AECL EACL

Design Requirement

FUEL HANDLING AND STORAGE SYSTEM

ACR

108-35000-DR-001

Revision 0

Prepared by
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APPENDICES

1. INTRODUCTION

This document establishes the general technical requirements that shall govern the design of the ACR™[1] Fuel Handling and Storage System (ASI 35000).

This document does not cover:

- Shielding doors around the fuel handling route
- The structure and auxiliary equipment of the spent fuel storage bays
- Dry Fuel Storage equipment
- Handling of Reactor Components

The Fuel Handling and Storage system[2] includes the handling and storage of new and spent nuclear fuel starting from the point when new fuel enters the station to the point when spent fuel is removed from the spent fuel storage bay for dry fuel storage. The manual loading of the first charge of fuel is also the responsibility of fuel handling.

The Fuel Handling (FH) system is divided into the following main subsystems:

- New Fuel Transfer and Storage (ASI 35100)
- Fuel Changing (ASI 35200)
- Spent Fuel Transfer and Storage (ASI 35300)
- Spent Fuel Shipping (ASI 35400)
- Maintenance and Servicing (ASI 35600)
- Fuelling Machine Transfer (ASI 35700)
- Fuel Handling Controls (ASI 63500)

1.1 Acronyms

ALARA	As low as reasonably achievable
ARC	AECL Random Coil
ASI	AECL Subject Index
ASME	American Society of Mechanical Engineers
CANFLEX®[3]	CANDU flexible fuel
CNSC	Canadian Nuclear Safety Commission
CSA	Canadian Standards Association
DBA	Design Basis Accident
DBE	Design Basis Earthquake
FAF	Flow Assist Fuelling
FARE	Flow Assist Ram Extension

1 ACR™ (Advanced CANDU Reactor™) is a trademark of Atomic Energy of Canada Limited (AECL).

2 Also referred to as the Fuel Handling System.

3 CANFLEX® is a registered trademark of AECL and the Korea Atomic Energy Research Institute (KAERI).

FCS	Fuel Handling Control System
FDS	Fuel Handling Display System
FH	Fuel Handling
FM	Fuelling Machine
FMTR	Fuelling Machine Test Rig
HTS	Heat Transport System
HT P & IC	Heat Transport Pressure and Inventory Control System
IAEA	International Atomic Energy Agency
LOCA	Loss Of Coolant Accident
MCR	Main Control Room
MSLB	Main Steam Line Break
NFP	New Fuel Port
NU	Natural Uranium
RB	Reactor Building
RAB	Reactor Auxiliary Building
SDG	Safety Design Guide
SEU	Slightly Enriched Uranium
SF	Spent Fuel
SFP	Spent Fuel Port
TBD	To Be Determined

1.2 Definitions

- *Bi-directional channel flow:* Flow direction in each channel is opposite to that in adjacent channels.
- *2 bundle shifts:* During fuel changing operations, two fuel bundles are removed from the downstream end of the channel while two new fuel bundles are inserted at the upstream end of the channel.
- *Capacity factor*: Ratio of the electrical energy generated to the theoretical rated output of the station over any time interval.
- *Critical power ratio*: The ratio of channel power that will produce dry out to the normal time-averaged channel power.
- *Decay*: The decrease in activity of a radioactive material as it spontaneously transforms from one nuclide to another or into a different energy state of the same nuclide.
- *Defective fuel:* Fuel bundle with a breach in its cladding that allows radioactive fission products to escape in detectable quantities. Also referred to as defected fuel in other documents.
- *Design Basis Earthquake (DBE)*: An engineering representation of the potentially severe effects of earthquakes applicable to the site that have a sufficiently low probability of being exceeded during the lifetime of the plant.

- *Dose*: The amount of ionising radiation energy absorbed per unit mass (usually per unit mass of tissue).
- *Dual ended fuelling:* A method of fuel changing where two FMs are used for fuelling. One FM is attached to each end of the fuel channel.
- *Dryout*: Fuel sheath dryout occurs when the heat flux from the fuel element increases to the point where a continuous liquid-to-surface contact between the fuel element and the coolant can no longer be maintained. The result is a sudden significant increase in the temperature of the fuel element in the dryout regions. A measure of the margin to dryout is the critical power ratio.
- *Dry Storage*: Interim storage of SF. Fuel is placed in a concrete canister or concrete vault after its decay heat allows it to be removed from wet storage in the SF storage bay.
- *Excess Reactivity*: The conditions under which neutron production is maintained to achieve criticality in the core.
- *Forced unavailability*: Unavailability caused by work that cannot be postponed beyond the next weekend; generally failures that disable the system and therefore demand immediate repair.
- *Fuel Element*: A cylindrical, hermetically-sealed, zirconium-alloy sheath containing fuel pellets stacked end-to-end.
- *Fuelling Machine Test Rig (FMTR)*: A test rig designed to allow ram cycle testing and calibration of the entire FM.
- *Fuelling Machine vaults*: The two rooms within the Reactor Building (RB), on either end of the reactor, that are used by the FH system to perform fuel-changing operations.
- *Maintenance locks*: The two rooms within the RB reserved for relatively minor maintenance of the FMs.
- *Maintenance unavailability*: Unavailability caused by work that can be deferred beyond the coming weekend but not to another season.
- *Planned unavailability*: Unavailability caused by work that can be postponed from one season to another, for example, scheduled overhaul and inspection.
- *Reactivity*: A term used to describe the kinetic behaviour of a nuclear reactor.
- *Reliability*: The probability that equipment will perform a specified function under stated conditions for a given period of time.
- *Safeguards*: A system of technical measures within the framework of international non-proliferation policy entrusted to the IAEA in its statute and by the Non-Proliferation Treaty.
- *Spent fuel*: Nuclear fuel that has been irradiated in a reactor. It is also termed “irradiated fuel” or “used fuel”.

2. FUNCTIONAL REQUIREMENTS

2.1 Safety Functional Requirements

- Maintain the heat transport pressure boundary integrity while the FM is connected to a fuel channel and the channel closure is not installed.

After SF is removed from the reactor, the FH system must:

- Cool the fuel up to the time it reaches the SF storage bay.
- Provide containment of failed fuel until it has been transferred to the SF storage bay.
- Provide biological shielding against nuclear radiation released by SF.

At all times:

- Maintain the availability of the FH portion of the RB containment system.

2.2 Operating Functional Requirements

2.2.1 Normal Operation

- The FH system has to be designed in a way it does not damage the fuel during the fuel transfer process. For more information refer to Section 15.3.
- Receive new fuel, unload it from the carrier, transfer it into storage, and store it securely outside of the RB until required.
- Transfer the new fuel to the fuel transfer area, uncrate the new fuel, inspect it and load it into the fuel transfer system.
- Under automatic control from the Main Control Room (MCR), perform fuel-changing operations. Fuel changing operations include:
  a) Transfer up to 6 pairs of new fuel bundles through the containment boundary and load them into the FM.

     Rationale: CANDU 6 fuelling scheme is an 8 bundle shift, and a CANDU 6 FM holds 5 fuel pairs in the FM magazine. ACR performs 2 bundle shifts and the FM holds up to 6 pairs in its magazine.

  b) Position the FMs at the reactor faces, attach them to the end fittings of the fuel channel to be fuelled, and remove the channel closures and shield plugs.
  c) Remove pairs of SF bundles from the downstream end of the channel, and insert pairs of new fuel bundles at the upstream end of the channel.
  d) Reinstall the shield plugs and channel closures and disengage from the fuel channel.
  e) Visit up to 5 other fuel channels and perform similar operations prior to the transfer of SF to the SF storage bay.

     Rationale & Clarification: The intent is to replace one pair of fuel bundles per channel visit. To minimize the cycle time for fuel changing, it will be necessary to service up to 6 channels before discharging the SF to the bay. Therefore, the FM and SF transfer magazine must be able to hold 12 fuel bundles, transfer the SF to the SF discharge port and maintain fuel cooling while doing so.

f) Unload the SF bundles in pairs from the FM into the SF transfer system, and transfer the fuel through containment to the SF storage bay.

- Make provision in the SF transfer system for the safe collection of active gases from defective fuel.
- At the SF storage bay, provide for the separation and segregation of defective fuel.
- At the SF storage bay, load SF into storage containers.
- Store the SF bundles in the SF storage bay in a manner that allows sufficient cooling to prevent fuel failure and bundle distortion.
- Defuel and fuel a complete fuel channel at any reactor power level, without making multiple visits to the channel.

  Rationale: To reduce critical path work during outages, the FH system must be able to defuel a channel at full power prior to channel inspection, and refuel it at full power following channel inspections. To minimise the time to do this, the FH system, including the FM and SF magazines, must be able to hold 12 fuel bundles.
- Fuel changing operations shall not increase the channel flow to a value greater than that specified in Section A.15 of Appendix A.
- Under operator control from the MCR, exchange the fuel channel shield plugs and closures without disengaging the FM from the channel end fitting.
- Under operator control from the MCR, unload the shield plug from the FM into the SF transfer system, and transfer the shield plug through containment to the SF storage bay.

  Information: Shield plugs are not transferred to the SF storage bay unless they need to be inspected or refurbished.
- Replacing defective ram adaptors, channel closures, shield plugs and closures with new or refurbished ones shall be achieved through interaction of operator control from the MCR and manual operations in the field.
- The normal fuel changing process shall include means of checking for leakage across the FM snout/end fitting seal prior to removing the channel closure, and across the channel closure plug and FM snout plug prior to unclamping the FM from the end fitting.
- Some means of channel flow verification prior to and following fuel changing must be provided. Consideration shall be given to channel flow verification throughout the fuel changing process.

  Information: Channel flow verification is performed prior to and following fuel changing at Pickering and CANDU 6 nuclear power plants.

2.2.2 Abnormal Operation

- Under operator control from the Main Control Room (MCR), perform fuel-changing operations. Fuel changing operations include:

  a) Transfer up to 6 pairs of new fuel bundles through the containment boundary and load them into the FM.

  b) Position the FMs at the reactor faces, attach them to the end fittings of the fuel channel to be fuelled, and remove the channel closures and shield plugs.

c) Remove pairs of SF bundles from the downstream end of the channel, and insert pairs of new fuel bundles at the upstream end of the channel.
d) Reinstall the shield plugs and channel closures and disengage from the fuel channel.
e) Visit up to 5 other fuel channels and perform similar operations prior to the transfer of SF to the SF storage bay.
f) Unload the SF bundles in pairs from the FM into the SF transfer system, and transfer the fuel through containment to the SF storage bay.

- Under operator control from the MCR, have the capacity to drain the water out of a fuel channel and header after the appropriate decay time. To drain a single fuel channel, that channel will be isolated from the HTS at its feeders.
- SF bundle transfer shall be based on the transfer of pairs of fuel bundles. Provision for occasional single fuel bundle handling shall be provided.
- Install a pressure tube seal ((PTSL) similar to a shield plug with o-ring seal).
- The FM shall provide a pressure relief path so that, if both feeders are being frozen, ice plug growth will not cause over-pressurization of the fuel channel.
- Remove fuel bundles from a channel by grappling them into a FM.
- Under automatic and/or operator control from the MCR, unload the complete reactor core load of fuel, and transfer and store it in the SF storage bay. This operation is to be carried out while the reactor is at cold depressurised conditions with standby cooling.

2.2.3 Upset and Emergency Operations

- It shall be possible to recover from any single failure of FH equipment.

  Included are:

  a) FM recovery operations where a malfunctioning FM must be removed from a fuel channel end fitting without the re-installation of the channel closure, with the fuel string still in the channel and/or FM magazine (assuming that FM magazine rotation is operational), or with channel hardware or FH hardware protruding out the snout of the FM, while the reactor is at shut down.
  b) The handling of a FM head containing SF that cannot be discharged in the normal manner. No special equipment or tooling is to be designed or supplied at this time. Containment integrity must be maintained during breakdown handling.
  c) New fuel being inserted into a fuel channel before the shield plug is removed.

2.3 Derived Requirements

Fuel changing shall be performed in accordance with the fuelling scheme.

- Fuel changing at the reactor face shall be with the flow using the Flow Assist Fuelling method (FAF) where sufficient fuel channel flow is available.
- In channels with insufficient flow to perform FAF, the Flow Assist Ram Extension (FARE) method shall be used.

- The selected number of spent fuel bundles will be removed from the fuel channel before new fuel bundles are inserted.
- To achieve the station's capacity factor target, the FM will carry a spare channel closure and shield plug during normal on-power operations.
- The FM bridge and carriage shall be adaptable to become a part of the fuel channel inspection and/or replacement tooling. It shall also support reactor face access for inspections during commissioning and operation, and shall support access to all fuel channels for manual fuel charging. For the number of fuel channels refer to Section A.2 of Appendix A.
- The FH mechanisms will have capacity for twelve fuel bundles. Refer to Section 2.2.1.
- Where redundant equipment or controls and instrumentation are provided, they shall be supplied from alternate power supplies.

2.4 Miscellaneous

- A means shall be provided to prevent crud/activity being transferred from the HT system to the FM while the FM is on channel.

  Information: Providing flow injection is a way of satisfying this requirement.
- A rehearsal facility and other equipment shall be provided in the RB to facilitate various FM testing and rehearsal activities while the reactor is at power. Consideration shall be given to locating this equipment so that the FMs are accessible when they are attached to the equipment and the reactor is at power. The rehearsal facility and other equipment shall meet the following requirements:
  a) To rehearse fuelling operations.
  b) To rehearse FM homing, clamping and snout seal operations, including reactor channel closure installation and removal operations at normal and shutdown channel pressures.
  c) To rehearse the FM operation in conjunction with other components normally handled by the FM during fuelling. This includes grappling tools used by the machine during special recovery procedures.
  d) To rehearse new operations.
  e) To test FM equipment after service and before use.
  f) To test fuelling sequence and electrical interlocks.
- Special equipment shall be provided for manual loading of the first fuel charge.
- During the dry loading of the first-charge of fuel into a new or retubed core, the fuel-bundle bearing pads shall not have sliding contact with the pressure tube.

  Clarification: New fuel bundles can cause severe gouging of pressure tubes when they are first loaded manually into a new reactor since there is no water for lubrication. In earlier stations, a shim was used to eliminate sliding contact. However, the necessity of the shim has been questioned.
- Provision shall be made for mounting remote viewing equipment to permit observation of FM operations from the MCR.

- Provisions shall be made for the inspection of defective fuel in the SF storage bay so that the causes of defects can be quickly assessed and can then be eliminated by changes in manufacturing of the fuel bundles or in FH operations.
- With loss of operating power, mechanisms and components shall fail to a safe condition which also minimizes operational, maintenance and economic penalties to the associated system or systems.
- Sufficient margin shall be provided around all moving FH equipment to avoid any collisions with any stationary FH or other equipment or/and civil structure. Sufficient margin shall be provided to account for manufacturing, construction and installation tolerances.

3. PERFORMANCE REQUIREMENTS

The FH system design shall meet the following requirements:

- The FH system must operate for the life of the station. (Refer to Section A.9 of Appendix A).
- The SF storage bay and associated equipment must have sufficient capacity as specified in Section A.3 of Appendix A, to store SF generated during station operation. In addition to this, it shall also have a provision for storing one core load of fuel. The time period is a derived quantity, driven by the need to limit the size of the bay and dependent upon the use of an inert gas in the dry fuel storage canister.
- The FH system shall meet the requirements of equilibrium fuelling, advanced fuelling and catch-up fuelling as given in Section A.3 of Appendix A.
- The equilibrium fuelling rate must be sustainable between scheduled outages.
- Catch-up fuelling must be sustainable until the reactivity deficit is removed following a fuelling outage.
- Daily fuelling should be accomplished with effort comparable to the current CANDU 6 method of fuelling unless it can be shown that a proposed system or technique will result in an overall benefit despite the additional cost of longer fuelling times.
- To control operational costs, normal operational staff requirements for FH should not be greater than a comparable CANDU 6 station.
- The minimum accuracy of channel flow verification is specified in Section A.3 of Appendix A.
- The minimum accuracy of on-channel leak test measurement determination is specified in Section A.3 of Appendix A.
- See also reliability and maintainability requirements in Section 9.
- The system must be able to accommodate the SF bundle decay heat load specified in Section A.3 of Appendix A. (See Figure 1). The fuel burn-up is also specified in Section A.3 of Appendix A.
- Defective fuel bundle handling shall accommodate the fuel defect rate specified in Section A.3 of Appendix A.

4. SAFETY REQUIREMENTS

4.1 Applicable Requirements from Safety Design Guide

- As identified in the Safety Design Guide (SDG) for Safety Related Systems, the FH System is a safety related system. Failure of the FH System shall not impact the radiological safety of the public or plant personnel (Reference [1]).
- Seismic Qualification of the FH System shall be in accordance with the Seismic Requirements SDG (Reference [2]). Failure of FH subsystems and components shall not compromise the safety related functionality of the FH System. During and following a Design Basis Earthquake (DBE):
  a) The containment boundary shall be maintained;
  b) The FM shall not unclamp from the New Fuel Port (NFP), Spent Fuel Port (SFP), or fuel channel if the channel closure is removed;
  c) The FM and its support equipment shall not damage an end fitting, the NFP or SFP;
  d) When off-channel, SF in the FM shall be kept cool to avoid fuel failure due to overheating;
  e) SF in the Fuel Transfer System shall be kept cool to avoid fuel failure due to overheating.
- The Environmental Qualification of the FH safety related subsystems and components shall be in accordance with the Environmental Qualification SDG (Reference [3]). Failure of FH subsystems and components shall not compromise the safety related functionality of the FH System. Therefore, during and following a Design Basis Accident (DBA):
  a) The containment boundary shall be maintained;
  b) The FM shall not unclamp from the NFP, SFP, or fuel channel if the channel closure is removed;
  c) The FM and its support equipment shall not damage an end fitting, the NFP or SFP;
  d) When off-channel, SF in the FM shall be kept cool to avoid fuel failure due to overheating;
  e) SF in the Fuel Transfer System shall be kept cool to avoid fuel failure due to overheating.
- The FH subsystems shall meet the physical and functional separation requirements in accordance with the Separation of Systems and Components SDG (Reference [4]).
- The FH system shall meet the Fire Protection requirements in accordance with the Fire Protection SDG (Reference [5]).
- The FH system shall provide Radiation Shielding required in accordance with the Radiation Protection SDG (Reference [6]).
- Sections of the FH system that form part of the containment boundary shall be designed in accordance with the Containment SDG (Reference [8]).

4.2 Specific Requirements from CNSC Regulatory Documents

- The design of the containment portion of the FH transfer ports and associated systems shall comply with the requirements of CNSC Regulatory Document R-7, "Requirements for Containment Systems for CANDU Power Plants."
- The CNSC containment requirements are identified in Reference [8].
- When storage of SF is considered, the following five licensing concerns must be satisfactorily addressed:
  a) Adequate fuel cooling,
  b) Adequate mitigation of radioactive release in the event of fuel failure,
  c) Adequate radiation shielding,
  d) Adequate physical security and ease of safeguards verification,
  e) Long term structural integrity against natural events.

4.3 Protection Against Environmental Hazards

- The seismic qualification, level and category of various FH subsystems and components will be specified in the related detail design requirements documents.
- The design of the FH System shall consider all events, which could cause harsh environmental conditions (Reference [3]).

4.4 Protection Against Impact Forces

The design of the FH System shall meet the relevant requirements specified in Reference [4].

4.5 Fire Protection

The design of the FH System shall meet the relevant requirements specified in Reference [5].

4.6 Industrial Safety Requirements

- The design of the FH system shall meet requirements of applicable Canadian national codes and standards pertaining to electrical safety, material handling and general industrial safety.
- All FH facilities including the reactor vault and maintenance lock shall be provided with adequate lighting, power supplies and breathing air.
- Where personnel will use moving parts of the FH system as a means of access to equipment; or where there is a risk of people being pinched or trapped by moving FH equipment, a local emergency stop button must be provided.

4.7 Other Safety Requirements

4.7.1 Safety Related to Criticality

- Special design and material management features are required to ensure against criticality during transfer and storage of new and spent SEU fuel including:
  a) The criticality hazard that could arise from the discharge of a core load of fresh fuel into the SF storage bay;
  b) The criticality hazard of new fuel in the event of flooding and/or seismic activity.

4.7.2 Operational Safety Requirements

- In situations where asynchronous or inadvertent operation of the equipment will compromise nuclear safety or have a significant economic impact, independent interlocks are required to minimize risk.
- Protection from accidental over-travel shall be provided.
- Equipment must be designed to be fail-safe.
- Sufficient manual control of individual drives shall be provided to bring the FH System to a safe state.

4.7.3 Supplementary Safety Related Requirements

- FH operations shall maintain the minimum margin to dryout.

  Clarification: The FM shall not significantly compromise cooling flow (for example, the FM ram head shall not reduce the flow in the channel to a point where cooling is compromised).
- If during the transfer of a SF bundles from the FM to the SF storage bay, the fuel bundles are required to travel through air, the fuel bundles shall not be exposed to air for more than the time limit specified in Section A.4 of Appendix A. In addition, provision shall be made for emergency cooling of the SF bundles that are exposed to air for an extended time period.
- The containment portion of the FH system shall be able to perform its safety function during and following an accident or seismic event.
- SF in the FH system shall be cooled during and following an accident or seismic event.
- If operator action is required for actuation of any safety equipment (fuel cooling or containment), all of the following requirements must be met[4]:
  a) Instrumentation shall be provided to give the operator clear and unambiguous indication of the necessity for operator action.
  b) The reliability of such instrumentation shall be commensurate with the requirements of the availability of the safety system. Consideration shall be given to the use of redundancy[5] to satisfy this requirement.

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4 These requirements have been taken from the CNSC regulatory document for containment R-7, and applied here to fuel cooling as well as containment.

5 Redundancy is not a requirement stated in the CNSC Regulatory Document R-7.

c) There shall be sufficient time as specified in Section A.4 of Appendix A, after such clear and unambiguous indication, before operator action is required, and

d) There shall be clear, well-defined and readily available operating procedures to identify the necessary actions.

- Facilitate the transfer of irradiated shield plugs and irradiated FH components to the SF storage bay.
- Minimise the risk of situations occurring where irradiated fuel or hardware can become stranded in the FM or SF transfer system.

  Rationale: This requirement comes out of reported incidences at CANDU 6 stations where new fuel has been inserted in the upstream side of a channel before the operators became aware that the down stream shield plug was stuck.
- Provision shall be made for emergency cooling of the SF, as a backup to normal cooling, during fuel transfer from the FM.
- Prevent damage to SF or the release of fission products from SF which is located in the FM, the SF transfer system and the SF storage bay.
- The station man-rem target is provided in Section A.4 of Appendix A. FH man-rem consumption shall be limited as specified in Section A.4 of Appendix A.
- Calculation of radiation shielding requirements, of material degradation due to radiation, and of heat load allowances shall be based on a FM head containing twelve SF bundles which have been freshly removed from a channel, either:

  a) All from a maximum rated fuel channel, or

  b) A total of twelve, with two each taken from six different maximum rated channels.

  The more restrictive of the above shall govern.
- The transfer of heat transport system coolant to the SF storage bay will be restricted such that the emission of airborne tritium from the SF storage bay is optimized.
- The release of off-gas produced by defective fuel to the environment, must be controlled in accordance with the FH man-rem exposure limits and the station release limits.
- Heat exchangers that are used for fuel cooling must exchange their heat with intermediate recirculated water loops, and not directly with service water.

  Rationale: To prevent accidental releases to the public from damaged heat exchangers, and to minimize the flooding hazard in the location of the heat exchangers.

5. APPLICABLE CODES, STANDARDS & CLASSIFICATION

5.1 Material Standards and Specifications

All material shall conform to the requirements of current issues of relevant sections of the following specifications.

Table 5-1
Material Standards and Specifications

AISI	American Iron and Steel Institute
AMS	Aerospace Material Specification
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
ASNT	American Society for Non-destructive Testing
ASTM	American Society for Testing & Materials
AWS	American Welding Society
CGSB	Canadian Government Specification Board
CSA	Canadian Standards Association
DIN	Deutsche Instituit fur Normung E V
ISO	International Organization for Standardization
MIL	Military Specification
IEEE	Institute of Electrical and Electronic Engineers

5.2 ASME Standards

ASME Boiler and Pressure Vessel Code, Section III, Division 1 –Nuclear Power Plant Components.

ANSI/ ASME B31.1, Power Piping.

5.3 CSA Standards

The following are the major codes and standards applicable for FH and storage system.

CSA N285.0 General Requirements for Plants and Pressure-Retaining Systems and Components in CANDU Nuclear Power Plants (N285.0).

CSA N285.2 Requirements for Class 1C, 2C and 3C Pressure-Retaining Components and Supports in CANDU Nuclear Power Plants (CAN/CSA-N285.2).

CAN/CSA N285.3 Requirements for Containment System Components in CANDU Nuclear Power Plants (CAN/CSA-N285.3).

CAN/CSA-N285.4 Periodic Inspection of CANDU Nuclear Power Plant Components.

CAN/CSA-N285.5 Periodic Inspection of CANDU Nuclear Power Plant Containment Components.

CAN/CSA-N286.0	Overall Quality Assurance Program Requirements for Nuclear Power Plants.
CAN3-N289.3	Design Procedures for Seismic Qualification of CANDU Nuclear Power Plants.
CSA N293	Fire Protection for CANDU Nuclear Power Plants (CSA N293-95).
CSA B51	Boiler, Pressure Vessel and Pressure Piping Code.
NBCC	National Building Code of Canada.

Code requirements will be updated when the project code effective date is decided.

5.4 IEEE Standards

IEEE 323	IEEE Standard for qualifying Class 1E equipment for Nuclear Power Generating Stations.

5.5 Fissionable Materials Safeguards

- The design of the FH system shall be suitable for incorporation of IAEA Safeguards (Reference [7]).
- The SF storage bay must conform to the IAEA definition of dual containment and surveillance.

  Clarification: Containment methods are means of verifying that items of interest have not been tampered with or removed from a containment area. Dual containment and surveillance means two redundant containment or surveillance methods based on physically independent and diverse principles used to safeguard the same material. Closed circuit television surveillance in combination with the application of ARC seals in the SF storage bays constitutes a dual containment and surveillance system to safeguard the SF in the bay.
- The SF in the SF storage bays shall be stored in baskets and stacking frames with tamper-indicating covers.
- The basket and stacking frame size shall facilitate sealing every SF bundle in a full stacking frame within a time frame that will satisfy the IAEA safeguards issue. For a suitable time frame refer to Section A.5 of Appendix A.

5.6 Classification and Quality Assurance Levels

In line with the general project objective of cost control, the FH system shall be designed to the appropriate nuclear classification and quality assurance levels while considering good economics.

Pressure Retaining Boundary and Supports:

The classification and the quality assurance levels for the fabrication and construction of specific systems and equipment will be specified in the design requirements of the individual systems and components in accordance with the requirements of CAN/CSA–N285.0.

5.7 Registration Requirements

The design of the pressure retaining portion of the FH system and its supports shall be prepared for registration with the regulatory authority in accordance with the requirements of CAN/CSA-N285.0 and CSA B51.

6. ENVIRONMENTAL CONDITIONS

The environmental conditions are defined by: the fuel channel, radiation from the FM, radiation from the HT coolant, conditions in the RB, and conditions in the Reactor Auxiliary Building (RAB), and the maintenance building. The conditions existing in these locations are given in Section A.6 of Appendix A.

7. OVERPRESSURE PROTECTION

- These requirements shall be identified as applicable in the individual system/component design requirements in accordance with the requirements of CAN/CSA-N285.0.
- The design of overpressure protection of Class 1, 2 and 3 portions of the system shall comply with the requirements of Clause 7.2 of CAN/ CSA-N285.0.
- The design of overpressure protection of Class 4 portions of the system shall comply with the requirements of CAN/CSA-N285.3.
- The design of overpressure protection of Class 6 portions of the system shall comply with the requirements of the department of the province of installation.
- An overpressure protection report shall be prepared in accordance with CAN/CSA-N285.0.
- Overpressure protection discharge must not breach containment.

8. INSPECTION AND TESTING

- Satisfactory operation of the FM head shall be verified by laboratory tests. These tests shall simulate all normal operations of the FM, both on and off reactor.
- Laboratory testing and site commissioning require measurement of system variables that cannot be made without operational instrumentation. Where appropriate, equipment shall be designed to permit the connection or insertion of the necessary short-term instrumentation.
- The design of the FH system and its components shall be based on proven technology. However, if the design depends on unknown critical parameters that cannot be established economically by analysis, verification testing shall be employed.
- The FH system shall be designed to ensure that testing of nuclear safety features or interlocks can be carried out both during commissioning and routine operation.
- Periodic Inspections:
  a) The portion of the FH system that is part of containment shall comply with the applicable requirement in CAN/CSA–N285.5.
  b) It shall be shown by analysis that the pressure-retaining portion of the FM head meets the requirement for inspection category C2 of clause 7.1.5 of CSA CAN3–N285.4. Otherwise it is subject to periodic inspection in accordance with the requirements of CSA CAN3–N285.4.
  c) When supports for components are designed or qualified by load–rating, tests shall be in accordance with the requirements of CAN/CSA–N285.0, Section 14.
  d) When support or control components require shake–testing these tests shall comply with CSA CAN3–N289.4.
  e) Inspection and Pressure Testing of FH subsystems shall be carried out as per relevant codes and standards.

9. RELIABILITY AND MAINTAINABILITY

9.1 Reliability Requirements

- The reliability of the FH system shall be assessed to demonstrate that no single failure of any portion of the system will:
  a) Compromise its and any interfacing system's safety related function.
  b) Prevent meeting the lifetime target capacity factors specified in Section A.9 of Appendix A.

  Information: The SF storage bay and associated cooling and purification system must remain available for the life of the plan, plus the time required for the last core load of fuel to decay to the point when it can be transferred to dry storage.
- Fault tree analysis must be used to determine which failed components and systems will result in a particular failure scenario, and the required reliability of those components to meet the target reliability of the FH system.
- The containment portion of the FH service ports shall be analysed to show that its contribution to the unavailability of the containment system does not raise the dormant unreliability of the overall containment system above the value specified in Section A.9 of Appendix A.

9.2 Unavailability Requirements

- The unavailability of the FH System shall not prevent the station from achieving its availability targets. The FH System unavailability contribution shall be as specified in Section A.9 of Appendix A.
- Where required, the design shall incorporate redundancy and/or accident recovery provisions to improve the reliability and the availability of the FH system.

9.3 Maintainability Requirements

- FH system components that require routine servicing shall be accessible with the reactor at full power.
- Routine checkout, set-up, and calibration of the FM head functions must be possible while the FM is in the maintenance lock (RB) and the reactor is at power. Remote readout of the measurements must be provided, to the greatest extent that is economically practical, to minimize the time personnel are in the RB.
- Sufficient equipment shall be provided in the maintenance building to check out and function test the FM following major overhauls and repairs. These shall include the ability to operate the rams and pressure test the FM.
- The frequency of routine maintenance shall be compatible with station dose targets. The targets for maintenance unavailability and for frequency of routine maintenance are identified in Section A.9 of Appendix A.
- Maintenance of components or assemblies that require major disassembly shall have service intervals that correspond to station planned shutdowns. The target for planned service interval is as identified in Section A.9 of Appendix A.

- Components and assemblies located in the RB, having maintenance intervals that are more frequent than the station planned shutdowns and can be maintained while the reactor is at power, must be designed so that work can be completed within the stipulated period of time specified in Section A.9 of Appendix A.
- Equipment design shall minimize the time required to maintain, repair or replace those parts/ components subject to normal wear.
- The fuel changing system design shall incorporate lifting and transporting equipment to facilitate transfer of the FM from the FM maintenance lock (adjacent to the FM vault) to the maintenance building with the reactor at full power.
- To reduce man-rem exposure and overall maintenance cost, the time required to replace a FM head or FM ram assembly shall be minimized. The design target for the replacement of a FM or ram is specified in Section A.9 of Appendix A.
- As far as practical, equipment shall be located in areas of low background radiation fields.

  Rationale: A significant cost of maintenance work is related to man-rem exposure. This cost can be reduced by locating equipment in areas of low background radiation. However, practical considerations and other design requirement may make this goal impractical.
- For maintenance purposes, it must be possible to pressurize the FM in the RB independent of the heat transport system.
- All underwater mechanisms and instrumentation of the fuel transfer system shall be removable for servicing without draining the water from the SF storage bay.
- The design of the FM maintenance equipment shall provide for inspection and functional testing of the FM ram assembly and pressure testing of a FM head assembly.
- Where practicable, components and manufactured parts shall be designed to be interchangeable.
- Components of the FH system shall be designed for easy purging of water contained in them.
- Where practical, the design shall be flexible enough to facilitate the easy replacement of obsolete equipment.
- Tools and calibration fixtures that are not commercially available, and that are necessary for the maintenance of the FH system, must be provided.
- The design of the FH system shall employ standardized components and parts. If non-standard components must be used, the number of different types and sizes shall be minimized.
- Wherever practicable the FH system shall use components and equipment that are common to other plant systems.

10. LAYOUT

- The FH system shall be compatible with the general layout of the RB and the RAB.
- The footprint of FH equipment in the reactor auxiliaries building must be minimized to reduce capital costs.
- FH equipment shall not inhibit the closure of any shielding doors, or access doors.
- FH equipment shall not inhibit inspection and maintenance of other equipment.
- Major assemblies and subassemblies shall be interchangeable.

11. INTERFACING SYSTEMS

Following subsections outline the requirements imposed by the FH system on interfacing systems. The interfacing requirements will be listed in more detail in the individual subsystem and component design requirement documents.

11.1 Reactor Building & Reactor Auxiliary Building (ASI 21000)

- Provide space for FH operations in the RB. See References [11] & [12].
- The FM maintenance locks and their shielding doors shall provide radiation protection to service personnel working on FH equipment in the maintenance locks, while the reactor is at full power. The maximum radiation level for the FM maintenance lock areas under normal conditions with the reactor at full power, the shielding door between the FM vault and maintenance lock closed, and no SF in the FM, shall be within the limits specified in Section A.11 of Appendix A for this regulated access areas.
- Provide facilities[6] outside the RB for the decontamination and maintenance of the FM and FH components. This shall include space for ram rebuilds, storage of a spare FM, and channel inspection equipment. In addition, space should be provided for large test equipment such as the FMTR.
- Provide the facilities[6] required for the removal of the FM, bridge and carriage components, process equipment and other FH hardware and maintenance equipment from the RB to the maintenance building for maintenance.
- Provide access for FH maintenance personnel to the FH equipment in the RB and RAB while the reactor is at power and SF is in the SF storage bay.
- Means shall be provided in the FM maintenance locks for emergency egress of personnel.
- Access to the FM maintenance locks shall be controlled.
- Provide space in the RB for the FH system piping/equipment.
- Provide space in the RAB for the storage of SF in water. The depth of water in the SF storage bay shall provide adequate shielding of the SF.
- Provide shielding for personnel from radiation hazards within the FM water system.
- Provide facilities[6] for the transfer of SF from the storage bay to the dry storage facility. This includes a location/space/support for the shielded workstation and shielding for operators.
- Accommodate service ports that can be accessed on one side by the FMs, and on the other side by personnel or a shielded flask.
- Provide facilities[7] in the RB and RAB for IAEA equipment and inspections.
- Additional requirements are specified in the design requirement documents of the FH subsystems.

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[6] Facilities refer to features such as equipment routes, access stairways, freight elevators, cranes, laydown areas, work areas, lighting, electricity, ventilation etc.

[7] Facilities refer to features such as equipment location areas, lighting, electricity, etc.

11.2 Fuel Channel Assembly (ASI 31000)

- Provide an interface on the fuel channel assembly to facilitate the following FM functions:
  a) Home the FM snout onto the fuel channel end fitting.
  b) Align the FM snout with the fuel channel end fitting.
  c) Clamp the FM snout to the fuel channel end fitting, making a pressure boundary seal between the snout and the end fitting without overstressing FM or channel components.
- The channel closure shall be provided with features to facilitate the following FM functions:
  a) Remove the channel closure from the end fitting and store it in the FM.
  b) Remove the channel closure from the FM, and install it in the channel end fitting, making a pressure boundary seal between the closure and the end fitting.
  c) Pass a channel closure through an ancillary port.
- The shield plug shall be provided with features to facilitate the following FM functions:
  a) Remove the shield plug from the end fitting and store it in the FM.
  b) Remove the shield plug from the FM, and install it in the channel end fitting.
  c) Deposit a shield plug into a shielded flask through an ancillary port.
- The thermal shock from flow injection cooling water must be accommodated by fuel channel components. Refer to Section A.11 of the Appendix A for the specific injection flow rate and temperature.

Additional requirements are specified in Reference [10].

11.3 Process Systems

- The Heat Transport Pressure and Inventory Control system (ASI 33310) shall supply sufficient water to the FM Water system (ASI 35230) to simultaneously cool twelve SF bundles in each of two FMs, under normal operating conditions. Water shall be available from the outlet of the HT pressurising pumps.
- Demineralised water shall be supplied to the SF Transfer Process system (ASI 35350) to fill the system and to provide a source of make-up fluid. Whenever the transfer system is open to the bay a sufficient flow of demineralised water shall flow from SF Transfer system to the bay to minimize crud and algae in the SF Transfer system originating in the bay.
- The Recirculated Cooling Water system shall supply sufficient water to the FM supply heat exchanger for cooling the heat transport fluid from the HT P & IC system before it is delivered to the FM.
- An environmentally and seismically qualified water system shall supply sufficient water in emergency operating conditions to simultaneously cool twelve SF bundles in each of two FMs, to prevent fuel failures due to overheating (ASI TBD).
- Air Systems shall supply breathing air for personnel (ASI 75130), instrument air for operation of pneumatic instruments (ASI 75120), and service air for pneumatically operated equipment (ASI 75110).

- Spent Fuel Bay Cooling and Purification System (ASI 34410) shall:
  a) Remove the decay heat generated by the SF at all times, including during and following an accident or seismic event.
  b) Maintain water clarity for FH operations and IAEA inspection.
  c) Remove the suspended and soluble radioactive material from the water.
- Active Drainage Reactor Building System (ASI 71730)
- Active Drainage Reactor Auxiliary Building System (ASI 71740)
- HT Purification System (ASI 33350)
- Inert Gas Systems (ASI TBD)

  Helium gas will be required for:
  a) Snout purge and blow-down,
  b) FM level lowering,
  c) Purging the SFT magazine.

See the Fuelling Machine Fluid System, New Fuel Transfer and Spent Fuel Transfer Design Requirements for details on these interfaces (Reference [12], [9] and [13] respectively). Also refer to the design requirement document for the interfacing Process systems. (Note that the Fuelling Machine Fluid System DR incorporates the design requirements for the FM water system, the FM emergency water system, and the FM gas auxiliary system.)

11.4 Fuel (ASI 37000)

- The fuel bundle end geometry must be provided with features to facilitate bundle separation by the FH equipment, especially the fuel separators in the FM.
- The bundles shall withstand all normal FH loads applied during bundle separation, by the rams in the FH system, and by the Flow Assist Ram Extension (FARE) tool (if used), without significant dimensional changes and without significant degradation of performance.
- The fuel bundle must withstand the thermal shocks that occur during fuelling operations. The normal temperature conditions in the FM and fuel channel are identified in Section A.11 of Appendix A.
- Fuel bundle spacers shall not become interlocked due to thermal bow or due to normal axial forces in the pressure tubes or the FH system.
- The fuel bundles shall be designed with allowance for irradiation swelling of fuel elements so that they will pass through the worst combination of fuel channel diameter and misalignment between the pressure tube and end fitting components and misalignment between the FM and the end fitting.
- The sliding resistance of the fuel bundle in the channel must be low enough to permit flow assisted fuelling. The design must account for thermal bowing and other service induced deformations that occur over the life of the fuel.
- The bundles shall be designed to withstand impact loads that occur during fuelling operations.

- The fuel bundles shall withstand the maximum flows predicted during fuelling in axial flow, radial flow and combined axial and radial flow at the cross flow region of the channel end fitting for representative fuelling dwell times.
- The time period when bundles reside in the cross flow region of the channel end fitting may occasionally be prolonged when fuelling problems arise. The mode of bundle failure and the time of failure shall be determined for a range of flows corresponding to one or more bundles (partly) in the flow.
- The fuel bundles shall withstand the maximum axial flows predicted during SF transfer.
- When in the FH system, the fuel sheath shall at no time contact the FH components. The bearing pad design shall meet this requirement. This applies to both new fuel and spent fuel bundles with permanent deformation due to creep.

11.5 Electrical Power System (ASI 50000)

- Provide the power necessary for the operation of all FH equipment.
- Seismically qualified, Class II power shall be provided for the monitoring of FH equipment that performs a containment function or an emergency fuel cooling safety function.
- Seismically qualified, Class II power shall be provided for the control and operation of FH equipment (valves, etc.) that performs a containment safety function, if the equipment requires power to perform its safety function, and if the equipment is required to operate during or following a seismic event to perform its safety function.
- Seismically qualified, Class II power shall be provided for the control and operation of FH equipment that performs an emergency fuel cooling safety function (pumps, valves, etc).
- Class II power shall be provided for the control and monitoring of the FH system (FCS, FDS, instrumentation, etc.). Except as identified above, this power need not be seismically qualified.
- Class III power shall be provided for the operation of the FM water supply pumps. This power need not be seismically qualified.
- Class IV power shall be provided for the operation of the FH equipment not identified above (electric drives, etc.)

11.6 Communications (ASI 60200)

- A means of communication shall be provided at or close to all FH equipment inside and outside the RB.
- Communication jacks shall be provided at each Breathing Air Station, if the environmental protection suits (plastic suits) are not provided with integrated wireless communication.
- A telephone, telephone jack, or the facility for wireless communication shall be provided wherever FH equipment is located, such as the NF transfer rooms/areas, FM vaults, FM maintenance locks, FM water supply major equipment, SF transfer process major equipment SF storage bay, control equipment room, FH control console.

11.7 Material Handling (ASI 76000)

- Provide the facilities (other than those identified in Section 11.1) that are required for the removal of the FM, bridge and carriage components, process equipment and other FH hardware and maintenance equipment from the RB to the maintenance building for maintenance.
- Provide facilities/support in the FM vaults for lifting equipment.
- Provide a forklift truck for transporting new fuel pallets and FH equipment.

11.8 Spent Fuel Dry Storage Facility (ASI 35370)

- The method of dry fuel storage must accommodate the decay heat that will be released by containers of spent SEU fuel bundles in a close-packed arrangement, after storage in the SF storage bay for a certain period of time specified in Section A.15 of Appendix A.
- The method of dry fuel storage must accommodate the radiation that will be emitted by containers of spent SEU fuel bundles in a close-packed arrangement, after storage in the SF storage bay for a certain period of time specified in Section A.15 of Appendix A.
- The dry fuel storage system must be compatible with the storage baskets/containers, and the shielded workstation.

12. DECONTAMINATION AND DECOMMISSIONING

The design of FH system equipment shall permit easy clean up and decontamination of external and internal surfaces from contamination arising from normal operation and accident conditions.

Consideration shall be given to minimizing the quantity of FH and Storage materials that cannot be decontaminated sufficiently to be released to the public domain.

13. MATERIALS AND CHEMISTRY

- Transfer of SF storage bay water to the HTS shall be limited.
- The transfer of tritium from the HTS to the SF storage bay shall be limited.
- The FM shall use water having the same cleanliness and the same chemistry control as the HTS.
- All materials in contact with HTS fluid shall be corrosion resistant and compatible with the chemistry of the HTS. They must be capable of withstanding the chemical, thermal and radiation environment to which they will be exposed.
- All materials in contact with SF storage bay water shall be corrosion resistant and compatible with the chemistry of the bay water purification system. They must be capable of withstanding the chemical, thermal and radiation environment to which they will be exposed.
- The use of the following elements and/or materials shall be eliminated in the design of components that are wetted by the HTS fluid:
  a) Aluminium – to avoid chemical interaction with other system materials, and chemical attack by the lithium in the HT coolant.
  b) Lead – to avoid cracking of high nickel alloys.
  c) Copper – to avoid corrosion products in the HTS.
  d) Halogens (chlorine, fluorine, etc).
- The use of the following elements and/or materials shall be minimized in the design of components that are wetted by the HTS fluid:
  a) Cobalt – to avoid formation of long life isotopes.
  b) Lubricants that may create problems with decomposition products.
- The absorption of air, nitrogen and carbon dioxide by the HTS coolant from the ambient atmosphere resulting from fuel changing operations must be limited.

  Rationale: Air and carbon dioxide change the pH of the water. Air also impairs the strength of welds in the primary heat transport circuit. Nitrogen and air in the water result in the formation of ^{14}C *&* ^{41}Ar*.*
- The pH of coolants are identified in Section A.13 of Appendix A.
- Materials that do not contact water shall be made from corrosion resistant material or protected by corrosion resistant surface treatments wherever practical.
- Liquid level detection equipment in process tanks and the mechanism magazines shall not be impaired by changes in the pH of the water.

14. LOADS, LOAD COMBINATIONS AND SERVICE LIMITS

The loading conditions are classified as design, service or test conditions. The service conditions are further classified as normal (Level A), upset (Level B), emergency (Level C) and faulted (Level D) in accordance with the ASME Boiler and Pressure Vessel Code Section III.

The FH system must meet the service requirements listed below.

Table 14-1
Service Conditions

Condition	Description	Requirement
Level A	Normal operating	Full functionality
Level B	Upset	Full functionality
Level C	Emergency	Safety functions must operate, with the possibility of service work required afterwards
Level D	Faulted	Failure must not interfere with safe shutdown

The service conditions are quantified in the design requirements of the relevant FH subsystems.

15. HUMAN FACTORS AND OTHER DESIGN REQUIREMENTS AND CONSTRAINTS

15.1 Design Constraints

- Design decisions must consider the impact to the overall cost of the station.
- The design shall accommodate the objectives of the ACR project for a substantial reduction in the capital cost, a short construction and commissioning period, low operating and maintenance costs, and low man-rem consumption.
- The delivery schedule for the FH equipment shall be compatible with the schedule for the construction sequence. Commissioning work at site shall be minimized.
- The design shall be based on the electrical design parameters identified in Section A.15 of Appendix A. It shall also facilitate a change to the supply voltages as in Section A.15 of Appendix A.
- FH controls and indicators mounted on panels and consoles in the MCR shall match others in the MCR, where practical.
- In general, the appearance and finish of FH panels and consoles in the MCR shall conform to other panels in the MCR.

15.2 Requirements Imposed By The Reactor And Fuel Channels

- The design shall accommodate the fuel channel lattice pitch specified in Section A.15 of Appendix A.

  Clarification: The FM shall be able to home onto any channel end fitting without interfering with adjacent channels.
- The design shall accommodate the values of channel creep specified in Section A.15 of Appendix A.

  Clarification:

  a) *The FM must be able to advance to stall against any end fitting.*

  b) *The FM must be able to retract clear of any channel end fitting.*

15.3 Requirements Imposed By The Fuel Bundles

FH equipment shall not damage the fuel, where the following applies:

- Impact loads must be within acceptable limits. Impact loads at cold temperatures must be minimized, particularly loads that are not applied squarely to the bundle ends. Impact loads shall not cause damage (structurally and, or internally) to the fuel.
- Handling of irradiated bundles that are returned to the core for continued operation must be performed with great care. Excessive static loading and impacts shall be avoided.
- Axial (compression & tension[8]) and radial loads must be within acceptable limits. Preliminary allowable maximum loads on fuel bundles are specified in Section A.15 of Appendix A.

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[8] Tension loads may be applied during grappling operations.

- Torque loads on fuel bundles are not permitted, at any time.
- Radial support shall be provided at the bearing pads only; axial support at the end plate only. No sheath contact shall be permitted under on-power fuelling operations, with the exception that contact is permitted for the purpose of sensing fuel bundle location. Normal contact forces on the fuel sheath during fuel sensing must not damage the fuel sheath. The maximum permitted force on the fuel sheath is specified in Section A.15 of Appendix A.
- During fuel changing operations on-channel, fuel-bundle axial support shall be provided at the downstream end. The two outer rings of the fuel bundle endplate (of the last fuel bundle in the fuel string) shall be used as the contact area, to support the fuel string. The face of the ram adapter (FM ram assembly end effector) shall be shaped to properly contact these two outer rings. This will ensure that all the elements of the two outer rings will react against the fuel string load. During separation operations, at least seven elements (preliminary) of the outer ring of the ACR fuel bundle must be supported, with a minimum of three (preliminary) supported elements on either side of the circular cross section. The maximum permissible axial compressive force on an individual fuel bundle element is specified in Section A.15 of Appendix A.
- The fuel bundle shall be radially supported at all times. Axial gaps in support surfaces shall not interfere with normal bearing-pad passage. The maximum axial length of "gaps" over which fuel must travel shall be limited as specified in Section A.15 of Appendix A.
- Fuel bundles undergo dimensional changes during irradiation. Equipment handling SF must accommodate the possible deformations of the fuel bundle described below. In addition, equipment must also handle defective fuel (for e.g., broken endplates, loose fuel elements). Fuel bundle end plates can crack if their downstream support (shield plug) does not provide full face support, including support of the centre elements.
  a) The design of FH components must accommodate a variation in the length of fuel bundles as identified in Section A.15 of Appendix A.
  b) Endplate doming occurs when the centre elements of the downstream bundle that are unsupported by the shield plug, creep in the direction of coolant flow. This results in axial displacement of the unsupported elements and plastically deformed endplates. The extent of doming depends on the type of support within the channel (fuel latches or shield plugs), hydraulic drag within the unsupported elements, and coolant temperature. Doming does not occur if fuel bundles are provided with full face support by the shield plug, including support of the centre elements.
  c) Fuel bundle parallelogramming occurs when coolant hydraulic drag is applied to a fuel string in a non-linear (or sagged) pressure tube. The endplates tend to align with the flat face shield plug while the fuel elements align with the pressure tube. This causes the bundles to skew. The angle of tilt between the centre line of the bundles and the plane of the endplates depends on the amount of pressure tube sag and the bundle position in the channel.
  d) The dimensions of any passage through which fuel passes, including bends, misalignments, and steps in the passage, shall be sufficient as identified in Section A.15 of Appendix A.

- Vertical steps in support surfaces shall not interfere with normal bearing-pad passage. The maximum vertical step height in a component, or misalignment of two components, that forms a part of the passage through which fuel passes shall be less than the ramp height of the fuel bundle bearing pads.
- The design of the FH system shall include measures to limit the time the fuel bundles are exposed to the cross flow region.
- New fuel must be handled and transported horizontally.

  Rationale: If the bundles are stored and handled vertically, the pellets drop to the bottom of the fuel element, leaving no space at one end of the element.
- New fuel must be transported with a bellyband. *Rational: Prevents spacer interlocking.*

15.4 Human Factor Requirements

Table 15-1 summarizes the requirements that have a direct impact on the human factors in the plant from a FH and storage standpoint.

Table 15-1
Summary of Human Factor Requirements

Section	Requirement	Human Factor
2.2.1	The uncrating, inspecting and manual loading of new fuel into the new fuel transfer mechanisms.	Operator • layout, access & productivity
	Automatic and/or manual control from MCR of the new fuel transfer sequences and mechanisms.	Operator
	Automatic and/or manual control from MCR of the FMs and carriages for reactor fuelling.	
	Automatic and/or manual control from MCR of the irradiated fuel transfer sequences and mechanisms.	
	Local operator handling of defective fuel in the storage bays.	
	Local operator handling of SF in the storage bays.	
	Automatic/manual control from MCR of the FMs and the SF transfer mechanisms to exchange faulty shield plugs in a fuel channel and transfer them to the storage bays.	

Section	Requirement	Human Factor
2.2.1	Manual handling of defective channel closures.	Operator
2.2.2	Automatic and/or manual control from MCR of FMs operations for: • channel draining, • installing a pressure tube seal.	Operator
2.2.3	Automatic and/or manual control from MCR of FMs operations for unloading a complete reactor core load of fuel and of SF transfer sequences and mechanisms for transferring a complete reactor core load of fuel.	Operator
	FM recovery operations, when FM is on-channel and/or contains SF.	
2.4	FM rehearsal facility location and operations.	Operator
	Manual loading of first fuel charge.	
	Remote viewing to permit observation of FM operations from MCR.	
	Provisions for the inspection of defective fuel in the SF storage bay.	
4.1	Design for radiation protection of personnel.	Operator & Maintainer • personnel safety
	Provide interlocks to prevent accidental exposure of personnel.	
	Use the ALARA principle to limit plant occupational targets.	Maintainer • personnel safety
4.2	Ease of safeguard verification.	• visual aids to indicate if a full basket or stack has been tampered with • visual access for inventory monitoring

Section	Requirement	Human Factor
4.6	Meet requirements of applicable Canadian national codes and standards pertaining to electrical safety, material handling and general industrial safety.	Operator & Maintainer • personnel safety
	Ensure adequate lighting, power supplies and breathing air.	Operator & Maintainer • personnel safety • layout, access & productivity
4.7.2	Sufficient manual control of individual drives shall be provided to bring the FH system to a safe state.	Operator
4.7.3	Operator action required for any safety equipment.	Operator
	Facilitate the transfer of irradiate shield plugs and FH components to the SF storage bay.	
	Minimise the risk of situations occurring where irradiated fuel or hardware can become stranded in the FM or SF transfer system.	
	FH man rem consumption shall be limited.	Operator & Maintainer • personnel safety
5.5	The SF storage bay must conform to the IAEA definition of dual containment and surveillance.	Safeguards • visual aids to indicate if a full basket or stack has been tampered with • visual access for inventory monitoring
8	Design to permit connection of testing/measurement equipment.	Maintainer • productivity

Section	Requirement	Human Factor
9.2	Incorporate (redundancy and/or) accident recovery provisions to improve reliability and the availability of the FH system.	Operator & Maintainer • ergonomics of remote handling equipment for FM recovery • design of fasteners etc. on FM for accessibility to remote tooling • consideration of remotely controlled tools • radiological shielding • contamination control
9.3	FH components accessible for routine servicing, check-out, set-up and calibration while reactor is at full power.	Maintainer • personnel safety • productivity
	Minimize the time to maintain, repair or replace components subject to normal wear.	
	Incorporate lifting and transporting equipment to facilitate transfer of the FM from the FM maintenance lock to the maintenance building with the reactor at full power.	
	The time required to replace a FM head or FM ram assembly shall be minimized.	
	As far as practical, equipment shall be located in areas of low background radiation fields.	
10	Access for maintenance and inspection of other equipment.	Operator & Maintainer • productivity
11.1	Maintenance lock design to provide adequate radiation protection with reactor at full power.	Operator & Maintainer • personnel safety
	Provide the facilities required for the removal of the FM, bridge and carriage components, process equipment and other FH hardware and maintenance equipment from the RB to the maintenance building for maintenance.	Maintainer • personnel safety • productivity

Section	Requirement	Human Factor
11.1	Provide access for personnel to the FH equipment in the RB and RAB while the reactor is at power and SF is in the SF storage bay.	Operator & Maintainer • productivity
	Means shall be provided in the FM maintenance locks for emergency egress of personnel.	Operator & Maintainer • personnel safety
	Access to the FM maintenance locks shall be controlled.	
	Provide shielding for personnel from radiation hazards within the FM water system.	
	Provide facilities for the transfer of SF from the storage bay to the dry storage facility. This includes a location/space/support for the shielded workstation and shielding for operators.	Operator & Maintainer • personnel safety • productivity
	Accommodate service ports that can be accessed on one side (by the FMs, and on the other side) by personnel (or a shielded flask).	Operator & Maintainer • productivity
	Provide facilities in the RB and RAB for IAEA equipment and inspections.	• equipment location areas • lighting • electricity • visual access for inventory monitoring
11.6	A means of communication shall be provided at or close to all FH equipment inside and outside the RB.	Operators & Maintainers • personnel safety • productivity
12	Consideration of materials and components for ease of decontamination.	Maintainer • personnel safety
15.1	FH controls and indicators mounted on panels and consoles in the MCR shall match others in the MCR, where practical.	Operators • familiarity • clarity • clear and unambiguous indication and controls
	In general, the appearance and finish of FH panels and consoles in the MCR shall conform with other panels in the MCR	

16. REFERENCES

[1] 108–03650–SDG–001 Safety Related Systems Safety Design Guide.

[2] 108–03650–SDG–002 Seismic Requirements Safety Design Guide.

[3] 108–03650–SDG–003 Environmental Qualification Safety Design Guide.

[4] 108–03650–SDG–004 Separation of Systems and Components Safety Design Guide.

[5] 108–03650–SDG–005 Fire Protection Safety Design Guide.

[6] 108–03650–SDG–007 Radiation Protection Safety Design Guide.

[7] 108–30100–DG–001 Safeguards Concept and Design Guide (in progress).

[8] 108–03650–SDG–006 Containment Safety Design Guide.

[9] 108–35100–DR–001 New Fuel Transfer and Storage System Design Requirements (to be produced).

[10] 108–35210–DR–001 Fuelling Machine Head Design Requirements (in progress).

[11] 108–35220–DR–001 Fuelling Machine Bridge and Carriage Design Requirements (in progress).

[12] 108–35230–DR–001 Fuelling Machine Fluid System Design Requirements (to be produced).

[13] 108–35300–DR–001 ACR Spent Fuel Transfer and Storage Design Requirements (in progress).

[14] 10810–01372–TED–001 ACR-700 - Technical Outline.

[15] 10810–33100–DR–001 Heat Transport System Design Requirements.

[16] 108–37000–DR–001 Design Requirements: ACR Fuel Bundle (in progress).

[17] 10820–01370–050–001 ACR-1000 Unit Data.

[18] 10810–01370–050–001 ACR-700 Unit Data.

[19] 69–35000–DR–001 Fuel Handling System Design Requirements.

[20] 10820-01372-TED-001 ACR-1000 - Technical Outline.

Appendix A
Numerical Data

Note: All data not accompanied by a reference is to be considered preliminary.

A.1 Introduction (Section 1)

No numerical data.

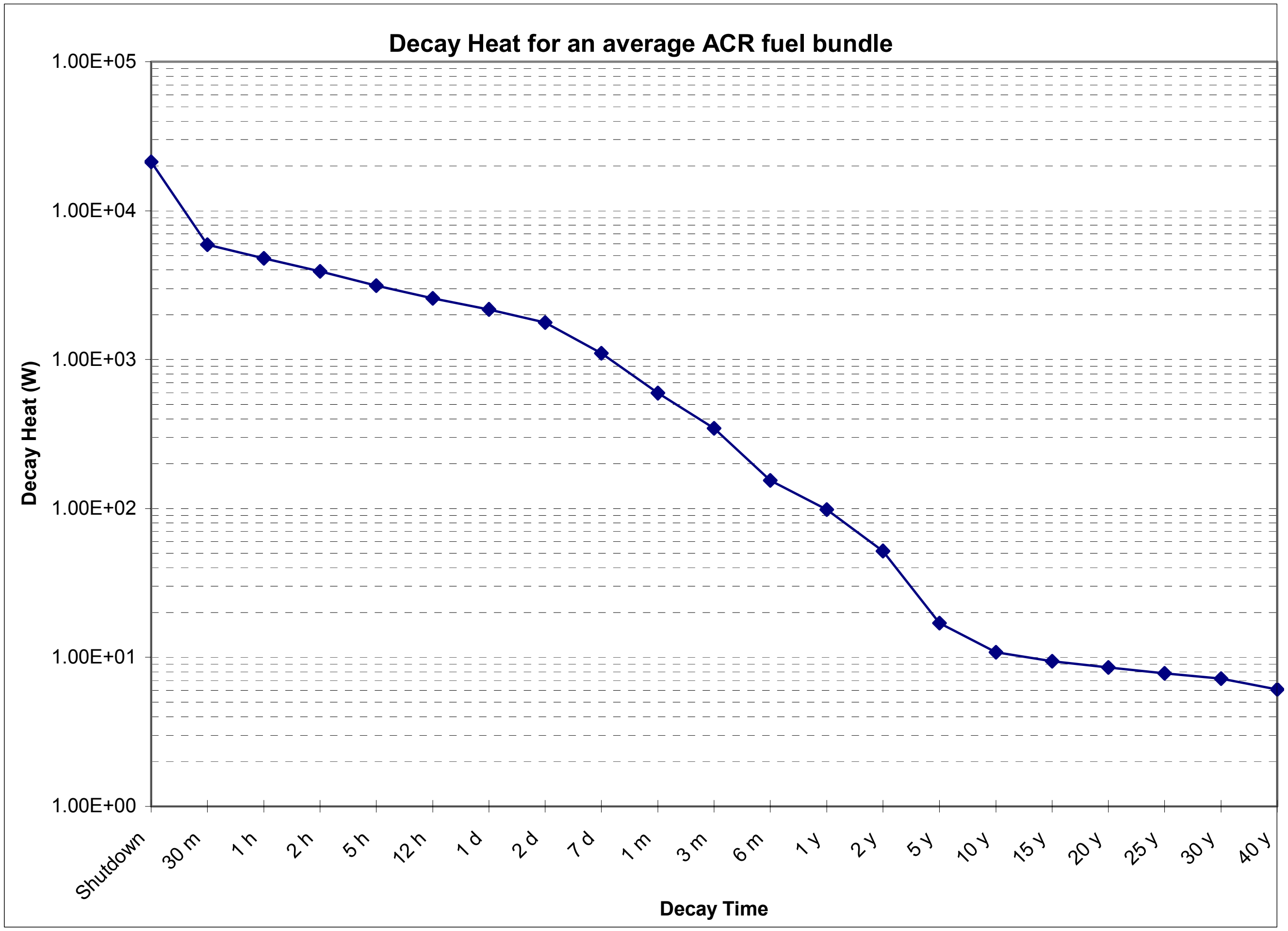
A.2 Functional Requirements (Section 2)

	ACR 700	ACR 1000
Number of fuel channels:	284 (Reference [14])	456 (Reference [20])

A.3 Performance Requirements (Section 3)

	ACR 700	ACR 1000
Fuelling rate at equilibrium (channels /day (2 bundles shift))	2.9 (Reference [14])	4.6 (Reference [17])
Advanced fuelling rate (channels/day)	5-6 (preliminary)	8-9 (preliminary)
Catch-up fuelling rate (channels/day)	6 (preliminary)	9 (preliminary)
Fuel burn-up	20,500 MWd/teU (Ref. [14])	20,500 MWd/teU (Ref. [20])
Minimum accuracy of channel flow verification	[TBD]	
Minimum accuracy of on-channel leak tests	[TBD]	
Fuel defect rate	0.1% of fuel throughput (preliminary)	
SF storage capacity	10 + 1 year of station operation at 90% capacity factor, + 1 core dump (preliminary)	

Shutdown	2.12E+04
30 m	5.92E+03
1 h	4.79E+03
2 h	3.91E+03
5 h	3.14E+03
12 h	2.58E+03
1 d	2.17E+03
2 d	1.78E+03
7 d	1.10E+03
1 m	5.97E+02
3 m	3.45E+02
6 m	1.54E+02
1 y	9.83E+01
2 y	5.19E+01
5 y	1.70E+01
10 y	1.08E+01
15 y	9.46E+00
20 y	8.57E+00
25 y	7.84E+00
30 y	7.19E+00
40 y	6.10E+00



(Based on burn-up of 20,000 MWd/teU)

(This curve is obsolete and will be replaced when a current one is available)

Figure A-1 Decay Heat Curve for ACR Fuel Bundle (Preliminary)

A.4 Safety Requirements (Section 4)

Station man-rem	[TBD]
FH System man-rem consumption	[TBD]
Peak Horizontal Ground Acceleration	0.30 g (Reference [2])
Maximum time allowed for fuel bundle to be in air	2 minutes (preliminary)
Time period that shall be available for operator action after clear and unambiguous indication	15 minutes (preliminary)

A.5 Applicable Codes and Standards (Section 5)

The basket and stacking frame size shall facilitate sealing every SF bundle in a full stacking frame within 3 months of transfer to the bay under normal operating conditions (Reference [7]).

A.6 Environmental Conditions (Section 6)

	ACR 700	ACR-1000
End fitting inlet temperature	278.5 °C (Reference [18])	279.6 °C (Reference [17])
End fitting outlet temperature	325 °C (Reference [18])	325 °C (Reference [17])
HTS pressure at outlet end fitting (for Max. power channel at 100% power)	12.2 MPa (Reference [18])	12.31 MPa (preliminary)
HTS pressure at inlet end fitting (for Max. power channel at 100% power)	13 MPa (Reference [18])	12.93 MPa (preliminary)

Radiation data (predicted):

At the tubesheet:	gamma	3.58E-01 Sv/h
	neutron	1.79 Sv/h
Closure plug:	gamma	8.69E-03 Sv/h
	neutron	0.8E-02 Sv/h
Outside vault (160-cm thick):	gamma	2.04E-05 Sv/h
	neutron	0.31 uSv/h

Normal Operating Conditions within the RB (Reference [19]):

Temperature	18°C - 40°C
Relative Humidity	up to 90%
Pressure	0.7 kPa below atmospheric

Abnormal Operating Conditions within the RB:

LOCA	see Reference [3]
MSLB	see Reference [3]

Operating conditions within the RAB (Reference [19]):

Temperature	18°C - 40°C
Relative Humidity	50% - 60%]
Integrated yearly radiation dose	[TBD]
Pressure	atmospheric

Operating conditions within the maintenance building (preliminary):

Temperature	[TBD]
Relative Humidity	[TBD]
Integrated yearly radiation dose	[TBD]
Pressure	[TBD]

Radiation around the FM (mrad/yr)(preliminary):

Snout lock	2.38E+01
Separators	1.52E+01
Magazine side/ top	2.95E+02
Magazine rear/ top	1.11E+02
Magazine side	8.82E+01
Level lowering pump	3.31E+01
Head trunions	1.25E+00
Ram midpoint	3.38E-01
Ram ¾ point	1.15E-01
Ram rear	5.07E-02

Radiation due to N^{16} activity in the HTS coolant (preliminary):

On reactor axis at end fittings	268,811 µS/hr
On reactor axis 1.1 meter back	301,547 µS/hr
On reactor axis 3.1 meter back	170,674 µS/hr
On reactor axis at concrete wall	50,270 µS/hr at shutdown (fields are approximately 250 µS/hr)

A.7 Over Pressure Protection Requirements (Section 7)

No numerical data.

A.8 Inspection and Testing Requirements (Section 8)

No numerical data.

A.9 Reliability and Maintainability Requirements (Section 9)

Reliability:	
Plant design life	60 years (Reference [14] & [20])
Lifetime target capacity factor	90% (Reference [14] & [20])
Life of SF storage bay (including cooling & purification)	71 years (preliminary)
Dormant unreliability of the overall containment system	[TBD]
Unavailability:	
FH System contribution to plant unavailability	< 10% (preliminary)
Maintainability requirements:	
Target for frequency of routine maintenance and maintenance unavailability	Once per week or less with maintenance time less than 20 hours per week (preliminary)
Target for planned service interval	24 months or greater (preliminary)
Target for maintenance time for components located inside RB, having maintenance intervals that are more frequent than the station planned shutdowns	3 hours (preliminary)
Target for the replacement time for FM or ram	8-hour shift (preliminary)

A.10 Layout, Modularisation (Section 10)

No numerical data.

A.11 Interfacing Requirements (Section 11)

Maximum permissible operation radiation with radiation shielding for ACR 700 and ACR 1000:

General Access Area	5 μSv/h (Reference [6])
Maintenance Lock Area	25 μSv/h (preliminary)
Emergency Access Area	[TBD]

Normal temperature in FM	32°C - 66°C (Reference [17] & [18])
Normal temperature in fuel channel	325°C (Reference [14] & [20])

Injection flow from FMs into the fuel channel:

Flow rate	1.57 l/s (preliminary)
Temperature of water	40°C - 66°C (preliminary)

A.12 Decontamination and Decommissioning Requirements (Section 12)

No numerical data.

A.13 Materials and Chemistry Requirements (Section 13)

The pH of coolants:

HT coolant	9.8 –10 (Reference [15])
SF transfer process system coolant	[TBD]
SF storage bay water	[TBD]

A.14 Load, Load Combinations and Service Limits (Section 14)

No numerical data.

A.15 Human Factors, Other Design Requirements and Constraints (Section 15)

	ACR 700	ACR 1000
Fuel channel elongation (total in 30 years)	190 mm (preliminary)	[TBD]
Pressure tube diametric strain	4.5% (preliminary)	[TBD]
Predicted sag (in 60 years)	35 mm (preliminary)	[TBD]
Maximum allowable channel flow	30 kg/s (preliminary)	
Arrangement	Bi-directional in adjacent channels (Ref [17]& [18])	
Lattice Pitch	220 mm (Reference [14] & [20])	

Fuel bundle geometry	CANFLEX (Reference [14] & [20])
Maximum allowable radial load on fuel sheath	[TBD]
Maximum compressive force, applied uniformly to end plates	[TBD]
Maximum axial compressive force applied to fuel pencils	[TBD]
Size of fuel passage ways shall be such that a fuel bundle can be pushed through the passage with a force not exceeding	200 N (Reference [16])
Allowable radial misalignment between two adjacent fuel passage ways	0.5 mm (Reference [16])
Maximum length of gap allowable in fuel passage ways	60 mm (Reference [16])
Variation in the length of fuel bundles	[TBD]
Period of time SF to be stored in the storage bay	10 years (Reference [14] & [20])

Electrical Design Parameters:

Design supply voltages	400/415 VAC, 3φ, 50 Hz 240 VAC, 1φ, 50 HZ
Alternate supply voltages	575/600 VAC and 208 VAC, 3φ, 60 Hz 120 and 240 VAC, 1φ, 60 Hz
	460/480 VAC, and 208 VAC, 3φ, 60 Hz 120 and 240 VAC, 1φ, 60 Hz