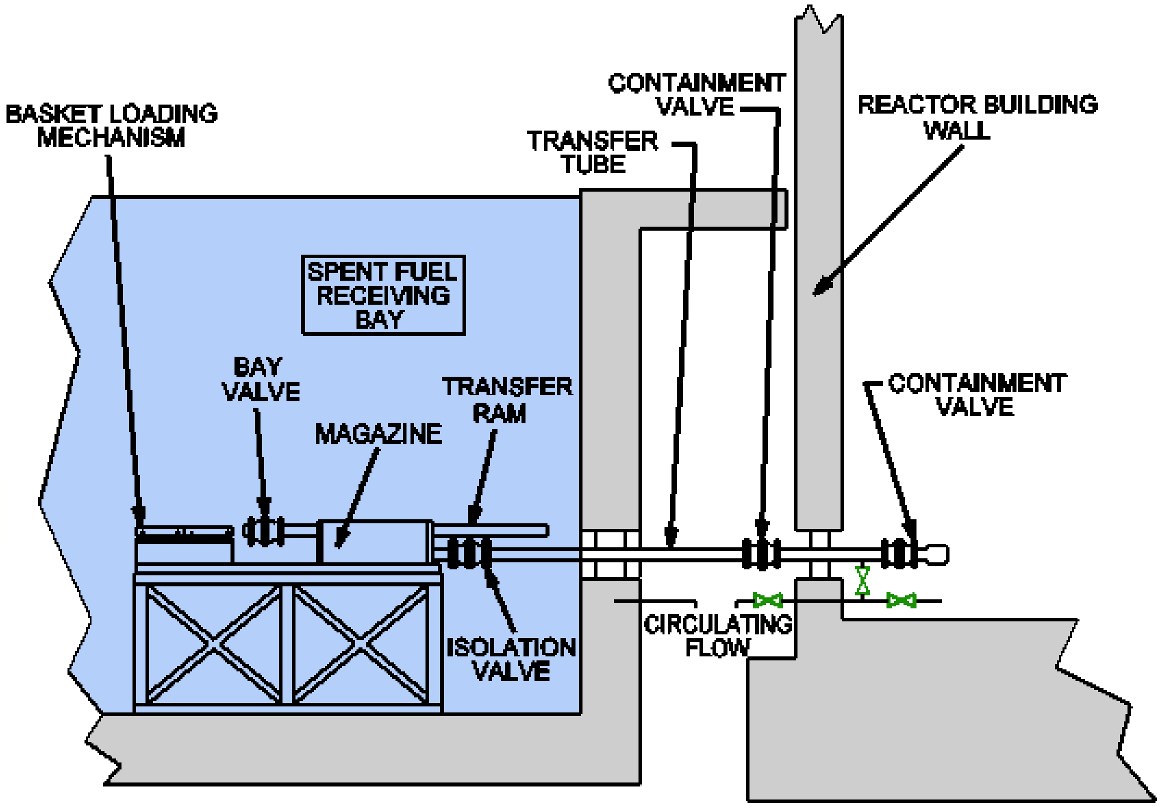


FIGURE 3-3 FUEL CHANNEL ASSEMBLY

Fuel Channel Interface

- The fuel channel has:
  - A restraint to react fueling and seismic loads
  - A removable shield plug to locate the fuel string
  - Removable closure plugs to provide the pressure boundary
  - An end fitting interface feature to allow the head to latch on, seal and extend the pressure boundary

Spent Fuel Transfer



Dry Storage Transfer

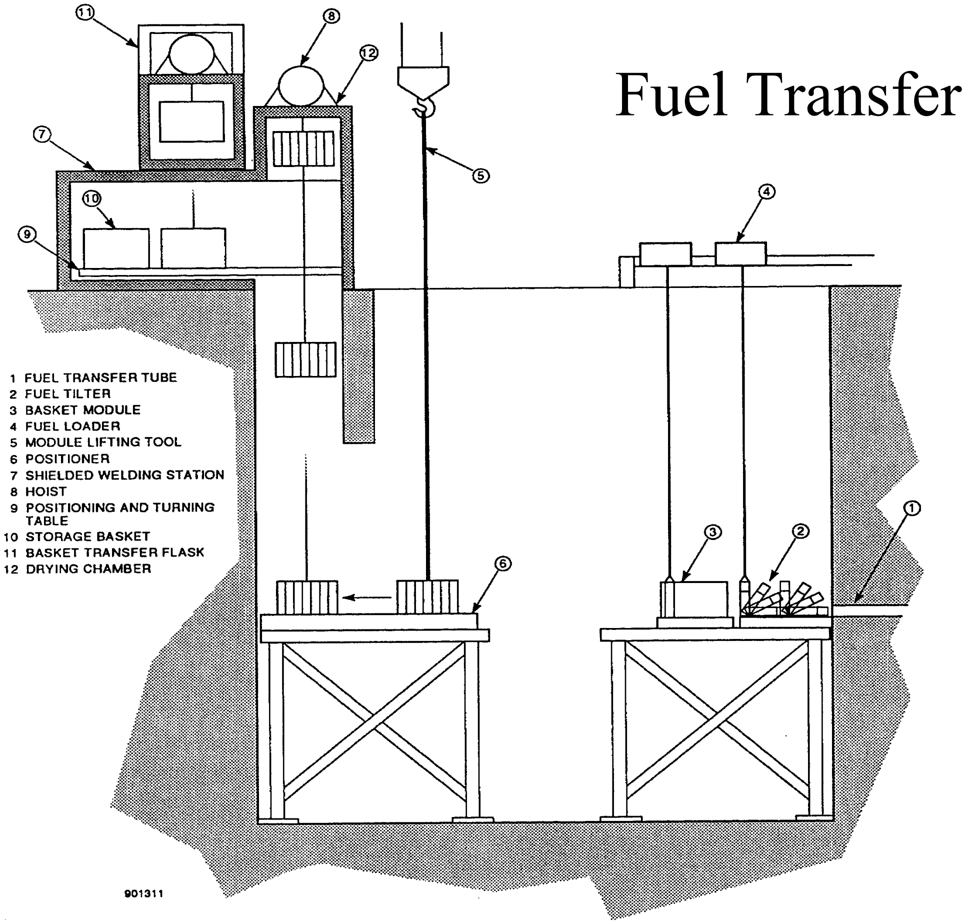


FIGURE 3-72 FUEL HANDLING AND STORAGE OPERATIONS

Spent Fuel

- A spent fuel port in the fueling machine maintenance lock allows the fueling machine to latch on and extend its pressure boundary
- Fuel is then inserted into the port and transferred through to the fuel bay
- In the bay the fuel is transferred into baskets which are first stored in a buffer zone and then moved into the main bay area
- After fuel decay heat is significantly reduced, fuel is typically loaded into dry storage vaults

Design Features to Enhance Safety During Fueling

- The principal safety features related to CANDU fueling are well proven and are designed according to recognized standards
- Pressure boundary components are designed to established piping and pressure vessel codes
- Key specialized materials and designs features are governed by Canadian Standards Association (CSA) codes endorsed by the Canadian regulator
- Additional interlocks, mechanical locks and backup systems are incorporated to enhance safety and operability
- Inherent benefit in reduction of reactor coolant system (RCS) activity from defective fuel bundles due to early detection/ removal

Codes and Standards

• ANSI B31.1	Power Piping
• ASME Section III/VIII	Boiler and Pressure Vessel Code
• CSA-N285.0	General Requirements for Pressure-Retaining Systems and Components in CANDU Nuclear Power Plants
• CSA-N285.2	Requirements for Class 1C, 2C, and 3C Pressure-Retaining Components and Supports in CANDU Nuclear Power Plants
• CSA-N285.3	Requirements for Containment Systems Components in CANDU Nuclear Power Plants
• CSA-N286.2	Design Quality Assurance for Nuclear Power Plants
• CSA-N287.3	Design Requirements for Concrete Containment Structures for CANDU Nuclear Power Plants
• CSA-N289.3	Design Procedures for Seismic Qualification of CANDU Nuclear Power Plants

Features from N285.2

This standard covers CANDU specific features that are outside normal ASME pressure vessel code practice

- Channel closure
  - Secondary mechanical lock to prevent accidental release
  - Limited leakage in the event of seal failure
  - Use ASME Section III class 1 rules
  - Leak test each use
  - Make installation fail safe
- Fueling machine snout attachment lock
  - 2 diverse locks including 1 positive mechanical lock
  - Engaged prior to removing channel closure
  - Regular tests

Features from N285.2 (continued)

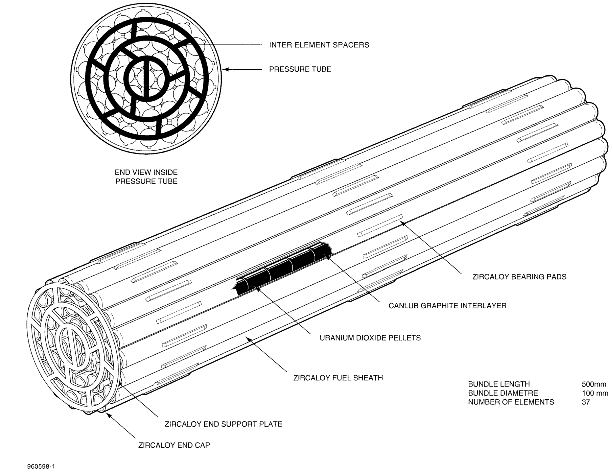
- Fueling machine catenary hoses
  - Qualification tests
  - Defined life
- Fueling machine supports
  - Analyse supporting mechanism using NF rules
  - Interlock to prevent motion that could affect pressure boundary
- Threaded connections
  - Limits and types of threaded connections for small diameter lines in class 1 applications defined

Safety Overview

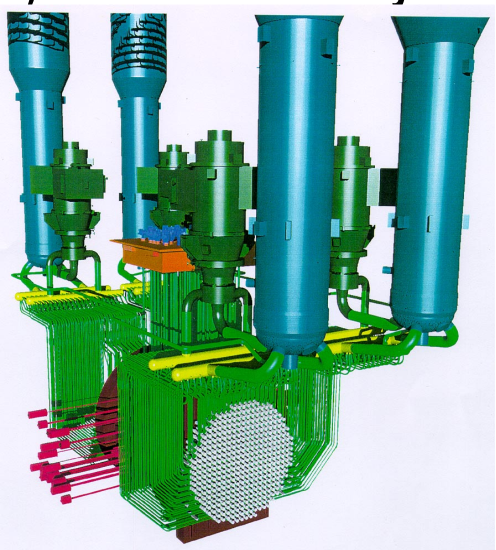
- Matrix – first line of defence against activity release
- Intact fuel clad
- Intact pressure boundary of the RCS – retains activity if there is a fuel cladding defect
- CANDU FM considered part of the RCS (whenever FM is on-reactor, it becomes an extension of the RCS pressure boundary)
- Containment designed to prevent dispersal of radioactive materials
- Exclusion zone maintained around nuclear power station – further defence against concentrated activity reaching the population at large

Barriers to Fission Product Release

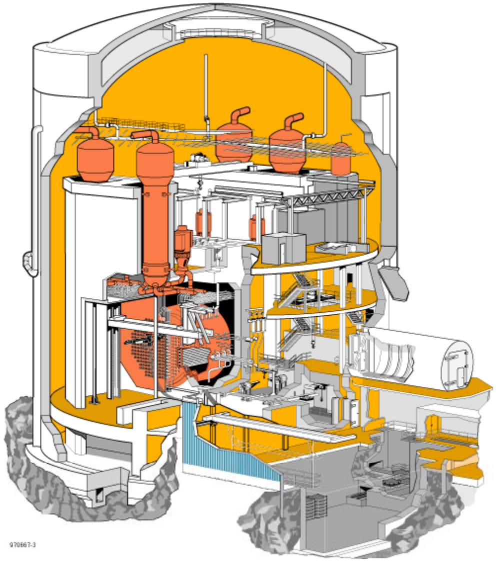
1) Uranium-Dioxide Fuel Matrix, and 2) Clad



3) Reactor Coolant System



4) Containment



5) Exclusion Area Boundary

Design Features to Enhance Safety During Fueling

- Latching snout connection mechanism and additional safety locks to prevent unintentional or unsafe release from a fuel channel
- Controls and instrumentation that are required to function properly during and following a Design Basis Earthquake (DBE), LOCA or MSLB are seismically and environmentally qualified
- A seismically and environmentally qualified emergency water system is included to maintain fuel cooling when the FM is off reactor during and following a DBE, LOCA or MSLB or if the normal system becomes unavailable
- Special stainless steel baskets guarantee sub-criticality of the fuel in all mediums

Barriers to Inadvertent Release of FM from Reactor Channel

- **FM snout-to-end-fitting clamping mechanism**
- **FM snout safety lock – engaged / locked by channel pressure**
- **Check for integrity of seal between FM snout and channel end fitting prior to removal of channel closure**
- **FM snout clamp interlocks on pressure and status of snout safety lock**
- **FM bridge drive / brake safety interlocks**
- **Limited force of carriage drives**
- **Check for partial blockage of channel prior to installing channel closures**
- **Check for integrity of seal between channel closure end fitting prior to unclamping of FM snout**

Review of Accidents and Incidents

- CANDUs have operated for an accumulated service life >450 years
- CANDU 6s have operated for an accumulated service life >60 years with approximately 43500 fueling cycles
- Fuel handling accidents and incidents (per International Nuclear Event Scale):
- Accidents: NONE
- Major or serious incident: FEW
- Lesser incidents were more numerous, but mostly of the nuisance type and easily corrected
- Fuel handling undesired events showed no major LOCA or major accidental radioactive releases or contamination
- Designs upgraded to prevent recurrence of past events

Events Discussion

Note: None of these events occurred in CANDU 6

- Interlocks added to prevent bridge movement whenever FM is near to, or on channel (past event on damage and leak from end fitting)
- Design changes and related loads limited of parts moving fuel (past event on fuel bundle damage and limited release in FM vault during recovery)
- ACRs use of light water coolant mitigates the past spill events of heavy water from the FM and release of tritium into containment
- Use of totally water borne spent fuel transfer mitigates a small number of bundle failures in past dry transfer systems (sprays retrofitted in some existing stations)

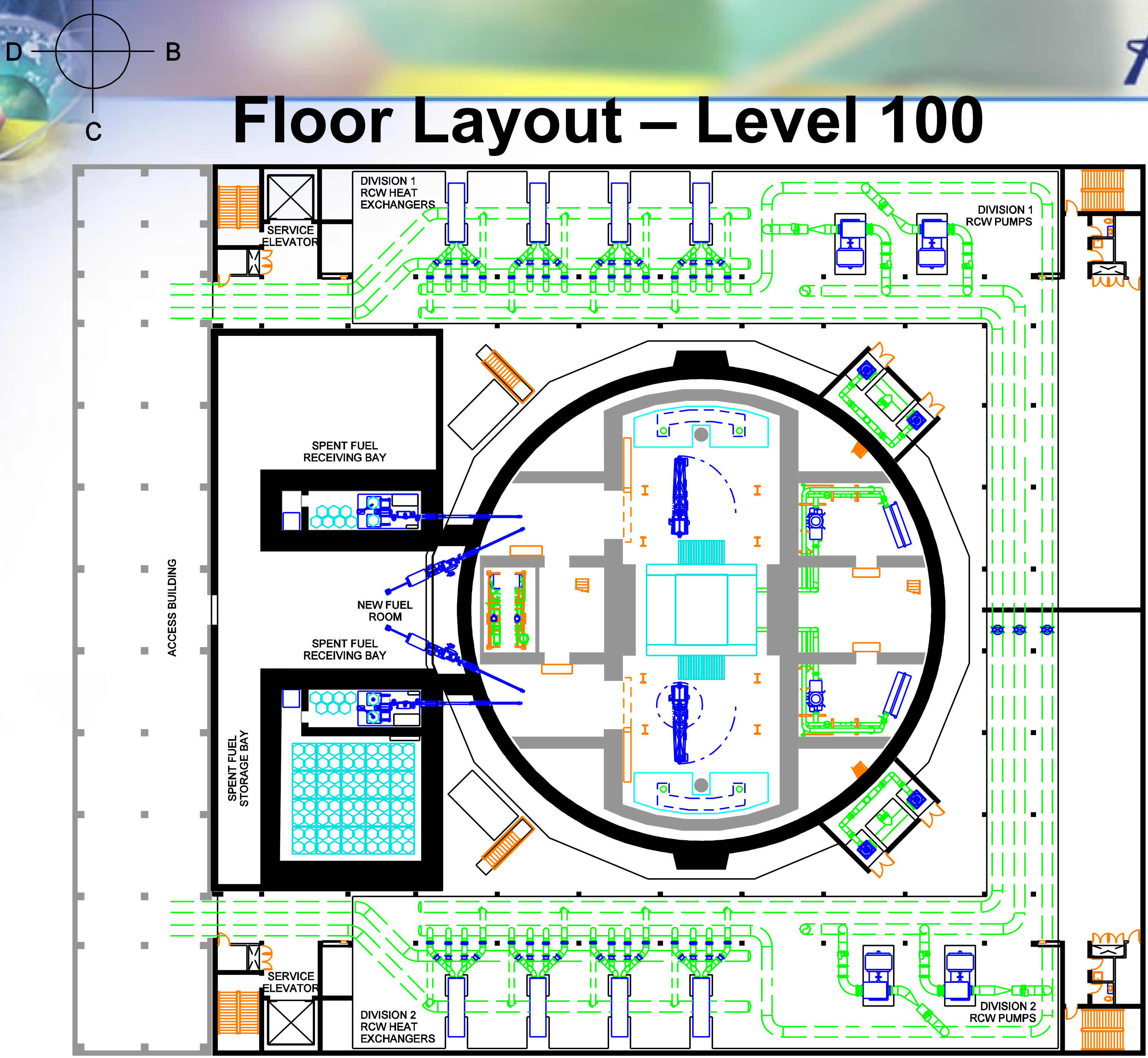
Safety Summary

- Existing CANDU stations have an excellent safety record related to fueling
- CANDU 6 fuel handling systems have evolved from past CANDU stations and incorporate many improvements
- ACR further builds on the best practices and design features with several safety enhancements further mitigating risk

Differences Between ACR and CANDU 6 Fuel Handling Systems

- Changes in the layout of fuel handling equipment in the ACR reactor buildings, including modifications due to increased seismic requirements and lack of reactor building basement
- Fuel Channel components
  - Channel closure changes
  - Shield plug changes
- Fueling Machine design
  - Enhancements to Bridge / Carriage
  - Enhancements to fluids and controls
  - Enhancements to Fueling Machine head
- Fuel Transfer Design

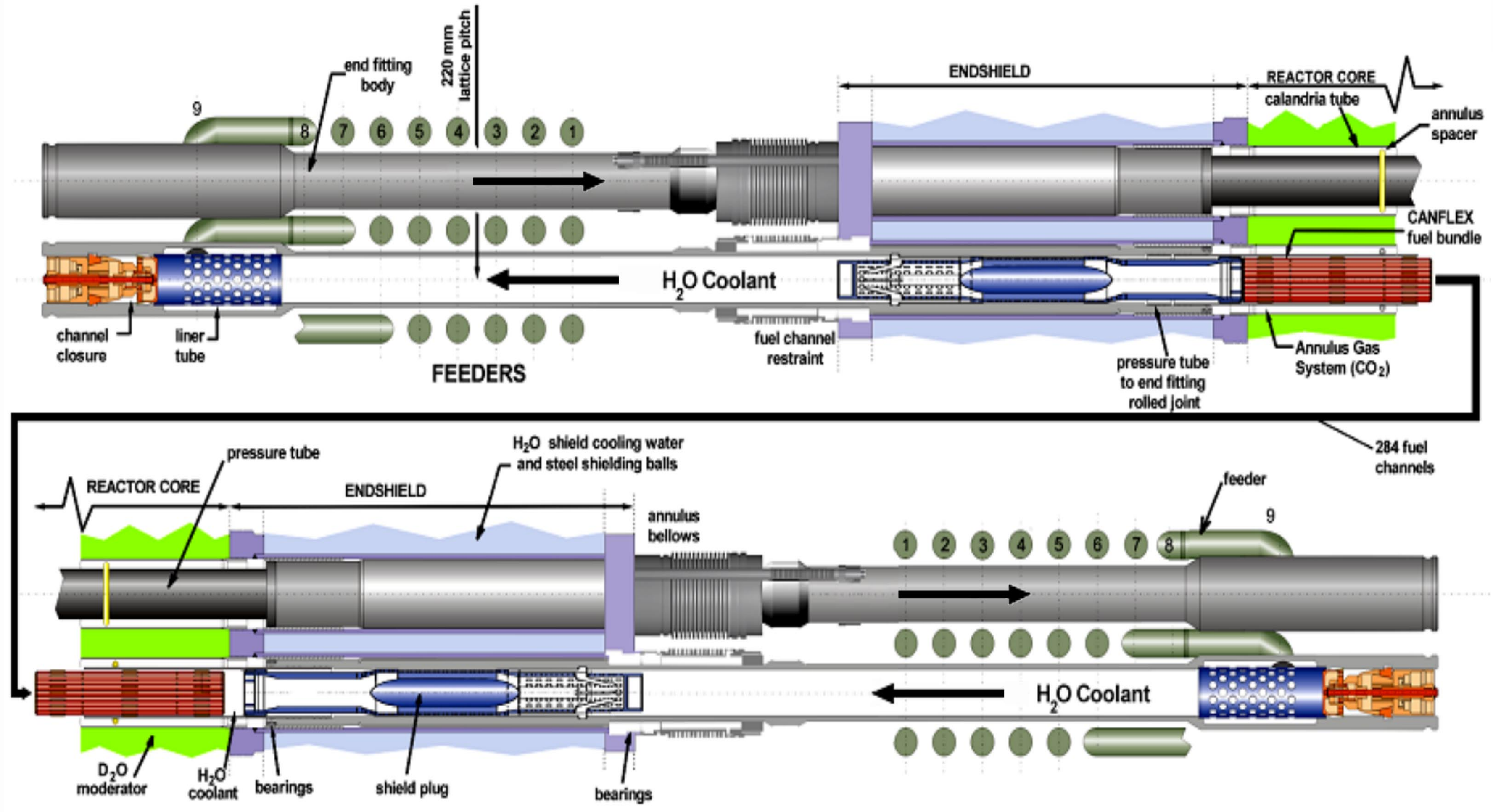
Floor Layout – Level 100



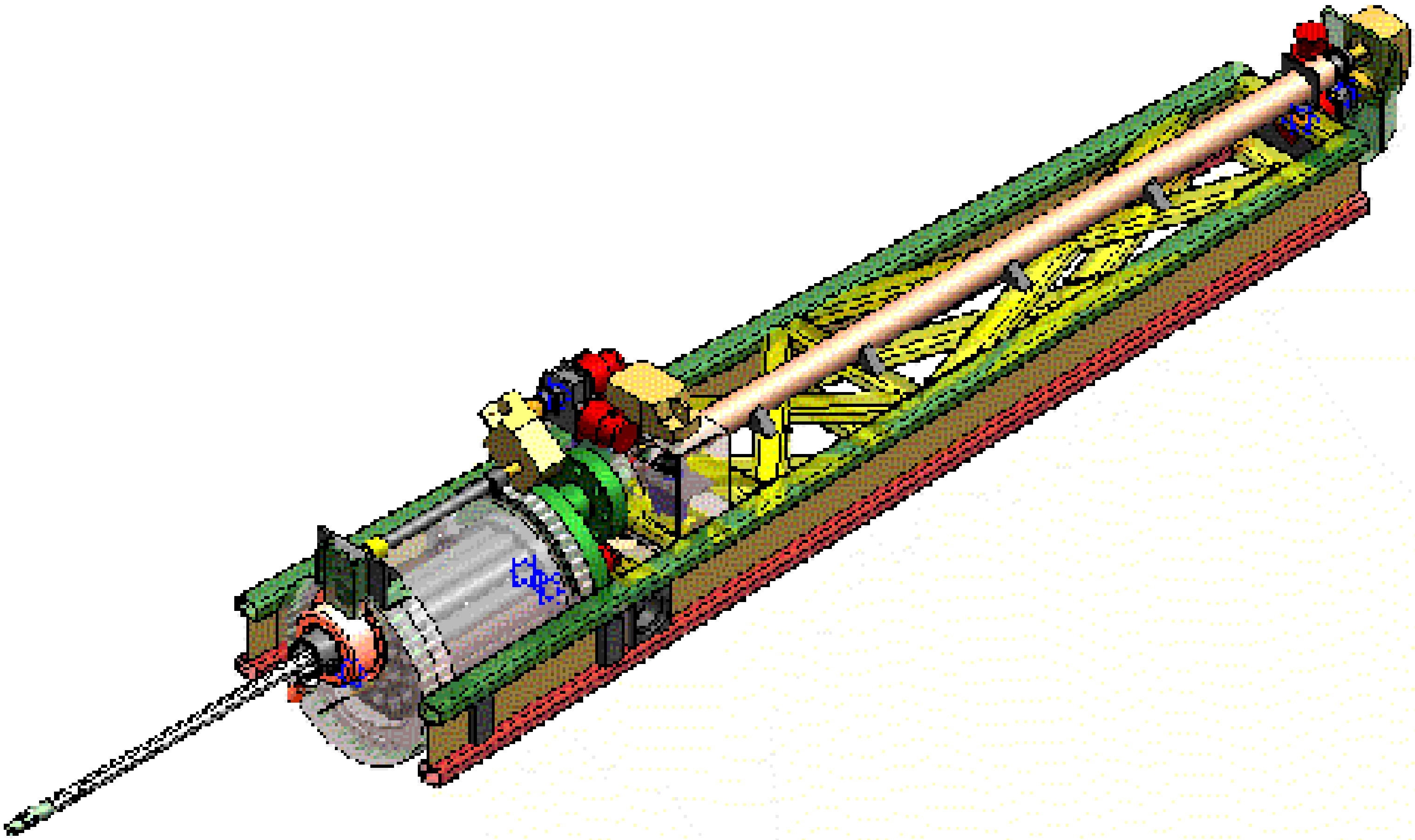
Fuel Handling Layout

- **Systems combined and centralised in both reactor auxiliary building and reactor building**
- **New fuel loading has been moved outside reactor building and containment features across containment boundary have been improved**
- **Backup drives added to mitigate the need to use emergency tools via access through a basement floor (as in CANDU 6)**

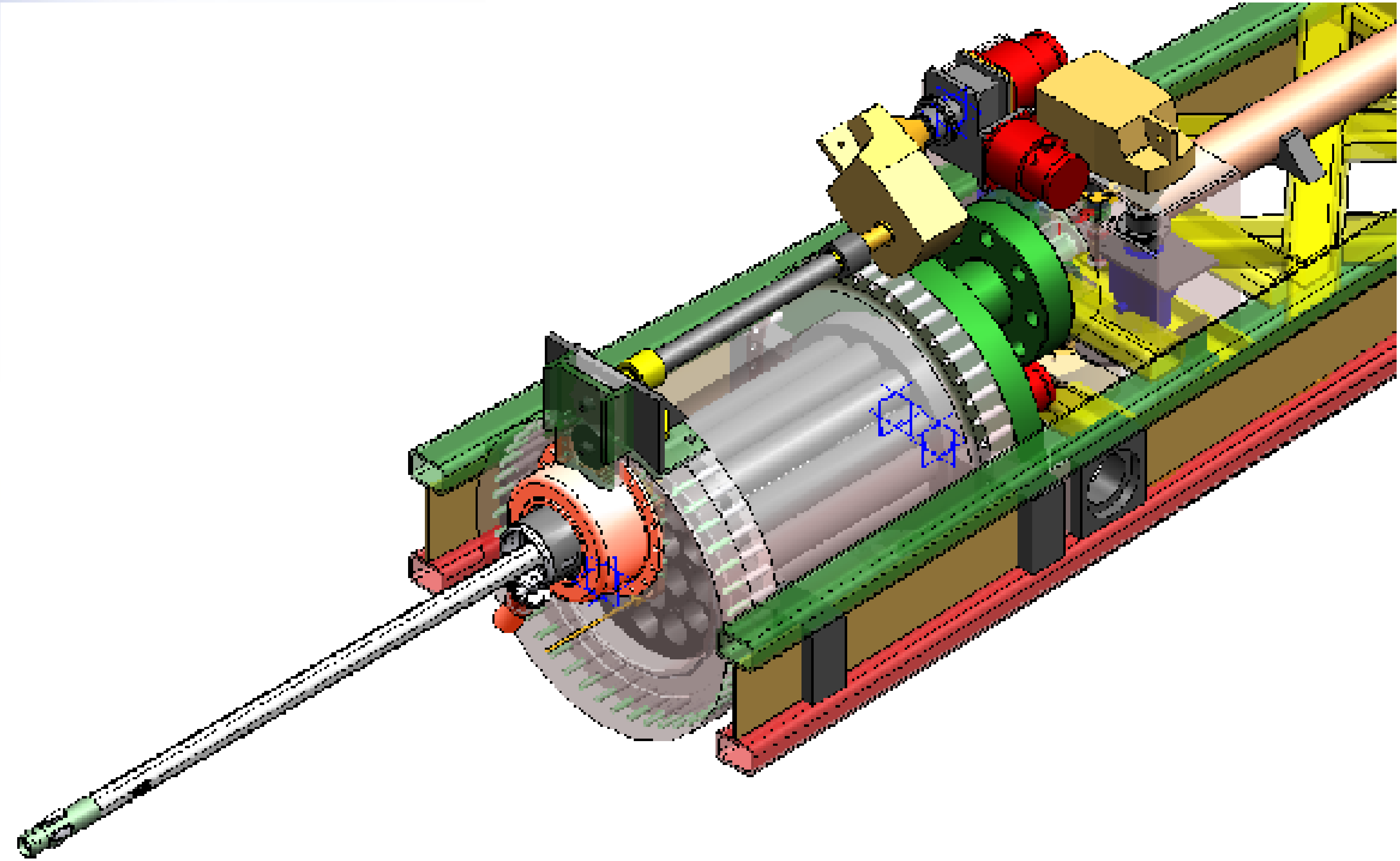
ACR Fuel Channel



Fueling Machine Head - 1



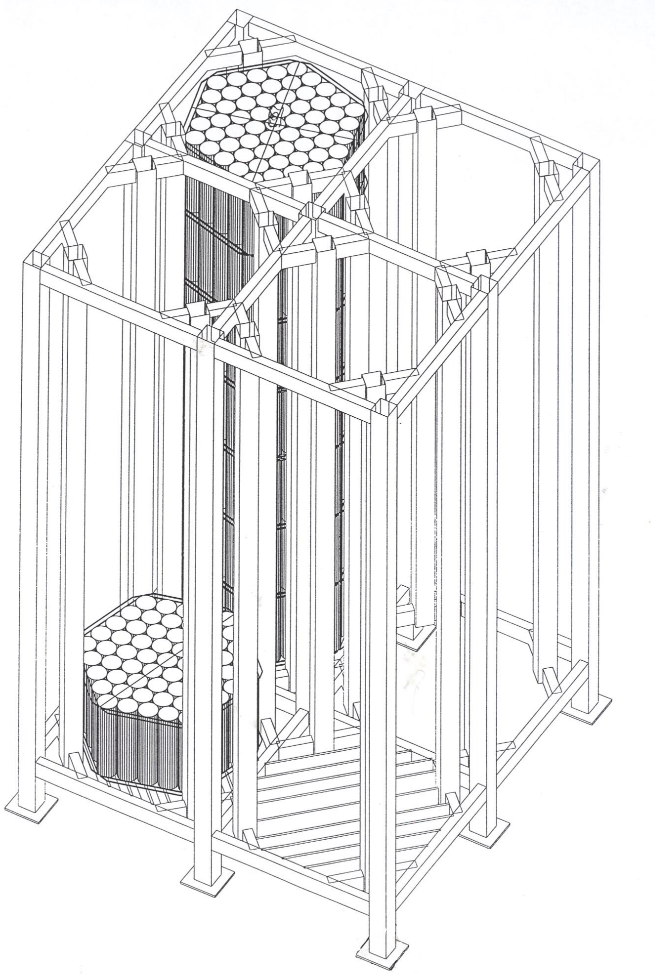
Fueling Machine Head -2



Fueling Machine

- Enhancements to Bridge / Carriage
  - Improved seismic and maintenance performance
- Enhancements to fluids and controls
  - Standardised modern distributed controls
  - Better sensors and move to all electric drives
  - Removal of old fluid (oil and water) based drives
  - Simpler cooling layout with increased redundancy and emergency cooling capabilities
- Enhancements to Fueling Machine head
  - Lower contact loads
  - Simpler more robust mechanisms

Fuel Storage Baskets and Racks



- Spent fuel stored in a hexagonal shaped basket
- Baskets stacked in rectangular, seismically qualified frames
- Basket fabricated of SS tubes which guarantee sub-criticality
- Ample space for convection induced flow

Fuel Transfer

- Consistent fuel storage techniques with built-in criticality prevention
- Water based spent fuel transfer
- Improved chemistry control of process fluids through removal of air interfaces
- Improved defect fuel handling including related gasses
- Use of dry store ready baskets for bay storage to simplify fuel tracking and minimise handling

Conclusions

- On power refueling has clear benefits for station operation and safety

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