ACR-1000® Design Features Minimizing Collective Occupational Dose and Public Dose to ALARA

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ACR Process Systems Integration

2010 ISOE North American ALARA Symposium, 2010 Jan 11-13

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Outline

- ALARA Requirements and Guidance for new build Nuclear Power Plant (NPP) in Canada
- Overview of ACR-1000 Design
- Application of the ALARA Principle to the ACR-1000 Design:
  - Overall ALARA Design Process
  - Application of ALARA Principle
- ACR-1000 Design Features to Minimize:
  - Occupational Radiation Exposure or Worker Dose
  - Public Dose

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ALARA Requirements and Guidance in Canada

- **Canadian Nuclear Safety Commission (CNSC)**
  - **The CNSC under the umbrella of the Nuclear Safety and Control Act establishes the rules and regulations to be followed for radiation protection in Canada.**
- **Nuclear Safety and Control Act**
  - **Radiation Protection Regulations (SOR/2000-203).**
  - **Regulatory Guide G-129, “Keeping Radiation Exposures and Doses "As Low as Reasonably Achievable (ALARA)”.**
  - **Regulatory Document RD-337, “Design of New Nuclear Power Plants”.**

Radiation Protection Regulations

- **CNSC Radiation Protection regulations include an ALARA requirement for all licensees to establish a radiation protection program to keep exposures ALARA through the implementation of a number of control programmes, including:**
  1) ***Management control over work practices***
  2) ***Personnel qualification and training***
  3) ***Control of occupational and public exposure to radiation***
  4) ***Planning for unusual situations***
  5) ***Verify the quantity and concentration of any nuclear substances released as a result of the licensed activity***

Regulations are focused on an operational ALARA program with Items 3 to 5 being addressed during the design process.

ALARA Guideline (G-129)

- **CNSC Guide G-129 Keeping Radiation Exposures and Doses As Low As Reasonably Achievable (ALARA)", specifically addresses how the ALARA principle should be applied to NPP design:**

  – ***The Radiation Protection Regulations require licensees to implement measures to keep doses received by workers and members of the public from exposure to sources of radiation ALARA. It is insufficient for the licensee to simply respect the appropriate dose limits; efforts must be made to further reduce doses.***

RD-337

- **CNSC RD-337 “Design of New Nuclear Power Plants” in which the need to keep the doses ALARA is outlined in Section 4.1.1 of the document:**
  - ***The radiation protection objective is to provide that during normal operation, or during anticipated operational occurrences, radiation exposures within the NPP or due to any planned release of radioactive material from the NPP are kept below prescribed limits and as low as reasonably achievable (ALARA).***

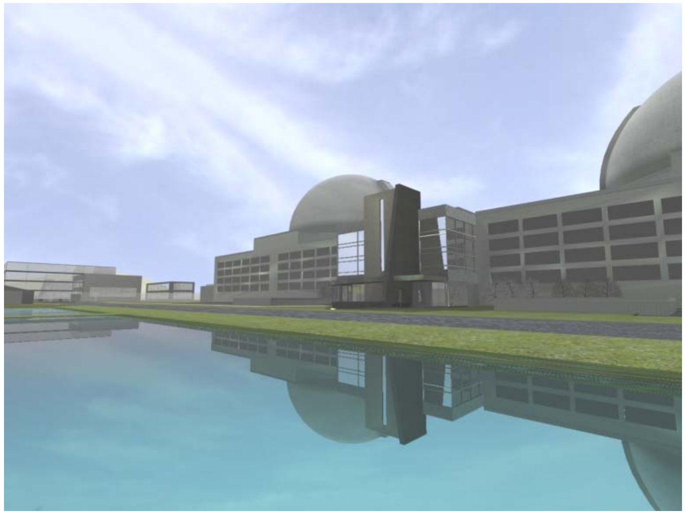
ACR-1000 Twin Plant Layout

State-of-the-Art Generation III+ Technology

ACR-1000 Technical Description

ACR-1000 evolves from the successful CANDU 6 family of units & combines domestic and offshore experience:

- Modular horizontal fuel channels
- Simple fuel bundle design
- Separated coolant from moderator
- Cool, low pressure heavy water moderator
- On-power fuelling
- Passive shutdown systems
- Water-filled reactor vault
- Accessible reactor building while on power



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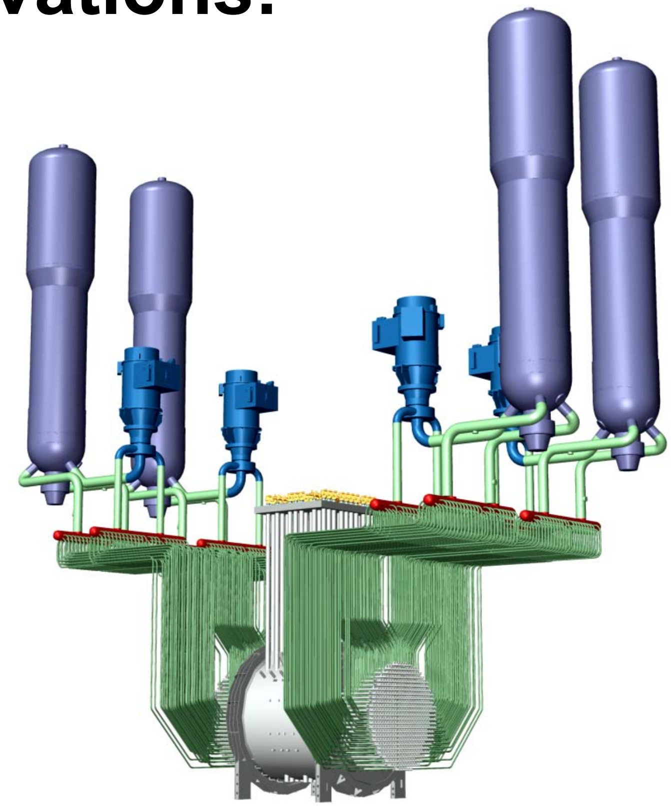
ACR-1000 introduces innovations:

- Low enriched fuel
- Light water coolant
- Higher thermal efficiency
- Enhanced passive safety features
- Smaller reactor core with improved stability and output
- Design features for simpler operations & maintenance → higher CF (> 93%)
- Optimized plant arrangement
- Advanced construction methods



ACR-1000 Technical Description

Safety enhancements

Latest international requirements for new plants (passive safety; design margins; physical protection)

Improved economics

Simplification; standardization; constructability

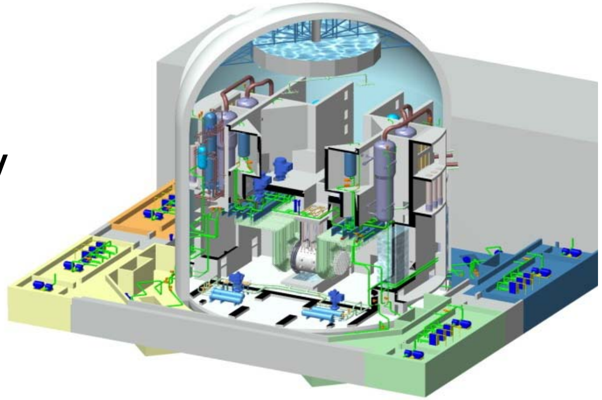
Operational enhancements and high performance

Longer regular operating period (3 years) and shorter outage time

Human factors

Maintainability

High QA standards



<u>ACR-1000 designed to meet Generation III+ requirements</u>

Overall ALARA Design Process

- **In the design phase of the ACR-1000, designers followed a series of established procedures to ensure that the design proceeded through an orderly process of review and quality checks:**
  - **Plant Performance Specification (PPS)**
  - **Safety Design Guides (SDG) (e.g., Radiation Protection)**
  - **Design Guides (DG)**
  - **Design Requirements (DR)**

- **To reduce radiation exposure to ALARA, designers reviewed:**
  - **Operating Experience (OPEX) and Feedback Monitoring System (FMS) from previous CANDU plants.**
  - **OPEX and FMS include, e.g., details of equipment reliability, frequency of maintenance, inspection or repair, as well as the station exposures associated with the equipment.**

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Application of the ALARA Principle to the ACR-1000 Design

- The steps in determining if an ALARA assessment is required are as follows:
  1) Identify systems and practices that result in radiation exposure to workers and members of public.
  2) Estimate the total doses resulting from identified systems and practices.
  3) If the doses are above the dose limits (worker dose: 50 mSv/a over one-year dosimetry period or 100 mSv/a over five-year dosimetry period, and public dose: 1 mSv/a), radiation protection must be improved.
  4) If the doses are below the ACR-1000 design dose targets (individual worker dose: 1 mSv/a, collective worker dose: 0.6 person-Sv/a and public dose: 10 μSv/a) no further ALARA assessment is required. Designers are encouraged to reduce doses below the design targets where this can be done without significant expenditure.
  5) If the doses are above the ACR-1000 design dose targets given above, an ALARA assessment is required, as described in the next slide.

Application of the ALARA Principle to the ACR-1000 Design

- **To apply the ALARA principle to ACR-1000 NPP systems, the following procedure is used in determining which design option is the ALARA option. The procedure is as follows:**

  1) **Define the situation which requires consideration of a dose reduction**
  2) **Identify the options for dose reduction and factors to be assessed**
  3) **Evaluate the options using quantitative techniques or judgments**
  4) **Evaluate other non-radiological or non-quantifiable factors**
  5) **Decide which, if any, of the options to implement taking into consideration cost associated to dose reduction**
  6) **Document the basis of the judgement**

Occupational and Public Doses

- **Occupational and public doses has been assessed based on radiation source terms, CANDU 6 station data, ACR design features/improvements and maintenance activities:**
  - **The estimated average annual occupational dose is well below the design target (0.6 person-Sv/a)**
    - **20% from reactor operations**
    - **80% from maintenance**
  - **The upper-bound annual radiation dose received by individual members of the public from radioactive gaseous and liquid effluent emissions is well below the design target (10 μSv/a)**

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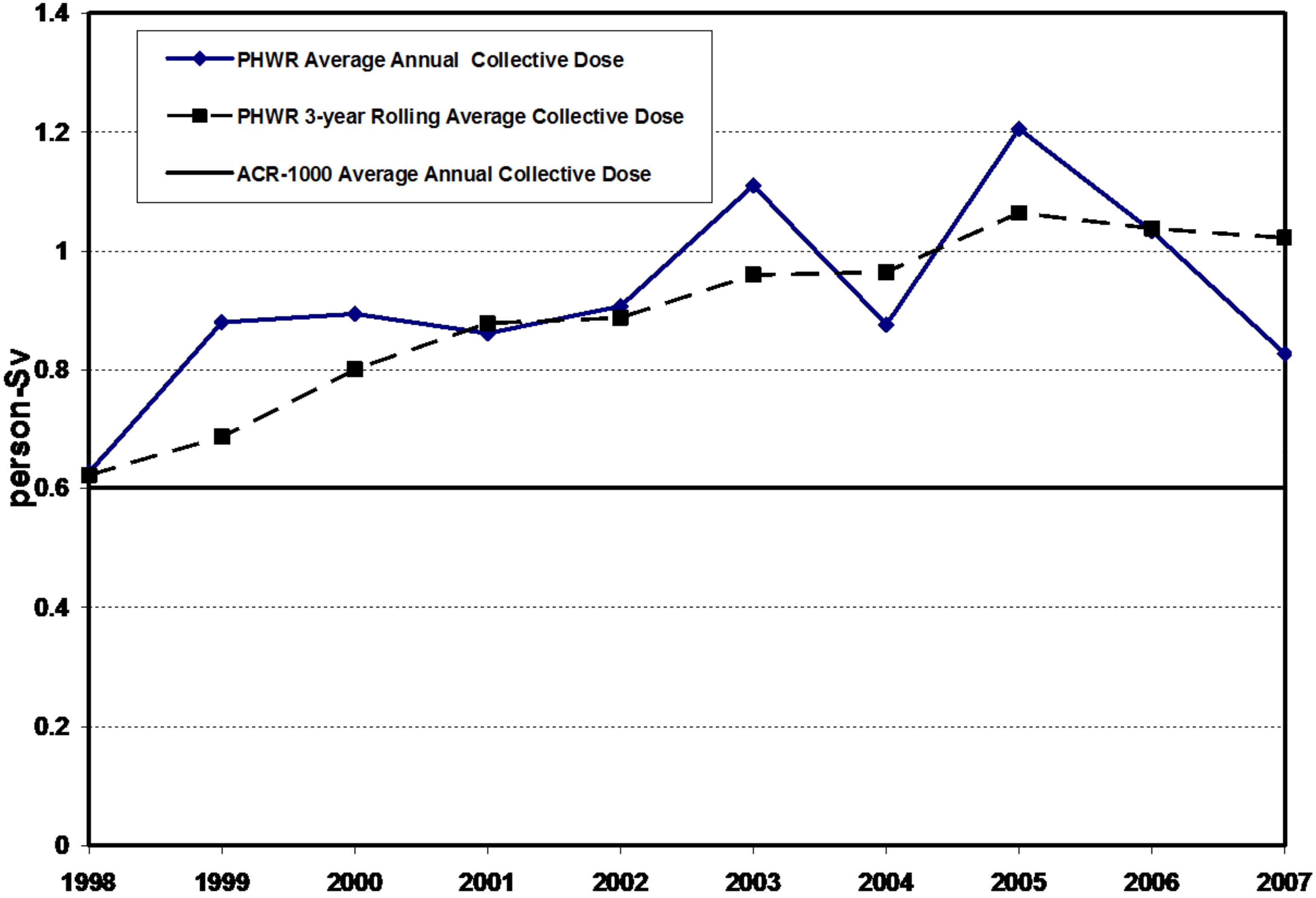
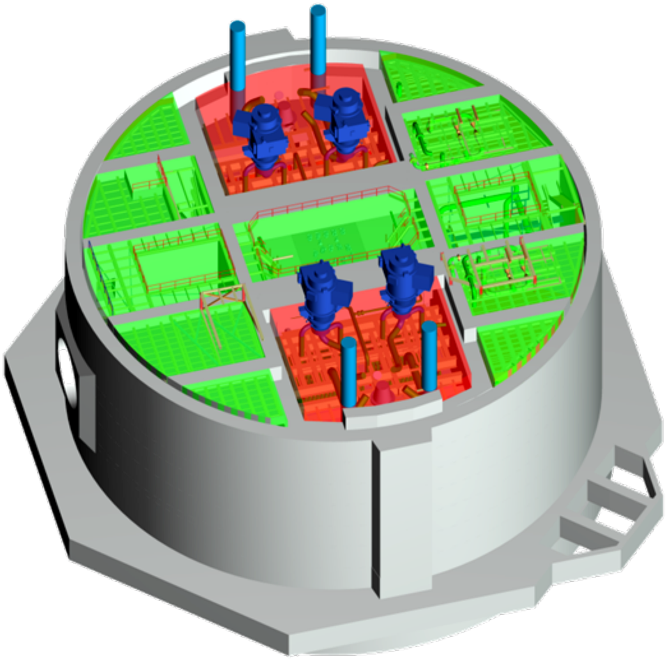
Average Annual Collective and 3-Year Rolling Average for PHWR and ACR-1000



ACR-1000 Design Features to Minimize Occupational Radiation Exposure (External Radiation)

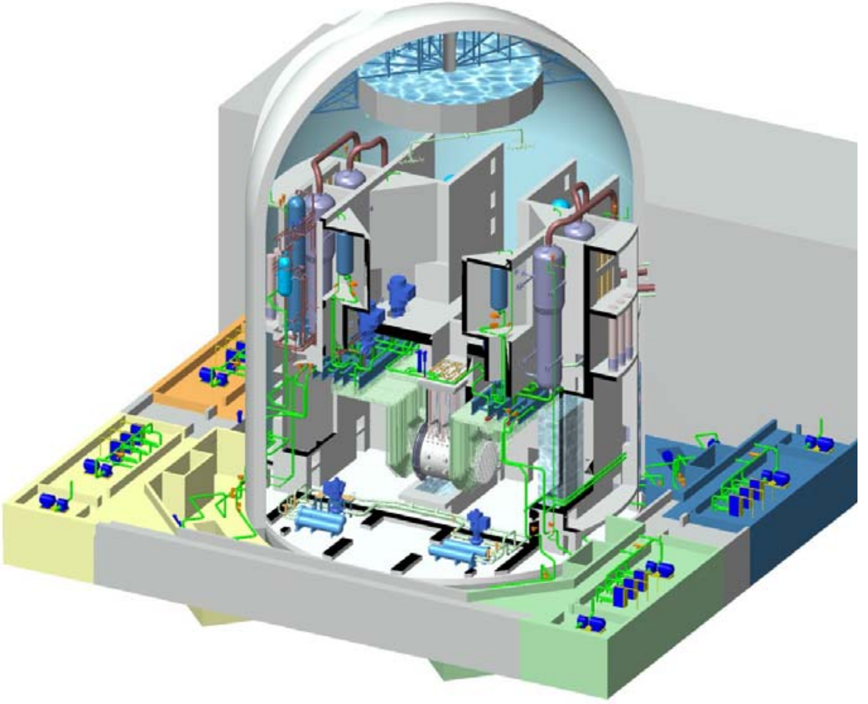
- **Common Equipment and Component and Layout**
  - **Plant has two major radiological zones, i.e., Radiological Control Area (RCA) and non-RCA. This reduces the time taken to enter and exit the facility, particularly during reactor shutdown, and makes it easier to control contamination.**
  - **Fewer monitoring stations at zone boundaries are needed, leading to reduced manpower needs at the fewer monitoring stations and reduced collective doses.**



ACR-1000 Design Features to Minimize Occupational Radiation Exposure (External Radiation)

<u>Common Equipment and Component and Layout</u>

- **Improved plant layout and improved access controls result in avoidance of high-radiation areas and provide increased radiation protection for operations and maintenance staff.**
- **Where possible, equipment requiring more frequent access and maintenance is located in low-dose and non-RCA areas.**
- **A maintenance-based design provides space allocation and reduction in temporary scaffolds and hoists, and includes provisions for built-in electrical, water, and air supplies for on-power and normal shutdown maintenance.**



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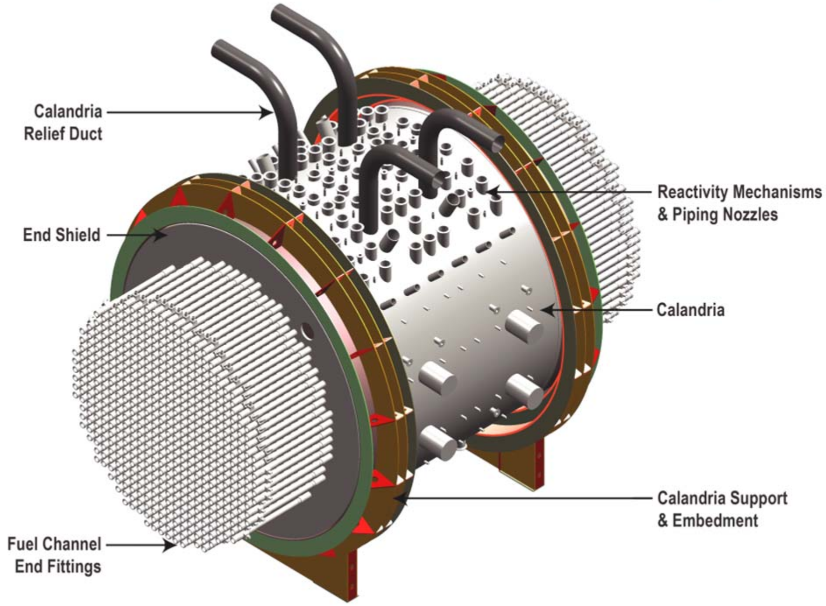
ACR-1000 Design Features to Minimize Occupational Radiation Exposure (External Radiation)

- Inherently lower thermal neutron flux due to the use of Low Enriched Uranium (LEU) fuel and a smaller lattice pitch combined with the use of stainless steel components in the HTS decreases corrosion product activity.

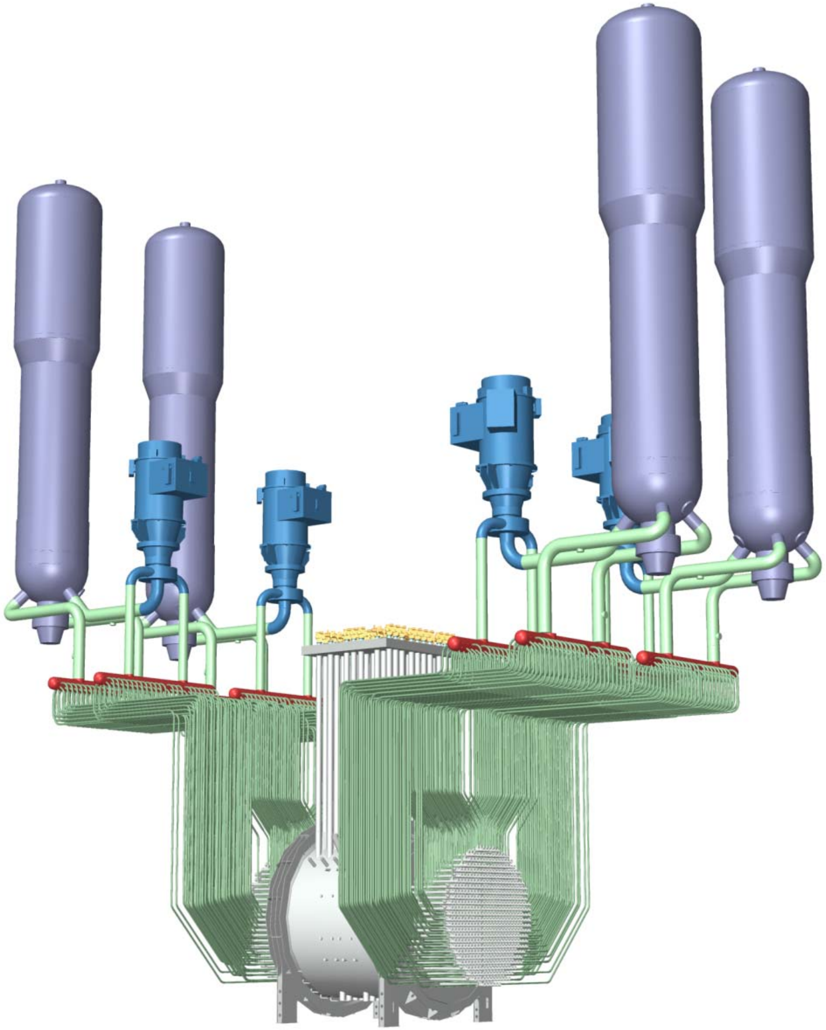
- The higher inlet reactor core temperature in the ACR-1000 increases the corrosion rate and solubility of dissolved corrosion product in the coolant. This effect is offset by reduction of thermal flux and change of feeder material from carbon steel to stainless steel, which decrease the corrosion product and activity transport and reduce reactor face fields.

Reactor Assembly as Installed in Reactor Building



ACR-1000 Design Features to Minimize Occupational Radiation Exposure (External Radiation)

- **Stainless steel for the Heat Transport System (HTS) feeders reduces flow-assisted corrosion and therefore reduces the quantity of mobile material available for activation and reduces the requirement for feeder-thinning inspections.**
- **Provision to supply nitrogen gas to the HTS to provide inert cover gas during drained state to reduce corrosion due to oxidation.**
- **The steam generators (SG) blowdown has been increased from 0.1% to 1.0% of the feedwater flow. This reduces the rate of fouling on the SG secondary side and the potential for degradation of SG material by removing more impurities from the SG.**



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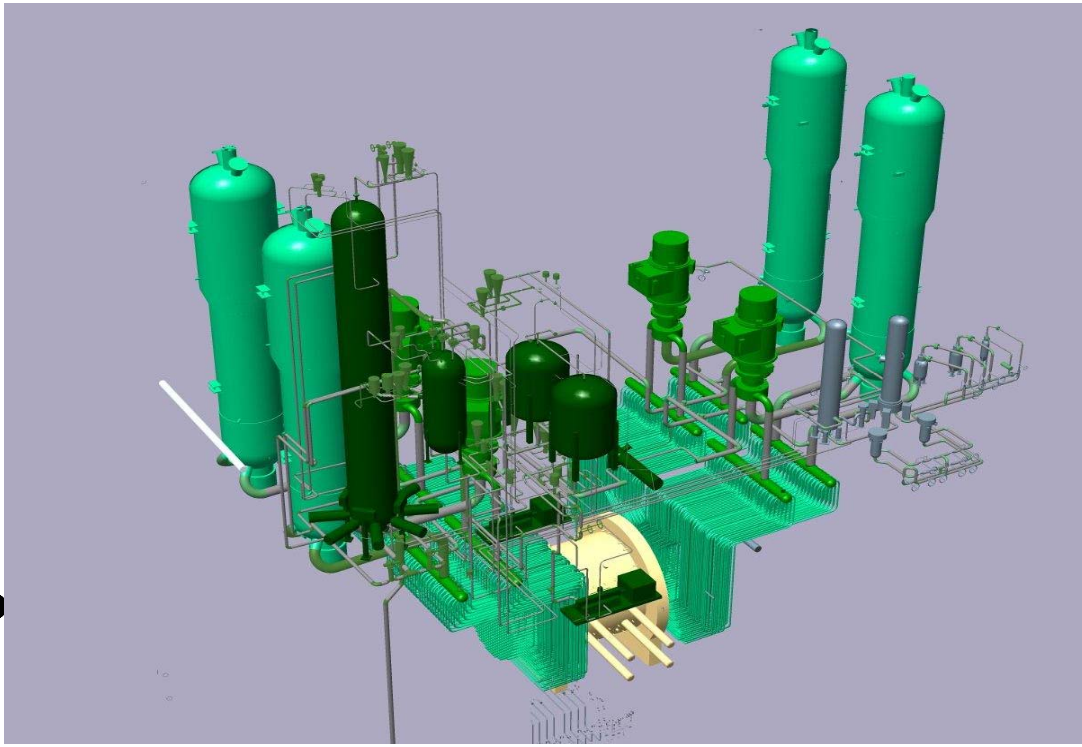
ACR-1000 Design Features to Minimize Occupational Radiation Exposure (External Radiation)

<u>HT Purification System</u>

- **Use of sub-micron filters to remove particulates from the HTS coolant.**
- **Use of a high flow purification system to provide a purification half-life of one hour or less to reduce activity transport and deposition outside the reactor core.**
- **Purification in-service during most shutdown configurations to maintain chemistry control, and to minimize start-up chemistry transients (e.g., crud bursts).**

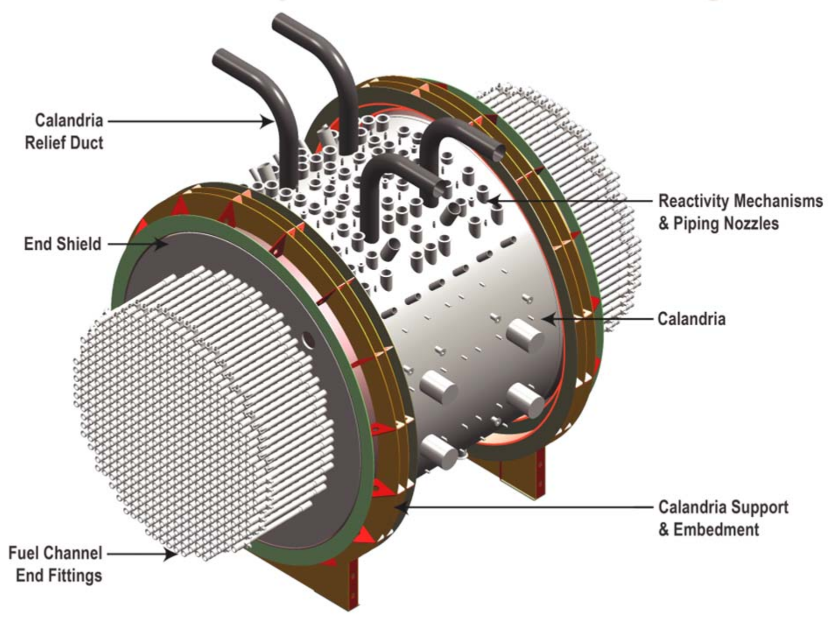


ACR-1000 Design Features to Minimize Occupational Radiation Exposure (Internal Radiation-Tritium)

Common Equipment and Component and Layout

- **Use of LEU and a smaller lattice pitch reduces thermal neutron flux, and the presence of smaller amount of D2O inside the calandria, lowers tritium production and therefore reduces the internal dose hazard from tritium escaping from the moderator system.**
- **HTS coolant is light water in the ACR-1000 plant, the tritium-in-air hazard from the HTS leakage is insignificant. Use of lithium depleted in Li-6 (0.1%) to reduce tritium production from Li-6 (n,α) ^{3}H reaction in the HTS.**

Reactor Assembly as Installed in Reactor Building



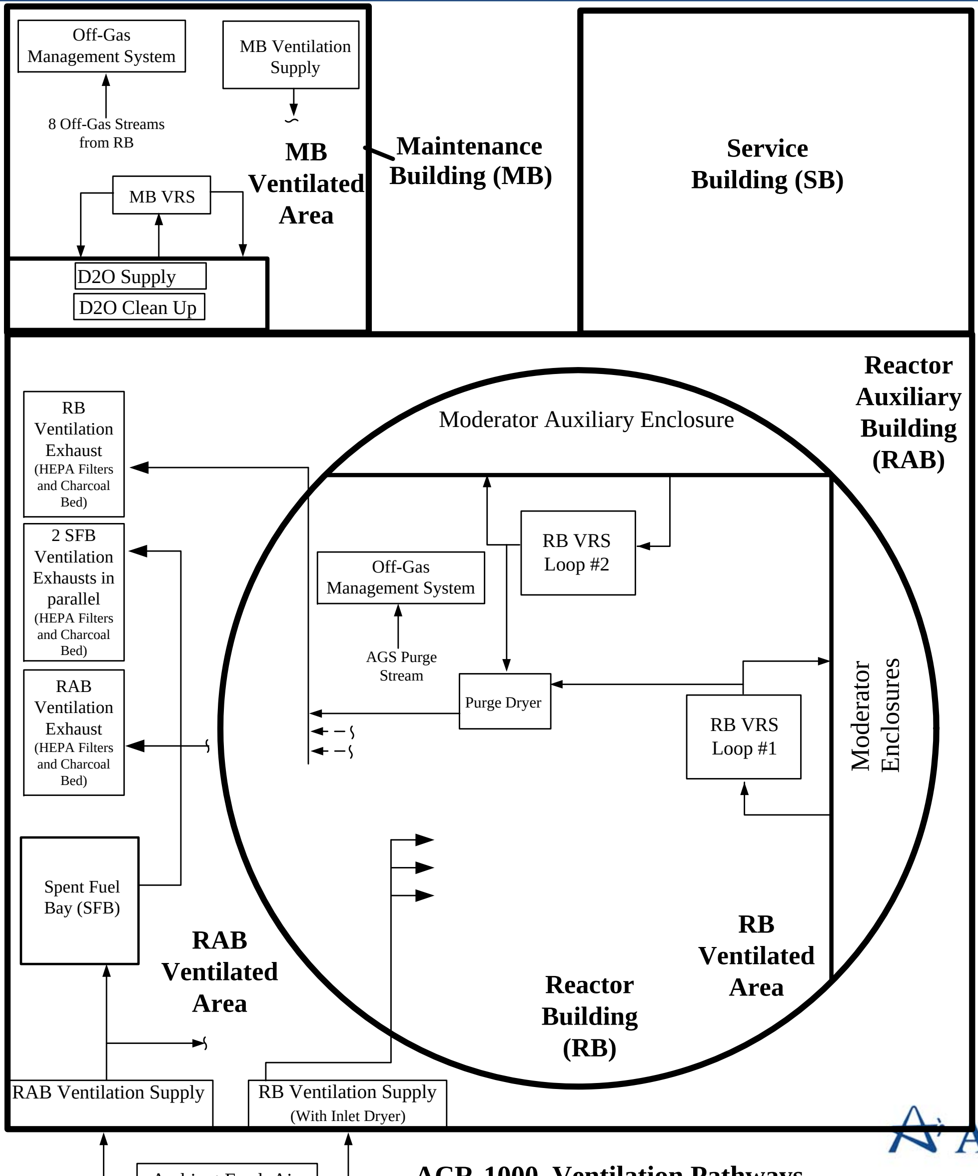
ACR-1000 Design Features to Minimize Occupational Radiation Exposure (Internal Radiation-Tritium)

Vapour Recovery Systems (Tritium Control)

- **The RB vapour recovery system minimizes tritium-in-air concentration in the moderator system areas to reduce worker dose:**
  - **Increased moderator dryer capacity (three rotary desiccant wheel dryer units) serving the Reactor Building (RB) and improved atmospheric control in the RB with higher purge flow from dried moderator areas.**
  - **Improved layout of moderator enclosure and moderator auxiliary systems by moving all moderator and moderator auxiliary equipment into dedicated dried rooms in the RB, making the management of their atmospheres more efficient and preventing diffusion of heavy water vapour to other regions of the RB.**
- **Addition of a single rotary desiccant wheel dryer unit to the MB D_2O Management Area minimizes tritium-in-air concentration in this area to reduce worker dose.**

ACR-1000 Design Features to Minimize Public Dose (Tritium Emission)

- Design features to minimize internal dose to workers also contribute to reduce tritium emissions (the last two slides).
- Additional design features include a RB purge dryer and RB inlet dryer (rotary desiccant wheel dryer units.
- All moderator tanks are vented to vapour recovery dryers.



ACR-1000 Ventilation Pathways

Summary

- ACR-1000 has evolved from top-performing CANDU 6 reactor line
- Retains proven CANDU design features while incorporating state-of-the-art innovations
- Evolutionary ACR-1000 design incorporates significant radiation exposure control improvements based on ALARA assessment using the latest technology and industry best practices with respect to:
  - limitation of potential worker and public doses
  - minimization of radionuclide production at source
- Annual occupational dose and public dose are ALARA and are below design targets 0.6 person-Sv/a and 10 μSv/a, respectively, over the operating life of a single unit ACR-1000 NPP.

Questions?

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