SECTION 7 Design of the Fuel Handling System (FH)

7.0 General Overview of Fuel Handling

The fuel handling (FH) facilities are comprised of equipment used for three primary functions: storing new fuel and transporting it to the reactor; changing fuel in the reactor; and transporting irradiated fuel and storing it for several years. Reactor fuel is changed on an on-going routine basis using two fuelling machines while the reactor is at full power. The general arrangement of the system is shown on **Figure 7-1**.

As is the case for RCUs, design of the fuel handling systems for CANDUs has evolved generically, from the early CANDU reactors such as the Nuclear Power Demonstration plant (NPD), Douglas Point, and through operating experience in many current Pickering, Bruce/ Darlington and CANDU 6 plants. The fuel handling system is made up of several sub-systems and devices, each having unique functions to perform, and each presenting a unique set of design requirements and design challenges. Because of the complex nature of the entire fuel handling operation, and because of the economic consequences of malfunction, CANDU fuel handling equipment designs are always based on experience with well-proven designs, and equipment changes are evolutionary, rather than revolutionary.

Unlike RCUs, the design of the fuel handling equipment is not closely linked to the short-term operation of the reactor core, or the functioning of the reactor regulating system (RRS) or the two shutdown systems (SDSs). Rather, the operating requirements for the FH system are closely dependant on the size of the core and the nature of the service, ie, the relative amount of time operating as a steady, base load plant and the frequency and extent of power maneuvers. These factors determine the frequency of visits to the channels and the number of bundles shifted during a visit. On average, the frequency of visiting a given channel is about the same for all present CANDUs, but it is obvious that, in a bigger reactor the FMs must service more channels each month; ie, bigger reactors place a heavier duty cycle on the FMs. On average, in a CANDU 6, two channels are serviced per day.

Bundles are always replaced in pairs because the FM magazine and actuating rams accommodate two bundles at a time. This configuration optimizes the space requirements for the FMs and the number of FM actuations needed to replace the twelve bundles in a channel. A four-bundle operation would halve the number of FM cycles per channel, but would need both the magazine and actuating ram to be twice as long. This in turn would require *four times* as much vault space *for each FM* and accordingly, a much bigger reactor building.

Fuel changes are programmed in conjunction with the long-term operating pattern of the RRS and RCUs to optimize the burn-up of fuel in each bundle, while maintaining the power distribution throughout the core as uniform as possible. The two outer rows of channels all around the core operate at a lower power level than the central channels, and therefore require a longer residence time in the core to accumulate full burn-up. Therefore, those channels are refuelled less frequently than the central ones.

In addition, the end bundles in each channel operate at lower power levels than those in mid-channel, and also require longer residence times. To achieve this, eight bundles are replaced at each visit, such that a group of four bundles resides first at one end, then in the centre, and finally at the other end, for equal periods. This recognizes that the distribution of power along the length of the channel is fundamentally sinusoidal, but that the central region is partly "flattened" by the presence of the adjuster absorbers, to produce an approximately trapezoidal distribution. See **Figure 7-2.** The central four bundles operate at essentially the same maximum level of bundle power, while the first and twelfth bundles operate at a very low power level, the fourth and ninth at slightly less than full power, and those between them operate at intermediate levels of power. Therefore, the bundles initially at low power will spend their final period in core in a correspondingly high level power, and vice versa. Accordingly, all bundles will accumulate irradiation at varied rates such as to achieve full burn-up before being removed. This practice permits efficient, "straight-through" fuel changing, from one FM to the other.

Other fuel changing strategies may also be used, but the eight-bundle shift described above has proved to be practical and effective under most operating situations, and plants tend to prefer to maintain a standardized mode of operation. For example, all the fuel bundles in one channel could be removed, "shuffled" and re-installed, at intervals during their residence time in the core, to make all bundles accumulate the same burn-up before replacing them all. In this scheme, bundles initially in low power positions would be removed and inter-changed with those in high-power positions, and the entire fuel string re-installed. Theoretically, more optimal burn-up might be achieved, but the duty cycle on the machines would become a burden to operators. Furthermore, the scheme depends on accurate forecasting of future operating maneuvers, and the actual gain in burn-up rates might be difficult to achieve.

The equipment used for CANDU FH systems is essentially the same in all CANDU plants, but the overall *lay-out* of the system is different in the different CANDU plant designs. As noted in the earlier sections, the lay-out of the plant and the design of the fuel handling systems are strongly inter-dependant, and the three dominant present designs have quite different routings through their reactor buildings, and use somewhat different devices for fuel handling. However, they all reflect similar fundamentals of design and design practises.

For example, the four-unit Pickering plant adopted common storage bays for new fuel and irradiated fuel, located at either end of the plant. This necessitated the fuelling routes inside their reactor buildings being compatible with a straight, common corridor passing adjacent to the bays and the four reactor buildings. This results in the FMs being rotated 90° from the fuelling position to engage the discharge ports. See **Figure 7-3.** The later Bruce plant is also a four-unit arrangement, but opted to have the corridor pass *under* the four reactors, and to have the four units and the FM duct all share a common containment envelope. This permits the FMs to remain in their fuelling direction. See **Figure 7-4.** This scheme provides simpler handling, and avoids passing fuel through containment air-locks, and this is reflected in more efficient handling. It also permits the units to share the fuelling machines. This feature was aimed at avoiding the early Pickering problem where a unit was occasionally de-rated temporarily if its fuelling machine became disabled. The concern was that the larger Bruce units (480 channels vs 340) would place a proportionately heavier demand on their fuelling machines and would therefore be at higher risk. (However, by the time the Bruce plants were put into service, the reliability of the Pickering fuel transfer systems had been uprated ten-fold, and this perceived advantage for Bruce was not needed.) The CANDU 6 design followed the Bruce reactors, and was intended primarily for single-unit plants. Its lay-out was therefore optimized for having dedicated fuel storage facilities. It also permitted accommodation of optimal arrangements for other systems, based on accumulated experience with the earlier plants. Such considerations included incorporating shielding around the fuelling machine vaults, which permits continual on-power access inside most other areas in the CANDU 6 reactor building. This permits maintenance of much of the plant's equipment on power. On the other hand, the CANDU 6 lay-out still includes accommodation for linking of units when used in multi-unit plants.

The arrangement and equipment for a CANDU 6 plant are described, to exemplify the design practices used for CANDU fuel handling systems.

The CANDU 6 flow of fuel is shown schematically in **Figure 7-1**. The arrangement of the fuel handling equipment in the reactor building is shown in **Figures 7-5 to 7-7.** The new fuel storage room and the irradiated fuel storage rooms are located in the adjoining service building, shown on **Figure 7-8.** Space and lifting facilities are also provided in those locations for receiving new fuel and storing or shipping irradiated fuel. The fuelling machine decontamination and service rooms are shared by both systems. These are located in the service building.

The fuelling machines, which load and unload the fuel at the reactor face, the new fuel transfer ports and the irradiated fuel discharge equipment, are normally operated remotely and automatically from the main control room of the plant.

Personnel are only required to enter the reactor building to load new fuel into the new fuel transfer mechanisms and for maintenance of the fuel handling system components. These access areas have biological shielding and atmospheric control to permit routine access on power.

7.1 Fuel Changing: the Fuelling Machine Head, Supports and Auxiliaries

7.1.1 Functional Description

The function of the fuelling machine, which is unique to CANDU reactors, is to take on new fuel from the new fuel port, load it into the reactor, receive irradiated fuel from the reactor and discharge it into the spent fuel port, while the reactor continues to run at full power.

This operation begins with a fuelling machine (FM), filled with fresh fuel, disengaging from the new fuel port, traversing to the chosen channel on the reactor, and engaging on the end fitting. At the same time, the mating FM serving the other face of the reactor will disengage from the *irradiated* fuel port, which is near its corresponding new fuel port, and will traverse to the opposite end of the same fuel channel. The route is shown on **Figure 7-1.** The FM head is supported and transported along this path on its cradle, carriage, bridge, columns and bridge extension, as shown on **Figure 7-9.** The bridge will initially be positioned at the same elevation as the extension, (it is shown at a raised elevation on the figure) and the carriage will traverse onto the bridge. The bridge will be raised on the columns to the elevation of the chosen channel (*Y-direction of travel*), while the carriage continues to traverse across the bridge, to the horizontal location of the chosen channel (*X-direction of travel*). The cradle will then move forward on the carriage, toward the reactor face, to engage the snout of the FM on the end fitting (*Z direction of travel*). Fine positioning sensors on the FM snout will cause the drives to adjust the X and Y positions as well as the FM pitch and yaw angles, to ensure proper engagement.

The next step in the operation is the process of changing the fuel in a fuel channel. This sequence is shown in **Figure 7-10.** Once the two FMs have clamped themselves onto the end fittings, their rams reach into the end fittings, clamp onto the closures and withdraw them into temporary storage in their magazines. The FM heads remain filled with D_2O from their own supply lines, to ensure cooling of the fuel. They then remove and store the shield plugs. Fuel bundles are then inserted into the end fitting at one end by the "charging" FM, where the coolant flow pushes them against the existing bundles. The ram on the "receiving" FM withdraws at the same time, allowing all the bundles to move towards it, and the first two bundles enter its magazine. Side stops, called "feelers" detect the trailing end of the second bundle and slide in behind it, to hold the remaining bundles back, while the magazine indexes to the next empty chamber. Three more pairs of bundles are moved similarly, then the shield plugs and closures are replaced. Finally, the two FMs disengage, withdraw and traverse to the new and irradiated fuel ports, to off-load the irradiated fuel and take on more new fuel, for the next channel.

7.1.2 Requirements for the Fuel Changing System

- The Fuelling Machine Heads shall be capable of performing the following fuel changing operations:

- Normal automatic refuelling of eight fuel bundles, loaded in the direction of flow.
- Change up to ten fuel bundles, loaded in the direction of flow.
- Change up to twelve fuel bundles using the Fuelling Machine 'C' Ram to push the fuel when the reactor is shut down.

- The mechanism of the Fuelling Machine must be capable of operating under the following temperature conditions:
    - Ram Assembly - up to 140°F (59.8°C).
    - Magazine Assembly - up to 300°F (148.8°C).

- The mechanisms of the Fuelling Machine must be capable of operating with the pressure inside the magazine between 758 and 11,376 kPa (g).

- A system must be incorporated within the Fuelling Machine to permit the level of D_2O in the Magazine and Ram Assemblies to be maintained at predetermined levels other than full. The system must maintain these levels even in the event of D_2O supply failure or control system failure.

- The fuelling system shall be designed so that the forces applied to the fuel bundles shall not exceed the following:
    - When supported by the ram adaptor, 4,000 lb(f) (17,792 N).
    - When supported by two side stops, 2,000 lb(f) (8,896 N).

- The fuelling machine must be capable of homing onto End Fittings which are up to 0.5 of an inch (1.27 cm) off their true position as referenced to an idealized square lattice grid covering all End Fitting positions.

- The fuelling machine head shall be seismically qualified and designed to withstand the Design Basis Earthquake (DBE) when attached to a reactor end fitting or the Irradiated Fuel Transfer Port; it shall remain engaged and shall maintain its pressure retention capability, and shall maintain the fuel in a safe state.

- Because it contains the fuel and its coolant, the fuelling machine head and associated PHT carrying items shall be designed and registered as a class 1 system, to meet the requirements of CSA standard N285.0 and the portions of the ASME code it designates. Other pressure retaining systems and housings, not directly joining to the PHT system, shall be designed and registered as class 3 systems. Some of the ports and similar items which may form part of the reactor building containment boundary shall be designed and registered as class 2 systems. Items which serve as supports for class 1 or class 2 items shall be designed and registered as supports as defined in CSA N285.0, clause 14, which specifies design to ASME

Subsection NF, support components.

- The bridge and column assembly shall fulfil the following basic operational requirements:
  - Align the bridge tracks such that the fuelling machine can be transported between the vault and the maintenance lock.
  - Move the fuelling machine vertically to a required lattice elevation (coarse Y motion).
- The bridge drive system shall incorporate two sets of equipment for continuous position readout to the control computer and main control console. The readout shall be of sufficient accuracy to allow coarse homing onto a reactor end fittings.
- Brakes shall be provided on the bridge Y-drive, of the spring-engaged, power-released type.
- The motors and brakes shall have separate power supplies
- Bridge motion and brake release shall only be permitted if the fuelling machine head is fully retracted in the Z direction.
- Bridge motion and brake release shall only be permitted if the fuelling machine shielding door is fully open.
- Bridge motion shall be inhibited when the F/M carriage is at a location where it may be spanning both the maintenance lock tracks and the bridge tracks.
- Bridge tilt shall be monitored, and bridge motion and brake release shall be inhibited when the tilt is beyond preset limits.
- Carriage motion on the maintenance lock tracks shall only be permitted if all the drain port actuators are retracted.
- Carriage motion between the F/M bridge tracks and the maintenance lock tracks shall be permitted only when the tracks are mated.
- Coarse carriage motion shall only be permitted if the fuelling machine head is fully retracted in the Z direction
- X and Y motions shall not be permitted once the fuelling machine head is fully advanced and locked onto any end fitting or port

- The electrical controls on the fuelling machine and its support and auxiliary systems shall facilitate remote manual and automatic control.

- All systems shall allow for normal operation of equipment for periods up to 20 hours per day, 5 days per week

- Equipment shall have a service life of 40 years subject to normal maintenance and overhaul. If items are life-limited, they shall be readily replaceable with minimal interference to adjustments and calibrations.

- All structural materials, lubricants, insulators and hoses shall be temperature and radiation resistant. If items are life-limited, they shall be readily replaceable with minimal interference to adjustments and calibrations.

- Cable jacket and conductor insulation materials shall tolerate 2 x 10^6 Gy (2 x 10^8 rads) at an ambient temperature of 38°C.

- Hydraulic oil shall withstand an accumulated radiation dose of 10^6 Gy (10^8 rads) and have a working viscosity of 100 to 350 SSU within the working temperature range

- Wherever practicable, redundant sensors shall be provided for position monitoring of the main sub–assemblies

- The catenary system shall have sufficient flexibility and length (or stroke) to allow the fuelling machine head and carriage to move without undue restriction in their specified coarse and fine motions in the X, Y, Z, pitch and yaw directions.

- Auxiliary equipment shall be located at a sufficient elevation to avoid flooding during a loss of coolant accident,

- Quality assurance during design, analysis, manufacturing, testing and commissioning shall be performed according to the requirements of the CSA Standards N286 and Z299.

7.1.3 Main Assemblies in Fuel Transfer System

a) Fuelling Machine Head, Cradle and Carriage

The fuelling machine head is supported in a cradle and gimbal assembly, as shown on **Figure 7-11.** The FM head is comprised of the snout assembly (to engage and lock onto the end fitting), the magazine (to store the fuel), the closure and shield plug, the ram assemblies (which control motion of those items in and out of the end fitting), and hydraulic actuators. The FM and cradle are suspended from the fuelling machine carriage, as shown on **Figure 7-12.** These assemblies include pivots to permit angular alignment to the end fitting, and the carriage includes the Z-direction actuator, to move the FM into engagement on the end fitting.

b) Bridge, Columns and Maintenance Lock Track (Bridge Extension)

The fuelling machine bridge and columns assembly is shown on **Figure 7-13.** It provides the means of supporting the fuelling machine head and carriage at the reactor face and raising the machine to the desired horizontal row of fuel channels, using the coarse Y–drive system. In its lower position, it aligns to the maintenance lock track (forming an the extension to the track). This permits the FM head to traverse to and from the ports in the vault wall, to take on new fuel and discharge irradiated fuel. The columns are attached to the vault walls on either side, and include tracks to guide the bridge Y-motion while controlling its X-Z-location. The columns support ball-screws on which the motorized ball-nuts on the bridge rotate to attain Y-travel.

c) Catenaries

The catenary system provides a means of conveying D_2O, hydraulic oil, electrical power, and control signals from the fuelling machine auxiliaries room to the mobile fuelling machine head and carriage. The two catenary trolleys, as shown in **Figure 7-14,** support a wide catenary chain which carries all the cables and hoses. The trolleys are independent of each other. Each trolley moves in the same direction as the carriage and allows the FM to visit all reactor fuel channel positions, plus the new and irradiated fuel ports, without straining the catenary hoses and cables. The catenary trolley is normally operated under computer control, chain driven from an electric motor through a worm–gear reducer and torque limiting coupling.

d) Power Supplies and Auxiliaries

Electrical, heavy water and oil hydraulic systems provide the means to control and power the movements of the FM head, carriage, bridge and catenary assemblies, as well as to cool the fuel in the head. All these services are supplied through the hoses and cables on the catenaries.

The oil hydraulic system provides the power to actuate most of the drives and rams of the fuelling machine head during the fuelling process, except for those enclosed or immersed within the D_2O boundary .

The F/M D_2O system provides a flow of heavy water, regulated for pressure and temperature, to the various parts of the F/M head. When engaged on a fuel channel, most of the return flow enters the end fitting to exit through the feeder with the main channel flow; when off channel it all returns through D_2O catenary line. D_2O is used in the F/M head for the following main functions:

- Cooling spent fuel stored in the F/M magazine
- Operation of the F/M C–ram
- Operation of the F/M separators
- Preventing high temperature heat transport D_2O from entering the F/M head

Electrical motors power the movements of the carriage across the bridge, the bridge up the columns, and the catenary trolleys along their tracks.

Only electrical sensors are used for controlling the actuators on the fuelling machine head and cradle, D_2O valve station, D_2O drain ports, D2O supply system, and oil supply systems. Sensors provide information to both the station control computer and the fuel handling operator via a complex arrangement of connected cable assemblies, junction boxes and panels.

7.1.4 Fuel Transfer System Component Description

7.1.4.1 Fuelling Machine Head

Each fuelling machine head is mounted in a supporting cradle, as shown in **Figure 7-11** which carries the D_2O, electrical and oil hydraulic equipment associated with the head. The cradle also supports the magazine manual drive equipment and the head counterbalance weights. The FM head is a very complex mechanical assembly which performs many operations with a high degree of certainty and precision. It must apply a number of precisely controlled motions and forces, in specific sequence verified by inter-locks, to assure safe handling of the fuel. A failure to properly complete a motion or operation, which might leave a bundle incompletely transferred, or the FM locked onto the end fitting, has onerous economic consequences. Maintainer access to make a manual repair is impossible, because of the radiation fields emanating from the fuel inside. The design and the quality of manufacture and maintenance must focus on high reliability to avoid maloperation, and means must be considered for remote manipulation of simple mechanical tools to effect corrections. Parts that come in contact with D_2O are made from corrosion resistant materials, namely stainless steel. Other parts are made from corrosion resistant materials or protected by corrosion resistant surface treatments. The magazine housing, magazine end cover, ram housing and rear forging are martensitic stainless steel forgings. The snout centre support as well as several other components are made of 17–4 PH stainless steel. The FM head is comprised of the following major sub-assemblies:

1) Snout Assembly

The snout assembly enables the fuelling machine head to clamp onto any reactor fuel channel and to seal the connection at high pressure and temperature. It is mounted on the front of the magazine assembly and shown in **Figure 7-15.** To achieve loading of new fuel bundles and the discharging of spent fuel bundles from the fuelling machine, the snout assembly must also be capable of locking onto the new fuel port and the spent fuel port. It is also capable of connecting to the ancillary port, or the rehearsal-facility port as required. The latter permits periodic calibration of actuating forces on the FM rams and tools.

The snout assembly comprises the centre support, the clamping mechanism, the emergency assembly, the head antenna and the snout probes. It is designed to prevent D_2O leakage under the high operating pressures and temperatures incurred during on–power fuelling operations. The pressure–tight connection is subjected to an axial separating load of 147 kN (33,000 lbf) due to the PHT pressure inside the channel. It must also react a maximum ram force of 31 kN (7,000 lbf). To accommodate this force while retaining a safety margin, the snout assembly has been designed to develop an axial clamping force of approximately 267 kN (60,000 lbf). This is accomplished by the mechanisms detailed in **Figure 7-16.** When the clamping barrel has engaged over the end fitting end (not shown) radial wedge blocks are driven into the groove on the end fitting, by a cam block acting on a lever arm. The clamping barrel is the drawn back to clamp against the seal ring face, by rotation of the screw member inside the barrel, actuated by a motorized gear engaged on the screw member.

2) Separator Assembly

For each fuelling machine head there are two separator assemblies, as shown on **Figure 7-17** which perform identical functions and operate in synchronism. The location of the assemblies on the magazine assembly can be seen at the upper left on **Figure 7-19**, (item 12). They penetrate radially through the magazine front end cover, and each separator assembly comprises of a feeler, a retractor and a fuel stop. **Figure 7-18** shows their action. The feeler or sensor acts as a mechanical finger powered by D_2O pressure in order to sense the presence of a fuel bundle or shield plug that is under the separator assembly. The main purpose of the retractor is to stop the 'B' ram at the correct position for separating fuel and to assist directly in the fuel separation. The fuel stops are used to prevent the passage of the fuel string beyond the end of the guide sleeve, so the fuel is clear of the end of the magazine rotor, when it rotates.

3) Magazine Assembly

The magazine assembly, shown on **Figure 7-19,** comprises a housing enclosing a rotor having twelve tubular stations, for storing fuel bundles, channel closures, shield plugs, a snout plug, ram adaptor, guide sleeve and guide sleeve insertion tool. The magazine is divided into three main parts; the magazine housing, the magazine rotor and the rotor drive unit.

The magazine housing assembly is a pressure vessel designed to operate at a rated pressure of 13.1 MPa (1900 psi) and an operating temperature of 149°C (300°F). It consists of two stainless steel forgings, the magazine front cover and the magazine rear housing held together by a bolted split-clamp and seal ring.

The magazine rotor consists of a solid rotor shaft and twelve magazine tubes. The twelve magazine positions provide for five fuel stations (holding two bundles each), two channel closures, two shield plugs, one snout plug, one ram adapter and one guide sleeve and tool.

The rotor is supported and driven by the shaft support, shaft seal, drive unit and magazine emergency drive. See **Figure 7-20.** The rotor shaft support is cantilevered from the housing rear wall. It holds the rotor shaft in the centre of the magazine cavity with one set of single-row, deep-groove, radial ball bearings in the front and a triple stack of angular contact ball bearings at the rear. The balanced shaft seal comprises a spring-loaded rotor assembly mounted to the magazine rotor shaft and running against a tungsten carbide stator, which connects to the magazine housing through a gland plate. The rotor shaft is driven by a Ferguson™ drive by means of a plate having twelve radially oriented, equally spaced roller followers. See **Figure 7-21.** The shaft also connects to a rotary potentiometer. A manual drive facility is provided to rotate the magazine if the oil hydraulic motor becomes disabled. The magazine emergency drive is located between the worm drive reduction gear and the hydraulic motor. The ball screws which drive the 'B' ram and latch ram and the magazine drive shaft extend through the magazine pressure boundary. Therefore, special mechanical seals are provided on the D_2O side to accommodate the high pressure differential with a minimum of friction loss. These mechanical seals are not completely leak tight. They allow a small leakage that acts as lubricant and reduces the friction between the stationary and the moving part of the seal. This leakage is collected and is returned to the D_2O collection tank.

4) Ram Assembly

The ram assembly provides the necessary axial movements and forces required for transfer and discharge of the fuel bundles; also installation and withdrawal of the guide sleeve, the channel closure plug, the shield plug, and the snout plug. It is mounted on the back of the magazine, secured and sealed by another split-clamp and seal ring. See **Figure 7-20.** The ram housing is a pressure vessel consisting of two parts: ram housing and ram rear forging.

The ram assembly consists of a 'B' ram, a latch ram and a 'C' ram. These rams are essentially concentric tube assemblies supported by the ram housing. Each ram has a different facilitator head assembly ("end effector") to perform the necessary plug or fuelling operation. Both the 'B' ram and the latch ram are driven by gear-reduced oil hydraulic motors which turn ball screws. The 'C' ram is powered from the D_2O control system. All three rams have rotary potentiometers to provide continuous information of the ram positions to the control system. **Figure 7-22** shows the front end of a ram assembly, with the three ram heads. **Figure 7-23** shows the rear end, with the drive motors and position sensing devices.

The 'B' ram is the outermost of the three ram assemblies. It consists of a ram head and tube, two ball screw assemblies, and a drive unit. The 'B' ram utilises three speeds and five force levels to perform its operational functions.

The latch ram is carried on the 'B' ram and is only required to move a short distance relative to it, to latch onto the plugs, ram adaptor and guide sleeve insertion tool. The latch ram has one speed and one force level.

The 'C' ram consists of one ram tube and three telescopic tubes. These tubes are concentrically fitted inside the latch ram tube. Tube number three is movable and is the longest tube, while tubes numbers one and two are stationary and are shorter.

The fuelling computer controls the 'B' ram positioning by a positioning loop program, to achieve the sequences of the various operations,. This enables the 'B' ram and latch ram to go to the preset position to accomplish the assigned task.

5) Snout Plug

The snout plug is used to seal the snout of the fuelling machine head when the fuelling machine is off the reactor. It is held in place by jaws engaging the locking groove of the centre support. The seal is made by expanding a radial bore seal in the smooth bore of the centre support.

6) Ram Adaptor

The ram adaptor provides a suitable face for contacting the end plate of a fuel bundle and acts as a buffer to absorb neutrons emitted by irradiated fuel bundles, consequently preventing both the fuel bundles and the ram head from overheating. The ram adaptor attaches to the 'C' ram and its body provides the contact face with the fuel. It also centralizes the 'C' ram, and minimizes its sagging. The ram adapter is shown in **Figure 7-24.**

7) Guide Sleeve Assembly

The guide sleeve is inserted into the end fitting to make up the step in its bore in which the closure is normally seated. It provides a smooth bore for the fuel when passing between the fuel channel end fitting and the fuelling machine.

7.1.4.2 Fuelling Machine Carriage and Cradle

The fuelling machine carriage and cradle support the fuelling machine head in the maintenance lock and at the face of the reactor. The carriage travels along the track in the maintenance lock and along the bridge in the reactor area (X motion) and can transfer from one to the other.
In addition to the coarse X motion, the carriage also provides fine X motion, fine Y motion, and Z motion, and allows a controlled amount of pitch and yaw motion of the head, ie, rotation about the horizontal and vertical axis, respectively. It also serves as the termination point for the main catenary loops and carries the catenary frame. The clamping mechanisms securely anchor the

carriage to the bridge rails, when the F/M head is clamped to an end fitting, to ensure that excessive loads are not applied to the end fitting by the F/M head during a seismic event. The carriage drives function in conjunction with the bridge and column drives to traverse and position the FM head at the ports and at the fuel channels, under control of the fuelling computer.

Each carriage consists of a three-part frame on which are mounted the wheels and X-drive assembly, the Z-drive assembly, and the upper and lower gimbal assemblies, as shown in **Figure 7-25.** The outer part carries the X-drive wheels, the inner part carries the yaw gimbal, and the lower part carries the pitch gimbals. The inner parts of the frame slide inside the outer to provide Z-direction travel, and they carry the gimbals. The lower part rotates on the upper gimbal system, which permits yaw rotation. The lower part also can move vertically relative to the inner part, to impart fine Y motion, actuated by three hydraulic motor-powered jacks. See **Figure 7-27**. The lower gimbals permit pitch rotation of the FM head, and also provide the means of attaching the head to the carriage.

The frame is fabricated from carbon steel plate. The wheels on the outer frame run on the bridge rails for X-motion. Each wheel is coupled to a gear which engages on a rack mounted on the bridge. The 'X' drive system on the carriage powers the wheels and allows for coarse and fine 'X' motion. The course 'X' drive motor is a two-speed electric motor with an integral, electrically-released, spring-applied brake. It transmits power through a speed reducer to a double-ended output shaft. The 'Fine X' drive is a second motor, connected to the coarse 'X' drive system through an electrically operated clutch. It provides final alignment prior to clamping the FM onto a channel end fitting. Two clamping assemblies are provided to lock the carriage to the bridge beam when the FM is locked onto a fuel channel. These clamps prevent the carriage from rolling back and forth along the bridge during a seismic event. Such motion would impose unacceptable bending loads on the end fitting to which the F/M is attached. Each clamping assembly consists of two sets of clamps supported by a common mounting structure which bolts to the carriage. Each clamp has caliper-type jaws which grip the side faces of the rail, and which are actuated by a machine screw and levers integral with the clamping jaws.

The inner portion of the frame slides in the Z-direction on guides on the outer portion, as shown on **Figure 7-26**. The Z-drive is a pair of hydraulic cylinders mounted on the underside of the outer part. The yaw gimbal assembly consists of a large bearing plate carrying a slewing bearing, from which the lower frame part is suspended. The lower gimbal attachment assembly is simply a rectangular seat, with a latch bar, into which the FM is attached. The actual pitch bearing is in the mating part on the FM head and cradle assembly. **See Figure 7-11.**

Carriage 'X' position is detected by a shaft encoder driven by a roller chain from the carriage idler unit wheel shaft. Position switches mounted on the carriage provide end of travel indication and assist the operator in retrieving the carriage in the event of encoder failure. A shaft encoder is driven from a gear box in the 'Z' drive mechanism to provide Z-position detection.

Some of the fuelling machine carriage and cradle components are supports for the fuelling machine head pressure retaining components. These component supports, are fabricated as Class 1 components in accordance with subsection NF of the ASME Code. Other items are designed and built or purchased to high quality commercial mechanical standards.

7.1.4.3 Bridge and Column Assemblies

Each bridge and column assembly consists of two fabricated steel columns with a bridge beam spanning between them. See **Figure 7-13.** The two bridges are about 15 m apart, on each end of the reactor. Each bridge beam is supported on elevators which travel up and down the columns on ball screws (coarse Y–drive)

Each bridge assembly accepts a FM head and carriage from the maintenance lock track and supports the FM head and carriage assembly while it is in the reactor vault. **See Figure 7-14.** The bridge structure consists of two, inward-facing, L-shaped box-beams joined by cross bracing. The tracks supporting the carriage are mounted on the lips of the Ls. An elevator assembly on each end of the bridge incorporates the guide bearings which run on the vertical round-way tracks on the columns. They also include the gear-motors which drive the ball-nuts on the stationary ball-screws on the columns, to power the Y-drive motion. These motors incorporate power-off, spring-actuated brakes. The motors on the two ends of the bridge are coupled together by a cross-shaft, to preclude bridge tilt caused by one end rising more than the other.

Shaft encoders signal the elevation position. Power is supplied by small catenaries mounted on the columns. A position switch on each bridge elevator actuates at a point just below the lower end of normal bridge travel. When both switches are actuated it indicates that the bridge is fully down and level. Limit switches are provided on each brake for positive indication of brake status. Two independent bridge tilt detection systems are provided: one through a single comparator module sensing the position feedbacks from the two shaft encoders, and the second by an accelerometer (tilt sensor) mounted on the bridge.

The maintenance lock tracks are fixed extensions of the fuelling machine bridge tracks, to which the bridge aligns when it is at its lowest elevation and the fuelling machine door is open. Under these conditions the fuelling machine carriage can be transferred from the reactor area to the maintenance lock or vice versa. The maintenance lock tracks enable the fuelling machine to be positioned at any one of the horizontal row of ports in this area, namely the new fuel port, service ports, rehearsal channel and spent fuel port. Their construction is similar to that of the bridge. They also provide a means of parking the fuelling machine in an area which can be made accessible during reactor operation provided the fuelling machine door is closed.

The columns are fabricated box-beams which support the vertical round-way guides and the stationary ball-screws. They are rigidly attached to the vault walls, 11 m apart, by sturdy brackets. The columns are of different lengths, as the one on the side of the sliding vault shielding door must allow clearance for the door to pass beneath it to open. The longer column extends down to the floor. This arrangement is also seen in **Figure 7-6.**

The horsepower of the Y-drive motor must be carefully selected. Its torque must be sufficient to lift the mass of the bridge, carriage and fuelling machine assembly for upwards travel, yet it must resist this same mass causing over-running during downwards travel.

7.1.4.4 Catenary Assemblies

There are two catenary systems, one for the 'A' side fuel handling system and the other for the 'C' side. See **Figure 7-9**.

Each system consists of a catenary loop, a powered catenary trolley, a Z–motion loop and a hose and cable carrier. The catenary loop is connected at one end to the fuelling machine carriage, and at the other to the powered catenary trolley which travels on tracks in the maintenance lock. The flexibility and length of the catenary loop and the travel of the trolley permit the head to connect with all the service ports in the maintenance lock and all reactor end fittings. System connections between the ends of the catenary loop on the catenary trolley, and the termination points in the maintenance lock are made through a flexible hose and cable carrier. An auxiliary Z–motion loop connects the end of the catenary loop on the carriage with the fuelling machine head to permit Z–motion, and pitch and yaw motions.

The catenary loop consists of a series of rubber hoses and cables, supported and protected by a catenary chain. The chain consists of two lengths of flat side plates interconnected by pairs of cross bars. The side plates are hinged together and can pivot in each direction, the amount of movement being restricted to limit the minimum bend radius of the hoses and cables in the loop to 15 inches (368 mm). Wheels are provided on each side of the chain in the area where the loop makes contact with the floor, to prevent damage to the floor and the catenary loop. There are four hydraulic oil hoses, 20 D_2O hoses and twin electrical cables, and the main section of the catenary is 1.1 m wide and 7.8 m long. High temperature D_2O hoses are made of corrugated stainless steel with outer stainless steel braided cover. Oil hydraulic and normal temperature D_2O hoses are made of Buna N elastomer with metal braid reinforcement covered with neoprene.

Flexible hoses and cables (power tracks) carry the D_2O, hydraulic oil, electric power and control signals between the rigid piping and junction boxes in the maintenance lock and the catenary trolley. The carriers permit the catenary trolley to travel the full length of the maintenance lock.

The catenary trolley supports the end of the catenary loop in the maintenance lock. It consists of two longitudinal beams interconnected by two transverse members. Round-way bearings run on guides mounted on the maintenance lock track. The catenary trolley is chain driven from a drive unit mounted below the trolley rails.

7.1.5 Process of Aligning FM Head to the End Fitting

To ensure proper sealing and locking of the FM snout onto the end of the fuel channel end fitting, the snout must be made precisely co-linear and co-axial to the end fitting. The consequences of becoming disengaged while transferring fuel are obviously severe, and special devices are incorporated to ensure this will never happen. Disengagement would cause a single-channel LOCA event, but might also lead to fuel bundles being ejected into the vault. This small LOCA would be easily dealt with by the reactor safety systems and is not a severe safety issue, but the difficulty and cost to clean up the mess created would be significant.

The FM head is initially aligned to the nominal channel X & Y co-ordinates stored in the memory of the fuelling control computer, which provides steering commands to the X, Y and Z drives. As the snout approaches the end fitting under Z-drive, the relative position is monitored by a set of sensors mounted on the snout. The first of these is the antenna ring, seen on **Figure 7-15**, used to detect gross positioning error. If it contacts the end fitting, switches are activated which detect the lack of clear, concentric entry, and these signals stop the Z-drive. The operator must withdraw the head and adjust X and Y positions, then re-start the engagement process. When initial alignment is acceptable and engagement begins, the FM head is free to pitch and yaw away from the true centered positions as the snout engages on the end fitting, and sensors on the carriage trunnions detect the errors, as shown on **Figures 7-28 and 7-29.** Their signals are used to actuate the fine Y-drive and fine X-drive, respectively. Final Z-drive is then permitted, and the snout probe sensors control this last phase. They are shown on **Figure 7-30** and can be seen also on **Figure 7-15.** They ensure the snout seal will be flat on the end fitting end and that the snout lock wedges will all enter the locking groove.

7.1.6 Remote TV Viewing

Remote viewing equipment is provided for the purposes of observing the fuelling machines at each end of the reactor, when they are at the reactor faces or in the maintenance locks, particularly during periods of high radiation fields, e.g. if spent fuel becomes stuck in a machine. They are also provided in the fuel discharge room for observation of the irradiated fuel discharge equipment and/or technicians in the discharge room.

The mountings are located such that the F/M can be viewed when it is at any reactor lattice site or during passage from the reactor vault into the maintenance lock. Other mountings are located such that the manual drives of the F/M can be viewed when the F/M is at the Irradiated Fuel Port, and both sides of the F/M in the regions where the trunnion latches can be viewed when the F/M is located at the exit doorway.

The mountings in the Irradiated Fuel Discharge room are located such that both equipment and personnel can be monitored.

There are nine access penetration embedments in each Reactor Vault Room and five in each Fuelling Machine Maintenance Lock. Shield plugs normally occupy these penetrations but will be replaced by the camera and mounting plug assembly when required. Insertion and removal of both the shield plugs and the camera mounting plug is accomplished from rooms beneath the Reactor Vault and Maintenance Lock. When the assembly is bolted into place in a penetration embedment, the 'O' ring gasket in the plug flange seals the penetration against leakage, in event of spillage in the Reactor Vault and/or the Maintenance Lock.

7.1.7 Analysis and Testing of Fuel Changing Equipment

7.1.7.1 FM Stress Analysis

1) Loading Conditions

The FM and supports are designed for the worst combination of loads that can occur during the complete refuelling cycles, including pressure, temperature, mechanical and seismic loads. Analyses are performed for a variety of conditions to calculate maximum loads for the following configurations:

- FM in Reactor Vault - Attached and unattached to the fuel channel
- FM on Maintenance Lock track
- FM on spent fuel port

Stress analyses demonstrate the structural integrity of the fuelling machine and its support structure during reactor operation. Finite element methods are generally used to calculate the loads and stresses for the various operating conditions in accordance with the CSA standard N285.0 and the designated ASME code requirements. Most of these components are analysed as class 1 pressure retaining items or class 1 supports. Internal components are not included in this category, and are treated as commercial mechanical items, but are analysed by the same methodology, and resulting stresses compared to material allowable strength values having similar or equivalent safety factors.

The loading conditions specified in the Design Specification document are classified as Design Level A, B, C or D Service conditions or Test conditions in accordance with the CSA standard N285.0 and the designated ASME code requirements.

2) Cases Analysed

At any time, the fuelling machine can be connected to one of the 380 channels on the face of the reactor. For seismic analysis purposes seven typical cases are selected to envelope all the possible configurations. These cases cover the locations representing most flexible column, bridge structure and ball screws, and most stiff locations close to the supports and embedment points at different elevations of the fuelling machine. Cases are considered for the FM being both unattached and attached, to both the fuel channel and the ports.

3) Analysis

FM stress analysis is performed using an optimum combination of classical and finite element methods. The stress analysis is based on linear elastic static analysis except for some assemblies in which non–linear gap elements are used in the finite element method to simulate the interfacing behaviour between contacting components for seismic analysis.

7.1.7.2 Carriage, Bridge and Column System Stress Analysis

The FM support and transport equipment is designed for the most severe combination of loads that can occur during the entire fuelling cycles, including mechanical and seismic loads. Analyses are performed for a variety of conditions to calculate maximum loads.

The carriage is a support structure and is analysed in accordance with the rules of clause 14 of CSA standard N285.0, and the designated ASME code, Subsection NF, for Class 1 supports. Calculated stresses are compared with the ASME Code allowable limits for all loading conditions specified in the Design Specification.

Non–code parts are stress analysed, where required, using the minimum strengths of the material for material specifications, using safety factors generally similar to those used for code items.

7.1.7.3 FM Production Acceptance Testing

Because of the complexity of the fuelling machines, prior to being shipped to site, each fuelling machine receives extensive testing. Any departures from specified performance revealed by testing are rectified and the tests are repeated.

Each ram assembly undergoes a functional test to confirm that it is assembled correctly and to confirm that it operates as intended before being mounted on a fuelling machine head. This functional test involves mounting the ram on a test rig and cycling it 300 times while the ball screw torques and ball screw seal leakage are monitored.

After a successful functional test, each ram is mounted on a fuelling machine head, and the fuelling machine head then undergoes acceptance testing to confirm that the fuelling machine is assembled correctly and to confirm that the fuelling machine will operate correctly when installed at the reactor site.

Acceptance testing involves installation of the fuelling machine on a test rig including a carriage and bridge, and a fuel channel supplied with ordinary water at operating temperature and pressure. The various systems are set up and calibrated prior to cycling the fuelling machine through its normal fuelling cycle. Both manual and computer controlled sequences are applied, in both 'step' mode and 'auto' mode.

7.2 New Fuel Storage and Handling

7.2.0 General Overview and Requirements

- Storage and handling facilities shall be provided to receive, store, inspect the new fuel and transfer it through a port into a fuelling machine.
- Sufficient storage capacity of new fuel shall be provided in the service building for nine months supply, with provision for the temporary storage of the initial load of fuel.
- New fuel bundles shall be loaded manually into the new fuel transfer mechanism, and it shall then transfer them through the port and into the fuelling machine on commands from the control room.
- The new fuel loading and transfer equipment shall be located inside containment in an area which has biological shielding and atmospheric control to permit uninhibited access for workers loading fuel. The area shall be readily accessed for fuel to be transported through the main air lock, and shall be serviced by suitable cranes, instrument air and electrical power.
- The transfer port shall pass through the fuelling machine vault wall from the accessible new fuel area, and include a valve to provide an atmospheric barrier.
- Quality assurance during design, analysis, manufacturing, testing and commissioning is to be performed according to the requirements of the CSA Standards N286 and Z299.

7.2.1 System Description and Operation for New Fuel Transfer and Storage

New fuel is stored in the new fuel storage room in the service building on the pallets on which it is delivered. See **Figure 7-8.** The flow path is shown on **Figure 7-31.**

A fork lift truck and a powered pallet cart are used to transfer bundles between the service building and the reactor building through the equipment airlock.

The new fuel transfer equipment is located in the new fuel transfer room in the reactor building, just adjacent to the reactor vault and in between the two fuelling machine maintenance locks. See **Figure 7-32**. The two new fuel transfer mechanisms (NFTMs) are mounted on a higher floor than that of the reactor vault floor. Part of this floor covers the passageway which interconnects the two fuelling machine maintenance locks. This section of floor can be removed whenever it is necessary to move a fuelling machine head to or from either of the fuelling machine maintenance locks. Normal personnel access to the room is by stairs from the main air lock level. An escape ladder to the level above is provided while an access ladder to the fuelling machine maintenance locks is provided at the opposite side.

The fuel transfer is made in two steps: first the fuel bundles are manually placed on the trough on the NFTM and pushed into the NFTM magazine by the loading ram; second, the bundles are transferred out of the NFTM magazine into the FM magazine by the transfer ram.

Once fuel has been moved into the new fuel transfer room, it is opened and unwrapped and inspected. Individual bundles are picked up and moved via the bundle lifting tool attached to the air-balance hoist, and then placed in the NFTM loading trough. See **Figure 7-33.** When there are two bundles in the trough, the bundies are pushed into its magazine by its loading ram. The magazine is indexed, and this process is repeated until the magazine contains the required number of fuel bundles.

An empty fuelling machine (FM) is then clamped onto the port, and the NFTM magazine is rotated to its shield plug station, and its transfer ram removes the port's shield plug and stores it in the NFTM magazine. The FM ram inserts its guide sleeve into the port and its magazine then rotates to an empty station, while the NFTM magazine rotates to a full station. The NFTM transfer ram pushes two new fuel bundles into the FM magazine. The process is repeated until the FM contains the required number of bundles.

After completion of the bundle transfer, the port's shield plug is re–installed and locked in place. The FM then retrieves its guide sleeve from the new fuel port, installs its snout plug in its snout, raises the FM D_2O level and unclamps from the new fuel port, to traverse to the reactor face.

7.2.2 Details of Equipment Design

7.2.2:1 Auxiliary Equipment

Major components in the new fuel handling and storage area are shown on **Figure 7-32 and 7-33.**

The NFTM rams and the air balance hoist are operated with compressed air from the instrument air supply system.

The NFTM magazine loading ram is an air/oil operated cylinder. Oil pressure is used to extend the ram to provide smooth ram operation and adequate lubrication. Adjustable cushions are provided in the cylinder to reduce the ram operating speed at each end of the stroke. Loading ram operation is controlled by a solenoid valve, which controls the flow of air to and from the retract side of the ram and to and from the air/oil tank.

The new fuel port is embedded in the walls of the fuelling machine maintenance lock. The port is a tubular connection with an end fitting extending into the maintenance lock, and the other end engaging with the NFTM port adaptor.

The air lock valve is controlled by a solenoid valve. When power is removed from the valve, it remains in the last selected position. A similar valve controls the shield plug lock cylinder. A solenoid valve is also used to control the transfer ram head unlatch cylinder. The operating speeds of the air lock valve, shield plug lock cylinder and transfer ram head unlatch cylinder, are controlled with flow control valves.

7.2.2.2 Electrical Controls

The NFTM uses two modes of operation, Local Loading Mode and Transfer Mode. In the local loading mode, relay logic is used to control the operations of the loading ram, airlock valve, and the magazine. However, the computer provides an initial safety check of related components before loading is initiated. The transfer mode, which is normally under the control of the reactor's RRS computer, controls the operation of the transfer ram, shield plug and the NFTM magazine indexing, to move new fuel bundles into the fuelling machine magazine.

Local loading of new fuel into the NFTM is controlled from the local control panel mounted on the new fuel loading mechanism.

The NFTM magazine is normally dry. A level transmitter gives a warning if D_2O should enter from the fuelling machine head into the new fuel magazine during the transfer of new fuel bundles.

7.2.2.3 Mechanical Items

The air balance hoist is mounted on a jib crane mounted on the building wall to cover the area of the new fuel transfer room. It is air–powered and can be adjusted to balance the load from a control on the operator's handgrip.

The bundle lifting tool is a manually operated device used with the air balancing hoist, which clamps around the end plates of the fuel bundles, through lifting adaptors.

The air lock gate valve is pneumatically operated and is installed between the loading trough and the NFTM magazine, to seal off the magazine whenever fuel is not being loaded into the magazine. This valve prevents the spread of any contamination from the fuelling machine head, the maintenance lock or the reactor vault, into the new fuel room.

The NFTM magazine assembly consists of a fabricated, leak tight housing, a rotor, and a drive unit. The magazine housing is a drum–like enclosure with a normally closed drain connection to the active drainage system and a vent to the reactor building vapour recovery system to remove any contamination through purging. The magazine rotor contains seven tubular channels, six for accommodating the fuel bundle pairs and one for the new fuel transfer mechanism shield plug. The shield plug, which is normally located in the new fuel port, reduces radiation streaming into the new fuel transfer room when the fuelling machine containing spent fuel passes the end of the new fuel port in the fuelling machine maintenance lock.

The NFTM magazine is driven by an induction motor through a Ferguson Indexing mechanism. An integral spring-engaged, electrically-released brake is provided to stop motor coasting. Magazine position is sensed by a shaft encoder, driven from the input shaft of the indexing unit. Micro-switches and relays provide inter-locks to ensure proper sequencing.

The NFTM transfer ram is driven by a variable speed, reversible DC motor, to the required position. This system permits control of speed and torque, as well as acceleration and deceleration and dynamic braking. Ram position is sensed by a shaft encoder driven from the transfer ram drive chain sprocket shaft.

The NFTM transfer ram has two functions: it removes and installs the shield plug between the new fuel port and the transfer mechanism magazine; and it pushes the new fuel bundles from the NFTM magazine into the fuelling machine. The openings for the transfer ram on the magazine front and rear covers are located at a bottom position, in line with the respective magazine station. The ram head incorporates a latch assembly for engagement with the shield plug. The ram is driven through a duplex chain.

The magazine-to-port adapter assembly is bolted to the NFTM front cover, at a bottom position in line with the respective magazine station and the fuel transfer ram. The adapter consists of a spool piece with two double-acting pneumatic cylinders. Its function is to hold the shield plug in position in the new fuel port.

7.2.3 Safety Considerations

Normal manual handling of new natural uranium fuel in air causes no radiation hazard or dose accumulation for the workers, from neutrons, α, β or γ emissions. In the absence of moderator, neutron emissions from the fuel are negligible, and CANDU fuel can be closely packed without concerns about criticality, even if accidentally submerged in ordinary water. New fuel contains small quantities of uranium daughter products but since the fuel is enclosed in a sheath and there is no driving force to move the uranium daughters out of the sheath, very little radioactivity is emitted into the surroundings.

The handling facilities provided are designed to avoid damage to the fuel bundles during manual or mechanized loading into the ports. The new fuel loading area is heavily shielded to block radiation emanating from either the operating reactor, or the fuel in the fuelling machine on the other side of the ports. Furthermore, the transfer of tritium from D_2O in the fuelling machine is prevented by interlocked valves that ensure atmospheric separation.

The general radiation levels in the new fuel loading room are 10 μSv/h.

7.3 Irradiated Fuel Transfer and Storage

7.3.1 Functional Overview and Requirements

The flow path is shown on **Figure 7-34.**

- Discharge of irradiated fuel from the fuelling machine shall be done by remote operation under automatic or manual control from the control room. Discharge to the fuel transfer port and elevator shall be done in air. Discharged irradiated fuel includes defected fuel.
- Transfer of irradiated fuel from the reactor building shall be done underwater. The transfer operation shall be done remotely, under either automatic or manual control; both options shall be available.
- During handling, the bundle shall be supported on at least two bands of its wear pads. No forces shall be directly applied to the fuel sheaths.
- Transfer of irradiated fuel requires passing it through the reactor building containment to the storage bay. Containment integrity must be maintained at all times.
- Defected fuel shall be identified by the defected fuel detection system prior to discharge through the irradiated fuel port.
- Receiving and routing of irradiated fuel, and of canned defected fuel, shall be a manual operation, and carried out underwater in the reception bay.
- The irradiated fuel storage bay shall be sized for ten years' accumulation at 80% capacity factor plus the emergency temporary storage of one half-full reactor core of fuel.
- All underwater mechanisms and instruments shall be removable for servicing without draining water from the bays and canals.
- There is no requirement to return irradiated fuel to the reactor after its discharge from the fuelling machine.
- The irradiated fuel storage racks shall be designed to withstand the design basis earthquake condition without structural deformation or toppling of the stacks, to ensure that there is no damage to the irradiated fuel bay causing leakage, or fuel bundle damage causing a release of fission products.
- A standby cooling system shall be provided to ensure that the maximum safe fuel

temperature is not exceeded during transfer operations in air, in the discharge bay.

- Quality assurance during design, analysis, manufacturing, testing and commissioning is performed according to the requirements of the CSA Standards N286 and Z299.

7.3.2 System Description and Operation

The irradiated fuel handling system consists of discharge and transfer equipment in the reactor building, and irradiated fuel reception and storage equipment in the service building. Fuel is initially discharged into the discharge bay, then immediately transferred through the transfer canal to the reception bay, and then to the storage bay. See **Figures 7-34, 7-35 & 7-36.**

The irradiated fuel bundles are received two bundles at a time from either fuelling machine, via its corresponding irradiated fuel port. The fuelling machine clamps to the irradiated fuel port in its fuelling machine maintenance lock and discharges the fuel through the port onto an elevating ladle. There are two elevator assemblies, transferring the fuel from either fuelling machine onto a common transfer system. See **Figure 7-37.** The irradiated fuel handling system is located in the discharge room, which is located in the reactor building, with the room walls forming part of the containment boundary. The room is physically located inside the containment building wall, but is normally considered to be outside of the containment whenever the port-ball valves are closed and the containment gate is open. The room is inaccessible during fuel transfer due to high radiation fields.

The elevator lowers the bundles into the water in the discharge bay, and deposits them on the transfer rack. Normally 8 bundles will be discharged onto the rack, but the rack has capacity for 12 bundles.

Once all fuel bundles are discharged onto the transfer rack, it is transferred on the discharge bay conveyor up to the containment gate. The containment gate is closed prior to the opening of the irradiated fuel port valves and kept closed during the whole irradiated fuel discharge sequence. After closing of the fuel port ball valves the containment gate is opened and the cart is transferred from the discharge conveyor to the transfer canal conveyor. The transfer canal conveyor carries the cart to the reception bay. See **Figure 7-34 and 7-38.**

In the reception bay, an operator on the walkway picks up the loaded transfer rack from the cart, using the transfer rack handling tool, and then places an empty transfer rack on the cart, for return to the discharge bay.

The loaded transfer rack is placed on a nearby rack stand in the reception bay. The bundles are manually transferred, individually, from the rack to an irradiated fuel storage tray. An operator performs this operation using the bundle lifting tool.

Each storage tray holds a total of 24 bundles, placed in two rows. The reception bay usually has one week's supply of empty storage trays available, for operational flexibility. After loading irradiated fuel bundles onto the storage tray, the tray is moved onto the storage tray conveyor for transfer to the storage bay. The storage tray conveyor is manually operated, and extends through an opening in the wall between the two bays.

Once in the storage bay, an operator on the man bridge picks up the tray using a hoist on the man bridge and the tray lifting tool, and the trays are placed on the base supports located on the bay floor. The storage tray conveyor then retracts until it seals the opening in the wall with its flow obstruction plate. This minimizes the movement of water between the two bays.

The man bridge is electrically driven and covers the width and length of the storage bay. The operator stacks the storage trays up to 19 trays high, using an electrical hoist and storage tray handling tool. Four stacks of trays are then secured by a covering frame which is connected to a common base. The cover is also used for installing IAEA Safeguards equipment. Trays are stacked to a height of 19 layers, making a total of 76 trays in one stacked group.

There is a minimum of 4.42 m of de-mineralized ordinary water shielding over the bundles on the top tray of a 19 tray stack. This maintains acceptably low general radiation levels of 60 μSv/h (6 mrem/hr) in the irradiated fuel bay. The irradiated fuel storage bay has sufficient capacity for ten years accumulation of spent fuel at 80% power.

The plant lay-out makes provisions for future addition of dry storage facilities outside of the Service Building, to permit transfer of early batches of irradiated fuel out of the irradiated fuel bay, to make more room. AECL has a developed the Macstore system for this purpose, for permanent storage. (On the other hand, at some point in the future, if the cost of new uranium fuel rises significantly, it may be economical to re-cycle this fuel, to extract Plutonium for use in another CANDU unit, perhaps mixed with Thorium.)

The spent fuel transfer auxiliaries comprise a series of systems which provide the fluid flows (air and water) for the irradiated fuel discharge mechanisms. The systems include a standby cooling system, a D_2O leak collection system, a fuel stop actuating system, a port relief system, a fuelling machine overflow detection system and a port valve actuating system.

7.3.4 Handling of Defected Fuel

Although failure of the fuel bundle sheath is a relatively rare occurrence, the fuel handling system must be able to separate it from the normal flow of fuel bundles, and provide special operations to enclose it and store it separately.

The presence of failed fuel in the reactor core is detected by monitors in the PHT system which detect abnormal levels of radiation at characteristic energy levels. The channel containing the failed fuel is identified, and the suspect bundle is picked out when the channel is refuelled.

After the fuelling-machine receives the defected fuel bundle, it is transferred onto the rack in the discharge bay by the same method as normal spent fuel. The defected fuel bundle is then manually removed from the rack and set into a carousal for temporary storage while it decays. **See Figure 7-34.**

After a decay period of four weeks or more, it is again manually moved from the carousel, inserted into a can and sealed with a lid. Using a canning device and a set of extension tools, the operator performs the bundle handling and canning operations from the discharge bay walkway. This method prevents fission–products escaping from the can containing the defected fuel bundle.

After canning, the defected fuel can is placed on the rack, and the cart is driven from the discharge bay to the reception bay. In the reception bay, the rack with the canned fuel is transferred to a special single rack stand–off, and an empty one is placed on the cart on the conveyor so that normal fuel discharge may resume.

The canned defected fuel storage trays are stored in the reception bay. Each stack of defected fuel storage trays are supported on a tray support, and can be stacked to a height of 10 trays.

7.3.5.1 Design Features of the Irradiated Fuel Handling Equipment

a) The Irradiated Fuel Port

In order to assure Reactor Building Containment integrity, a set of double ball valves in series is provided on the maintenance lock side of the port.

The inner and outer ball valves are actuated by separate air cylinders, each controlled by –way 2–position solenoid valves. These valves remain in the last selected position until the opposite solenoid is energized. Both hardware and software interlock logic is provided to prevent the valve from opening unless certain specific conditions have been met, such as, "head locked onto the spent fuel port"; "spent fuel port drain is open"; "containment gate is closed", etc.

b) Elevating Ladle

Two elevator ladles accept the fuel bundles from the spent fuel ports and are electrically driven to lower them onto the rack on a conveyor at the bottom of the discharge bay. The two elevators consist of ladles running on tubular and angle rails. The 30° inclination of the rails allows both elevators to terminate at the single conveyor at the bottom of the discharge bay. The two elevators are interlocked so that only one ladle is in the unloading position at any one time. Each ladle accommodates two fuel bundles and is suspended and driven by a stainless steel cable from a drum mounted above the rails. The cable has a safety factor of 15. The rails are manufactured and assembled in three major sections, two upper sections and a lower section.

The elevating ladle is driven by a variable speed reversible, 2 kW, DC motor through a solid state controller. The motor has an integral spring applied, electrically released brake. In addition to speed and torque control, the system provides timed acceleration and deceleration. The motor is located in the new fuel room, the controller in the motor control centre and the speed and torque control potentiometers on the equipment panels in the control equipment room.

c) Containment Gate

The fuel transfer canal containment gate is located at the entrance to fuel transfer canal in the spent fuel discharge bay. Its function is to provide containment boundary during the discharge of spent fuel from the fuelling machine to the spent fuel discharge bay.

The canal gate assembly consists of a base plate, posts, and gate and guide frame. The base plate is a stainless steel plate, with an opening to allow the transfer cart to pass from the discharge bay conveyor to the transfer canal conveyor. The two stainless steel posts hold and guide the moving portion of the canal gate assembly. The gate is made of stainless steel plate. The gate contains two sets of 'O' ring type seals, set in dove tail grooves. When the gate is closed it is pressed against the base plate by a set of rollers traversing between a cam shaped plate attached to the gate and a flat plate attached to the guide frame. This applies pre-load on the O–ring seals and compresses them against the machined sealing surface of the base plate.

The gate is operated by pneumatic actuators via two position, 4 way pilot operated solenoid valves to open and close and also to latch and unlatch the gate at the fully open and closed positions. Automatic and manual control of the gate is possible.

When the gate is closed, a double set of O–ring seals are compressed and an automatic leak tightness check is carried out prior to opening the port ball valves and transferring fuel. Control console indications are provided for the gate being open or closed, the latch being latched or unlatched, and confirmation of acceptable leak test. In order to minimize damage to the seals when closing the gate, logic derived from proximity limit switches is provided to switch the gate to low speed prior to reaching the fully closed position, and also to ensure low speed is selected when moving away from the fully closed position.

d) Conveyors

The spent fuel bundles are loaded onto a rack supported on a cart, which runs on the two conveyors between the spent fuel discharge elevator and the reception bay.

The conveyors are of similar construction and consist of a welded stainless steel frame with a flat upper surface on which the cart runs. A rectangular guide rail on the upper surface mates with three sets of rollers on the cart to provide lateral guidance for the cart. The cart runs on eight stainless steel wheels which enable it to traverse the gap between the two conveyors. A mechanical stop is mounted at the end of cart travel.

The discharge bay conveyor performs two functions. In the spent fuel discharge bay, it indexes the cart to its next position after two spent fuel bundles have been deposited on the rack by the elevator. When the rack is full, it is moved from the elevator in the discharge bay to the end of its travel, transferring the cart and rack onto the transfer canal conveyor.

The discharge bay conveyor is driven by a 370 W, 3-phase induction motor with an integral spring-applied, electrically-released brake. Manual and automatic control of the motor is possible. The conveyor position is detected by a shaft encoder, and digital comparator modules provide signals for interlocks and control relays. The encoder position is displayed on a control console meter and also provides inputs to the computer. A limit switch provides control console lamp indication and a computer inputs to confirm that an empty rack is in position at the load end of the conveyor.

The drive system for the transfer canal conveyor is identical to the discharge bay conveyor drive system except for the position detection and interlocks. Two cam operated limit switches detect transfer canal conveyor being at the unload end (receiving bay) and at the transfer end (discharge bay) respectively, and are used to provide control console lamp indication and computer inputs.

A local control panel for the conveyors is located in the reception bay area. The panel contains two indicator lamps and a push button switch. The lamps are operated by the computer, one to indicate when the cart is at the unload end of the reception bay conveyor, and one to indicate that the computer has acknowledged receipt of the signal from the push button. The push button allows the reception bay operator to provide an input signal to the computer to signal that the cart is empty and can be returned to the discharge bay.

e) Emergency Spray Cooling System

When transferring fuel from the F/M to the elevating ladle, there is a period of time when the fuel is not submerged, and therefore, not cooled. The standby cooling system supplies cooling water for fuel bundles which may be trapped in the air for longer than few minutes during a spent fuel transfer system malfunction.

A pressurizing pump powered by a 3-phase 11 kW induction motor provides the cooling water supply. The pump can be automatically or manually controlled. One air-operated globe valve operated by a solenoid valve, controls the water flow for the spent fuel port cooling. Position switches are provided for valve position indication open and closed and for computer inputs.

A second air-operated globe valve, also operated by a solenoid valve, controls the water flow for the spent fuel discharge bay cooling spray which is directed at the elevating ladle. A water flow detector in the bay cooling spray line provides control console lamp indication that the cooling spray is on.

f) Storage Bay Man-bridge

The spent fuel storage bay man bridge consists of an over–running, electric, travelling crane to which an under–slung walkway is attached. A two–speed electric chain hoist with an electrically driven trolley provides the lifting capability. The walkway spans the width and runs the full length of the storage bay to provide a working platform for operating personnel engaged in handling spent fuel or other active reactor components. The crane and hoist are controlled from a single pendant control station suspended from the hoist so that an operator can manipulate the crane from the walkway or the side of the bay as desired. Power supply to the crane bridge is via enclosed conductors with sliding shoe collectors on the 'D' side. Power supply to the hoist and trolley is via festooned cable on a box–type track.

Suitable lighting is provided around the periphery of all of the bays to provide the operator with the visibility required for handling of spent fuel trays and bundles from above water and for the inspection of the bay equipment and liner. The lighting is easily detachable for maintenance. A shroud around the lamp penetrates the water surface to eliminate lamp reflection on the surface and to provide cooling to the lamp. There are six lamp support brackets under the walkway floor for mounting of 1500 watts lamps if operating experience shows that extra lighting is required. There are six hinged hatch covers in the checkered plant walkway decking for lamp maintenance.

g) Storage Trays

Each storage tray can hold 24 fuel bundles in two rows of 12 each. The trays are of stainless–steel welded construction, with contoured cradle strips welded to support the fuel bundles. The trays are normally stacked no more than 19 high. Storage tray supports are provided in the reception bay, and in the main storage bay, to support the stacks of trays. Each support consists of a diagonally braced, stainless–steel frame, supported on four raised pads.

Table 1-1

List of Key AECB Documents for Power Reactor Design*

Document	Title
Chap. A-16	Atomic Energy Control Act
R-7	Requirements for Containment Systems for CANDU Nuclear Power Plants
R-8	Requirements for Shutdown Systems for CANDU Nuclear Power Plants
R-9	Requirements for Emergency Core Cooling Systems for CANDU Nuclear Power Plants
R-10	The Use of Two Shutdown Systems in Reactors
R-77	Overpressure Protection Requirements for Primary Heat Transport Systems in CANDU Power Reactors Fitted with Two Shutdown Systems
R-99	Reporting Requirements for Operating Nuclear Power Facilities
C-6	Requirements for Safety Analysis of CANDU Nuclear Power Plants
C-22	Quality Assurance Programs for Nuclear Facilities

* Extracted from AECB Publications Catalog, # Info 9999-2, 1997.01.03, issued by AECB Office of Public Information, AECB, Ottawa, Ontario, K1P 5S9.