CANDU 9 FUELLING MACHINE CARRIAGE

CA9700730

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ABSTRACT

Continuous, on–power refuelling is a key feature of all CANDU reactor designs and is essential to maintaining high station capacity factors.

The concept of a fuelling machine carriage can be traced to the early CANDU designs, such as the Douglas Point Nuclear Generating Station. In the CANDU 9 480NU unit, the combination of a mobile carriage and a proven fuelling machine head design comprises an effective means of transporting fuel between the reactor and the fuel transfer ports. It is a suitable alternative to the fuelling machine bridge system that has been utilized in the CANDU 6 reactor units.

The CANDU 9 480NU fuel handling system successfully combines features that meet the project requirements with respect to fuelling performance, functionality, seismic qualification and the use of proven components. The design incorporates improvements based on experience and applicable current technologies.

1. INTRODUCTION

CANDU reactor operation is based on the concept of continuous, on–power fuelling, which is carried out by the remotely controlled Fuel Handling System. The fuelling machine head, a pressure vessel which contains new or irradiated fuel during its transport between the reactor and the transfer ports, can be supported either by a bridge system, such as that used in the CANDU 6, or by a mobile carriage such as in Douglas Point NGS. For the CANDU 9 480NU design, a carriage system has been adopted.

An important consideration in the selection of the carriage system for CANDU 9 was having a design that would lend itself to seismic qualification for future sites with potentially higher seismicities than those of the previously constructed CANDU stations. Other design goals included reduced construction time and improved on–power maintainability of the carriage and the fuelling machine head. Simplicity and the maximum use of standard, commercially available components were also a part of the design intent. Supplier and operator input was incorporated.

In the following sections, an outline of the requirements applied to the fuelling machine carriage concept is provided, along with a detailed description of the carriage system functional and structural design. A summary of the benefits of the carriage system is included.

2. DESIGN REQUIREMENTS

The key CANDU 9 480NU project requirements, related to the fuelling machine carriage system performance and functionality, included:

i) meeting the fuelling demands of the CANDU 9 480NU reactor in support of the target lifetime capacity factor of 90%;

ii) access, with the required positioning accuracy, to all fuel channels, the new and irradiated fuel transfer ports, the rehearsal facility and the ancillary port;

iii) drive mechanisms compatible with computer control in the fully automatic, semi automatic and manual modes;

Design requirements related to safety and licensing were:

iv) meeting the requirements of the CAN/CSA N285 series of standards for Class 1C pressure boundary component supports, with references to the ASME Boiler and Pressure Vessel Code, Section III, Subsection NF;

v) application of quality assurance programs during design and construction, based on the CSA CAN3–N286 and Z299 standards;

vi) carriage design licensable in Canada;

vii) seismic qualification to ensure structural integrity during a 0.2 g Design Base Earthquake (DBE);

viii) providing safe and reliable transport of the fuelling machine head, thus ensuring the integrity of the contained new and irradiated fuel and of the interfacing components;

ix) meeting the environmental qualification requirements for normal operating conditions and postulated accident conditions;

x) satisfying the current human factors requirements with respect to the system layout, equipment maintenance and overall minimization of dose expenditures;

Other requirements:

xi) minimizing construction time.

3. CARRIAGE SYSTEM DESIGN

The design of the CANDU 9 480NU carriage is functionally based upon the Douglas Point NGS carriage. There are two dedicated fuelling machine and carriage assemblies per reactor that operate in concert to fuel a single channel. Correspondingly, there are two independent fuel transfer systems to handle new and irradiated fuel.

Each CANDU 9 480NU carriage (Figure 1) operates between the fuel transfer ports inside the maintenance lock and the fuelling machine vault. Once in the vault, the carriage turntable rotates 90° so that the fuelling machine faces the reactor. The carriage positions the fuelling machine head at the selected lattice location in the X (lateral) and Y (vertical) directions, engages the seismic locking mechanisms, and then advances the fuelling machine head in the Z direction. Once the head arrives at the pre-stop position, X and Y correction measurements are established. If necessary, the head is retracted clear of the end fitting and X and Y homing corrections are carried out by the fine X and carriage Y drives, respectively. The repositioned fuelling machine is then advanced to contact the end fitting with sufficient force to stall the Z drive. At this point, a standard CANDU fuelling sequence commences.

The carriage is designed to the requirements of the CAN/CSA N285.0, General Requirements For Pressure Retaining Systems and Components in CANDU Nuclear Power Plants and CAN/CSA N285.2, Requirements for Class 1C, 2C, and 3C Pressure Retaining Components and Supports in CANDU Nuclear Power Plants. These standards recognize the unique design of CANDU fuel handling systems and allow pressure vessel supports such as the carriage to be designed in accordance with the ASME Boiler and Pressure Vessel Code, Section III, Subsection NF. Through conformance to these design standards and codes, the carriage system becomes eligible for licensing in Canada.

The carriage assembly structure consists of six main sub-assemblies: the base, turntable, columns, outer elevator, inner elevator, and guide plate (Figure 1). The movements of the carriage sub–assemblies relative to one another and with respect to fixed supports facilitate the fuelling machine positioning at the reactor. The fixed supports consist of a floor rail and an upper guide beam. The carriage rail runs parallel to the reactor face and into the fuelling machine maintenance lock. The upper guide beam is centered over the rail, spanning its full length. The guide beam supports the carriage structure in the Z direction by trapping the guide plate within a slot in the bottom of the guide beam.

The base is a structure on two wheels that provides the X motion and half of the rotation freedom of the carriage. It is a welded assembly consisting of two beams, internal bracing and a circular skirt. The beams run parallel to the rail with cross members spanning the rail. Additional bracing, perpendicular to the main members, supports the skirt. One wheel of the base is driven by an electric motor through a reduction gear train, while the second wheel is an idler that, when required, can be driven by the backup X drive. The base is guided along the rail by guide rollers that contact the outside edges of the rail. Hold down hooks, that run in slots in the sides of the rail and are bolted to the main beams, prevent lifting of the carriage during an earthquake. The skirt supports a mounting ring at the top and four outriggers at the bottom. The outriggers are provided for construction and maintenance purposes and are capable of supporting the carriage assembly independently of the wheels. Finally, the inner race of a slewing ring is bolted to the mounting ring at the top of the skirt.

On top of the base, the outer race of the slewing ring is bolted to the underside of the turntable. The outer race is manufactured with an external gear cut in its outside perimeter. For carriage rotation, this gear meshes with a pinion fixed to the base through another reducer and an electric motor. The turntable structure is of a welded, sandwich style construction. It has internal cross–bracing that runs diagonally between the main members and it is enclosed on top and bottom with steel plates. Access openings are provided for the construction of the turntable, and for inspection and replacement of the bolts between the inner slewing ring cage and the base.

The column sub-assembly is bolted to the top of the turntable and it consists of two vertical columns and two horizontal crossbeams (Figure 2). The vertical columns are internally braced and have Y guide tracks along their front and back sides. The internal bracing at the bottom of the columns is in an X pattern facing upwards, providing high torsional rigidity. The bracing in the active portion of the columns is arranged in a zig-zag pattern with the edges of each brace corresponding to a reactor lattice position. These angled braces support loads imparted by the outer elevator Y guide bearings to the columns through the Y guide tracks. The top outside stub of each column houses a radial thrust bearing which holds the ballscrew. The lower stub on each column supports the ballscrew tensioner, while the Y drive seismic brake and gear reducer are bolted to the outsides of the columns below the stubs. The Y drive electric motors and drive trains are mounted on the turntable for improved access. The lower horizontal crossbeam between the two columns serves as a mechanical lower stop position for the outer elevator. Permanent shielding is bolted to the lower crossbeam that will shield the underside of the fuelling machine head magazine during maintenance. The upper crossbeam houses the bearings which in turn hold the shaft of the upper guide plate. These bearings provide a pivot point to allow rotation of the turntable and the columns relative to the base and the upper guide beam. The mating surfaces between the upper crossbeam and the columns are provided with keys that limit seismic shear loads through the bolts.

The outer elevator is positioned between the columns and allows the vertical movement of the fuelling machine. The outer elevator consists of a frame, four pedestals, outer crossbeams, a Z drive mounting beam and Z drive tracks (Figure 3). The frame fits between the columns with extensions on the sides of the frame protruding ahead of and behind each column. The pedestals are bolted to these extensions and they house the Y guide bearings. The Y guide bearings provide support to the outer elevator in both the X and Z directions by riding along both the face and sides of the Y guide tracks mounted on the columns. An outer crossbeam spans between the front and back pedestals along the outside of each column, thereby surrounding each column. This outer crossbeam is the mounting point for the Y drive ballnut. The Z drive mounting beam bolts across the back two pedestals and serves to transfer Z drive reaction and seismic forces from the fuelling machine to the columns through the pedestals and Y guide bearings. The Z drive tracks are mounted on the bed of the outer elevator and provide a track for the inner elevator to ride along. The Z drive is an Acme screw which is turned by an electric motor through a reducer. The screw, while rotating, drives an Acme nut along its length. The nut itself is fixed to one end of a seismic spring pack which in turn is fixed to the inner elevator. The spring pack is comprised of a tuned stack of hard Belleville spring washers. Its purpose is to allow relative movement of the fuelling machine with respect to the carriage, thereby limiting the carriage seismic inertial forces imparted to the end fitting should the fuelling machine be clamped on to an end fitting during an earthquake.

The inner elevator moves relative to the outer elevator to provide the Z motion of the carriage. The inner elevator consists of a base, a yaw turntable, and a cradle support. The base has linear guide bearings along the bottom that run on the top and sides of the Z tracks. The yaw turntable is a smaller slewing ring that has its inner race bolted to the top of the inner elevator base, and its outer race bolted into the bottom plate adjoining the cradle support pillars. The support pillars house the pitch pivot trunnions of the fuelling machine cradle and the cradle moves laterally within the support pillars to provide the fine X motion. Spring centering mechanisms between the fuelling machine cradle and the cradle support pillars, and between the cradle support and the inner elevator base provide the pitch and yaw freedom necessary to allow a fuelling machine to center over an end fitting.

4. SEISMIC DESIGN FEATURES

Undesirable motion of the CANDU 9 480NU carriage under seismic conditions is prevented through several means. The first restraint mechanism is an arrangement of wedge and pin style seismic locks (Figure 4). When activated, these mechanical devices prevent rotation and translation by locking the carriage sub-assemblies to one another or to fixed supports. The seismic locks are engaged during every channel refuelling sequence, prior to the fuelling machine being advanced over the end fitting. Both types of locks employ electric motors and Acme screw drives, and readily accessible manual drives for recovery operations are available.

The wedge style seismic locks accommodate thermal expansion between interfacing sub-assemblies and/or fixed supports. The locks employ force control feedback through the Acme screw drives to limit the depth of lock engagement. The force control establishes a positive contact between the locking wedge face and the locking striker plate but it limits the force in order to prevent any tendency of the lock system to move the carriage. The lower arrangement consists of two locks bolted back to back and mounted at the reactor side of the carriage base. These two locks then engage locking holes in a floor embedment. At the top of the carriage, one lock is bolted to the back of each column and it engages a corresponding hole in the upper guide beam. The locking holes in the upper guide beam and floor plate are spaced one lattice pitch apart. Due to the various angles at which the carriage must operate in the fuelling machine maintenance lock, a radial pattern of locking holes exists in that section of the upper guide beam. Because the base does not rotate, only a single embedment with two locking holes is sufficient to lock the base to the floor when the carriage is in the maintenance lock.

The locking of the turntable to the carriage base is accomplished with a straight pin style seismic lock. The straight pin style is used only in this location because the two sub-assemblies, given their physical proximity, will be subject to the same thermal transients, thus leading to minimal misalignment. One lock is located at the base of each column. The pin extends through the bottom of the turntable and engages a mating hole in a locking ring welded to the base structure within the slewing ring.

In addition to the wedge and pin type seismic locks, all electric drive motors have integral brakes which are automatically applied when the drive is de-energized, making them fail-safe. For further safety, the ballscrews are equipped with seismically qualified fail-safe brakes and are pre-tensioned with spring packs that prevent compression of the ballscrew under seismically induced lifting loads.

In order to protect the fuelling machine carriage assembly from an earthquake occurring while the carriage is in transit, a seismically activated and qualified switch will cut the power to all drives, thereby activating their brakes. As a backup to the motor brakes, seismically qualified snubbers and mechanical stops prevent overtravel and provide for controlled deceleration of any component should the motor brakes slip.

5. DESIGN BENEFITS

The benefits of the carriage design range from simplified construction to improved reliability and reduced time and radiation dose expenditures during operation and maintenance activities. The new design incorporates feedback from operators and suppliers. The CANDU 9 480NU design is also expected to be adaptable for CANDU sites with seismic levels higher than the 0.2 g DBE currently being considered.

Manufacturing tolerances are eased by the use of shims between sub-assemblies because customized shims bring critical sub-assemblies into alignment. Along with these shims, simple bolted connections between sub-assemblies allow for a shorter carriage set up time at site. Procurement, manufacturing and construction of the carriage are all simplified by maximizing the use of standard commercial parts. Additionally, the selection of proven electric motors as the prime movers has led to a significant reduction in the number of mechanical parts required for the CANDU 9 carriage in comparison to the CANDU 6 carriage, largely due to the elimination of the carriage oil hydraulic system.

The reliability of the CANDU 9 carriage is expected to be improved over that of the CANDU 6 carriage. The structure is inherently robust, with all carriage components that support the fuelling machine being designed to accommodate loads resulting from a DBE. Given that the normal operating loads are, typically, an order of magnitude lower than seismic loads, the mechanical equipment of the carriage is expected to have considerable operating lifespan. In order to further improve the system reliability, a backup X drive is provided and a single Y drive unit can safely lower the elevator and fuelling machine head assembly. As well, one seismic brake and one ballscrew can support the entire suspended mass. Other features that enhance safety and reliability include an increased Z drive range for recovery purposes; if required, the full Z drive range will allow the recovery of a fuelling machine with a guide sleeve stuck in the snout, even with a crept pressure tube.

Maintenance activities, and the anticipated radiation dose expenditures attributable to these activities, were a significant consideration in the selection of a carriage system. The CANDU 9 480NU mobile carriage system allows for carriage maintenance to be carried out inside the shielded and environmentally isolated maintenance locks, rather than in more active locations such as the fuelling machine vaults. On–power maintenance of the carriage is possible, a feature that positively contributes to the station capacity factor as carriage maintenance does not require a reactor shutdown. Other improvements are obtained through ready access to carriage components and the use of bolted component connections. Bolted connections facilitate the removal of sub-assemblies that can then be taken to low activity locations for maintenance. For field work, strategically placed shielding for the fuelling machine head will be incorporated into the carriage structure so that fuelling machine head maintenance can be carried out with less dose commitment than in the previous CANDU designs. Finally, through the use of commercially available parts, carriage maintenance can be performed by less specialized work groups, thus enabling dose equalization programs to succeed.

6. SUMMARY

The CANDU 9 480NU fuelling machine carriage design represents a departure from the bridge system utilized in the successful CANDU 6 reactor design. The carriage concept is not new, however, as its origins can be traced to the earlier CANDU reactor designs such as that at Douglas Point Nuclear Generating Station.

The two wheel fuelling machine carriage design, described in the foregoing sections, meets the functional, performance, safety and constructability requirements of the CANDU 9 480NU project. The combination of a robust CANDU 9 carriage, fully integrated with the proven CANDU 6 fuelling machine head, has the capacity to support the station lifetime target capacity factor of 90%.

The carriage design has the potential to satisfy the requirements of future CANDU sites with higher than 0.2 g DBE levels. Other significant benefits include on-power maintenance access to both the carriage and the fuelling machine head, and the use of commercially available, standardized components. These features are intended to minimize dose expenditures and the costs associated with fuel handling system maintenance. In addition, a high degree of pre-assembly is planned in order to shorten in-situ construction and the commissioning time requirements.

The carriage system, as a pressure boundary component support, meets the requirements of the applicable CSA standards and ASME Code requirements. It is designed to be licensable in Canada, as well as other comparable international jurisdictions.

ACRONYMS

CANDU – Canada Deuterium Uranium

ASME – the American Society of Mechanical Engineers

CAN/CSA – Canada / Canadian Standards Association

DBE – Design Basis Earthquake

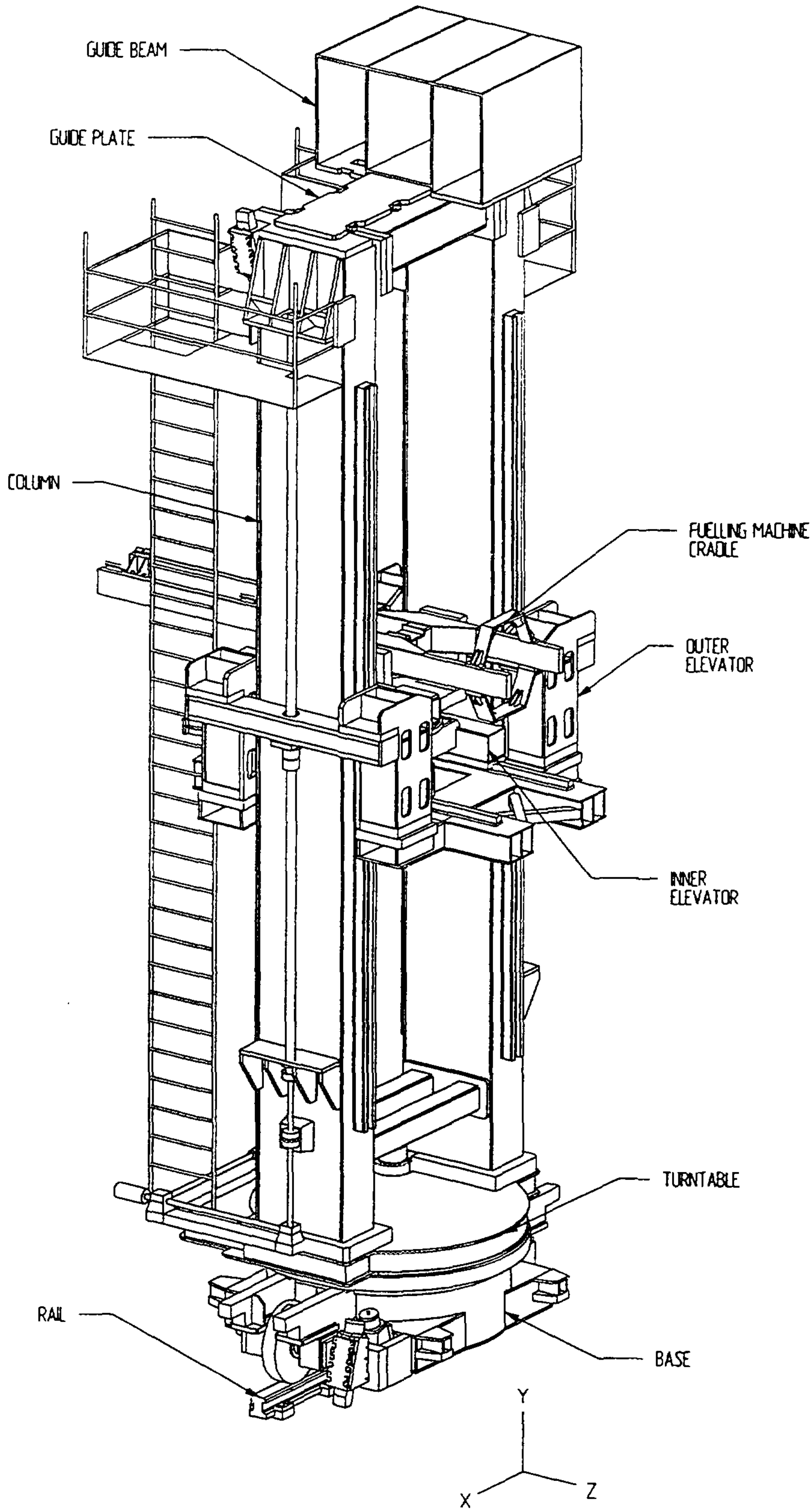


FIGURE I CARRIAGE GENERAL ARRANGEMENT

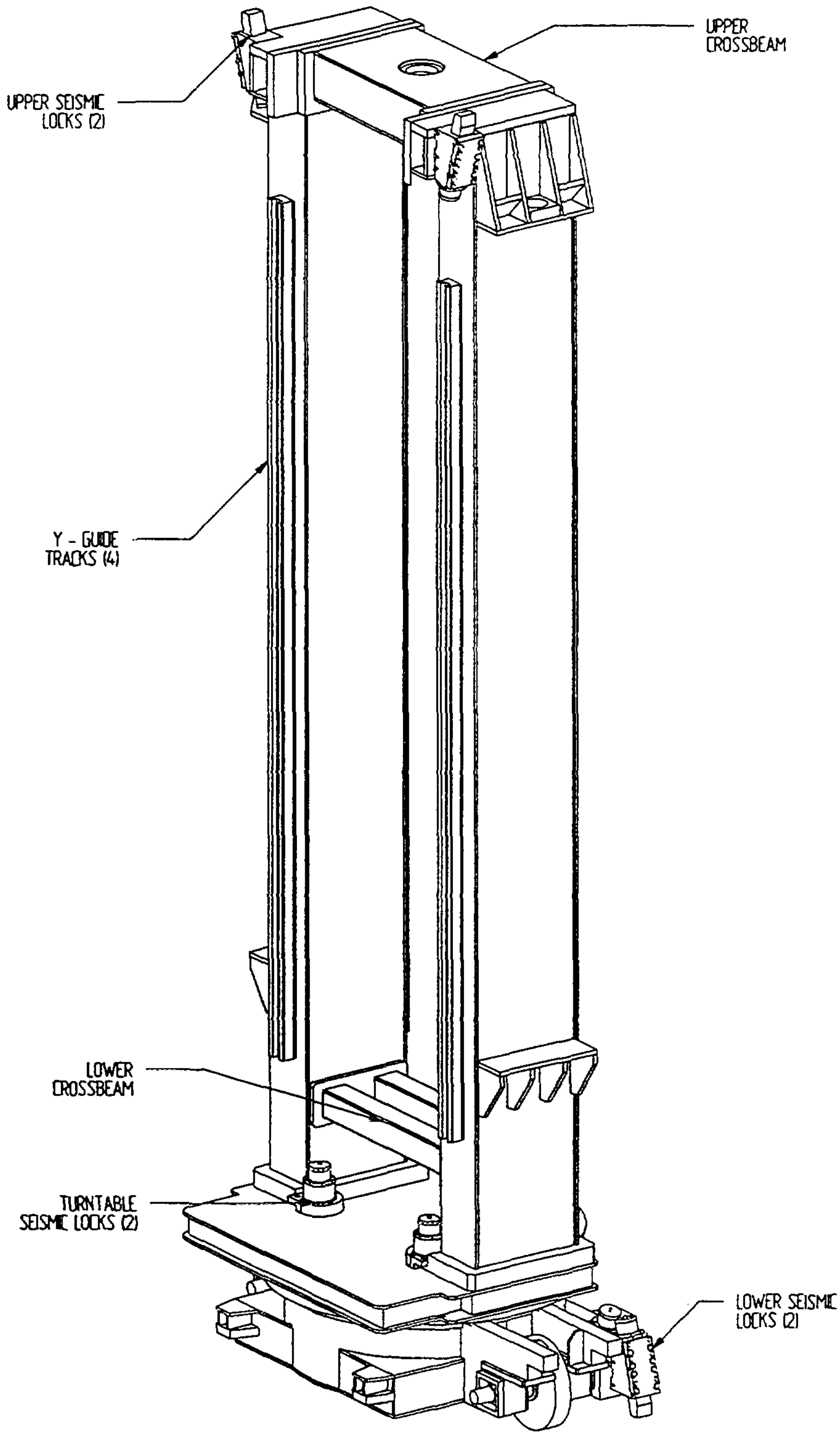


FIGURE 2 CARRIAGE COMPONENTS

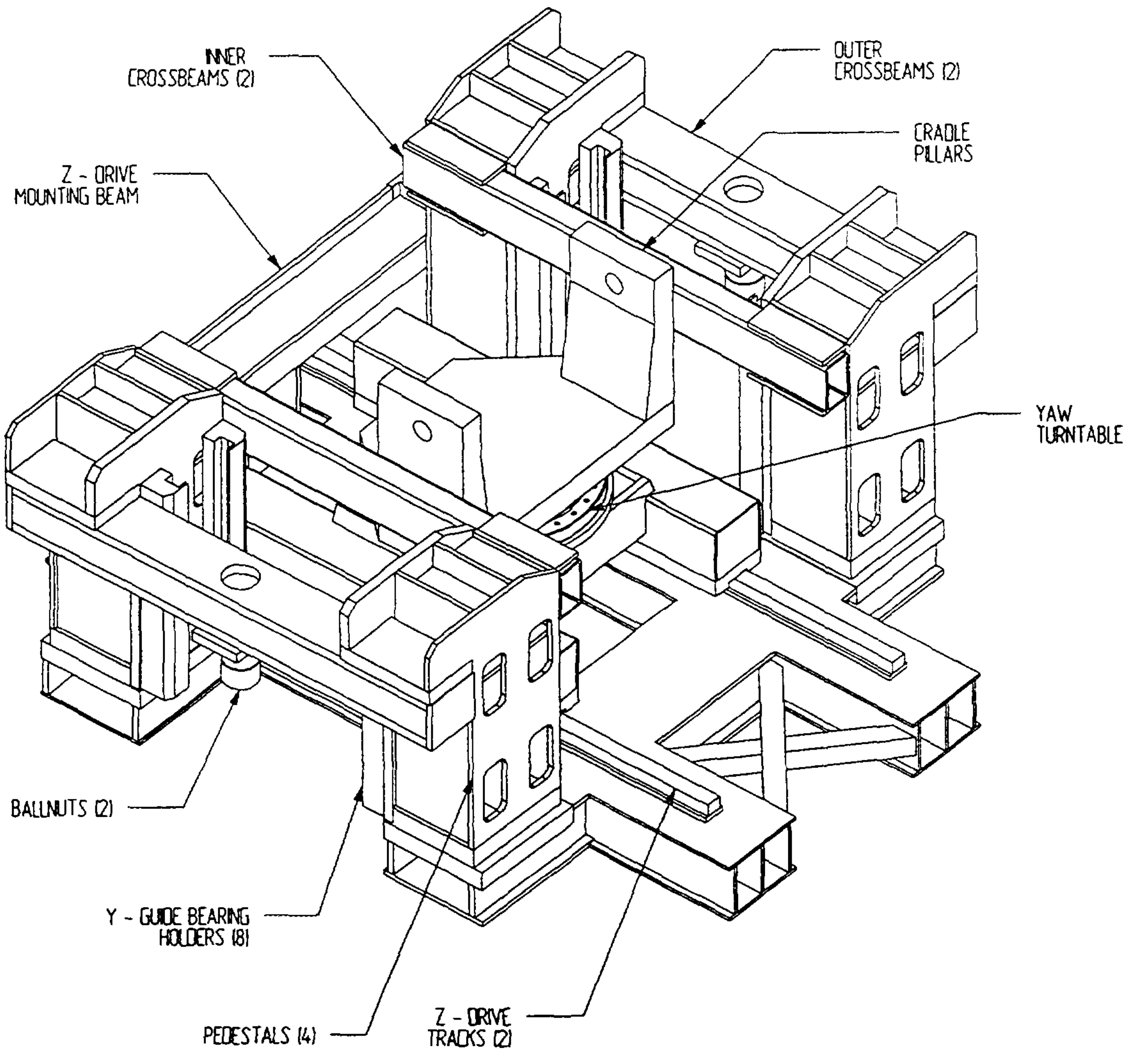
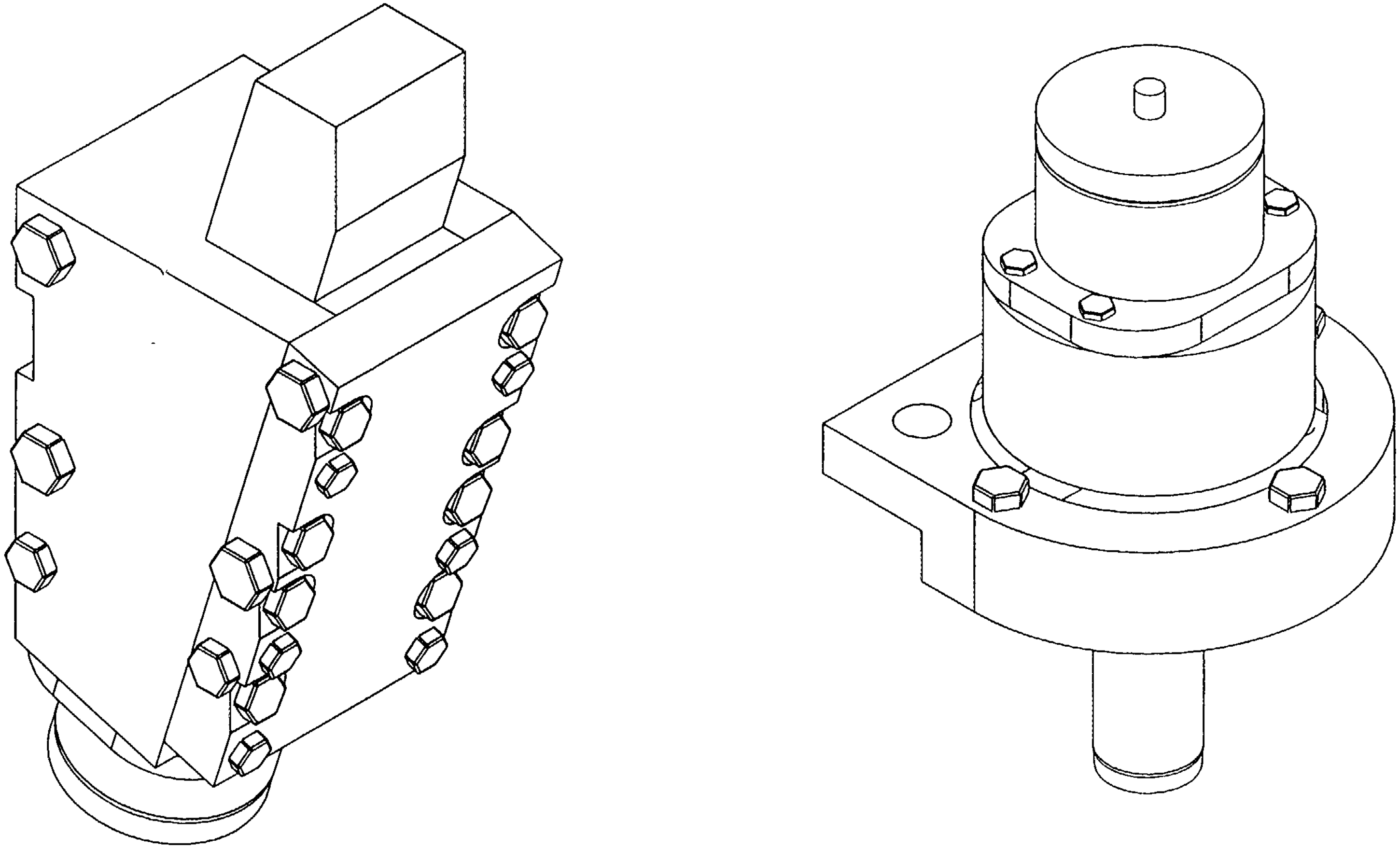


FIGURE 3 ELEVATOR COMPONENTS



WEDGE - STYLE
SEISMIC LOCK

PIN - STYLE
SEISMIC LOCK

FIGURE 4 SEISMIC LOCKING MECHANISMS

THE CANDU 9 FUEL TRANSFER SYSTEM

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ABSTRACT

The CANDU 9 fuel transfer system is based on the CANDU 6 and the Ontario Hydro Darlington NGD designs, modified to suit the CANDU 9 requirements. The CANDU 9 new fuel transfer system is very similar to the CANDU 6, with modifications to allow new fuel loading from outside containment, similar to Darlington. The CANDU 9 irradiated fuel transfer system is based on the Darlington irradiated fuel transfer system, with modifications to meet the more stringent containment requirements, improve performance, and match station layout.

1. INTRODUCTION

The CANDU system is based on on-power fuelling. An important aspect of the system is 'fuel transfer' which includes all the equipment and operations required to load new fuel into a fuelling machine for delivery to the reactor and later to transfer the irradiated fuel between a fuelling machine and the storage bay.

This paper describes an advanced fuel transfer system being designed for the CANDU 9.

CANDU 9 is the latest version of the Pressurized Heavy Water Reactor (PHWR) system developed in Canada by AECL. It has a net electrical output in the range of 870 MW.

The seemingly simple fuel transfer system must satisfy many stringent requirements. The basic ground rules for this equipment are safety and reliability. The equipment must be designed and built, for instance, in such a way that at no time will the operator be confronted with a situation which leaves him without any means for solving a break-down problem involving a stuck, uncooled fuel bundle in the irradiated fuel port.

The paper provides a brief description and illustration of the new and irradiated fuel transfer systems at both the CANDU 6 and Darlington stations. The paper continues with a more detailed description of the proposed CANDU 9 fuel transfer system which is being designed by a joint team of AECL and GE Canada designers.

2. DESCRIPTION OF NEW FUEL TRANSFER SYSTEMS

2.1 CANDU 6

In the CANDU 6 stations, new fuel is stored outside the reactor building and delivered into the reactor building when needed. Once in the reactor building, new fuel is loaded manually into the new fuel transfer mechanism. It is then transferred into the fuelling machine head under remote control from the main control room. (See Figure 1).

Two new fuel transfer mechanisms are provided; one to supply each fuelling machine head.

The new fuel transfer mechanisms are located in the reactor building, within containment, between the two fuelling machine locks.

The new fuel transfer mechanism consists of a loading trough and ram, a magazine and indexing drive, a single-stage transfer ram, and a port/magazine transition piece.

The magazine assembly consists of a housing and rotor, with capacity for 12 fuel bundles and the new fuel port shield plug. The magazine is indexed by an electric motor and a mechanical indexing unit.

An airlock gate valve is installed between the new fuel magazine and the loading trough to seal off the magazine whenever fuel is not being loaded into the magazine. This valve reduces the spread of contamination from the fuelling machine maintenance lock into the new fuel room. Contamination is also reduced through a duct connected to the vapour recovery system which maintains a slight negative pressure in the new fuel magazine.

The loading ram is an oil/air driven ram. The transfer ram is driven by an electric motor and chain drive.

The port/magazine adapter connects the magazine and the new fuel port. This assembly locks the new fuel port shield plug in place and releases the shield plug from the transfer ram when needed.

The new fuel ports are mounted in embedments in the maintenance lock walls. A shield plug is normally latched in the new fuel port to provide shielding for the new fuel room.

2.2 DARLINGTON

There are four new fuel transfer mechanisms in each of the two loading areas. These mechanisms are located directly above the irradiated fuel reception bay in the fuelling facilities auxiliary areas. (See Figure 2).

The new fuel port penetrates the containment wall between the new fuel loading area and the fuelling machine room. The containment integrity is maintained by two gate valves between the new fuel port and the magazine assembly. A third gate valve is located between the loading trough and the magazine and is interlocked with the other gate valves to prevent simultaneous opening. The magazine is maintained at a slightly negative pressure through an active vent to prevent any flow of tritium into the new fuel loading area.

The fuel bundles are transferred from the loading trough into the magazine by a ram, the force of which is restricted to limit the force applied to the bundles.

The fuel bundles are transferred from the magazine into a transporter located in the new fuel port and then into the fuelling machine head by a two-stage ram. The transporter is moved from the new fuel port into the head by one ram while the second ram transfers the bundles from the transporter into the fuel carriers in the fuelling machine head magazine.

2.3 CANDU 9

The CANDU 9 new fuel transfer mechanism is based on both the CANDU 6 and Darlington designs. The design permits new fuel to be loaded into the fuelling machine head from outside containment.

The CANDU 9 design uses the standard 37-element fuel bundle, but will also be able to accommodate the 43-element CANFLEX fuel bundles in the future. The fuel handling sequence for CANDU 9 is illustrated in Figure 4.

2.3.1 Description

Two new fuel transfer mechanisms are provided; one to supply each fuelling machine head.

The mechanisms, shown in Figure 5, are located outside containment in the reactor auxiliary building on either side of the airlock. New fuel is therefore loaded into the new fuel transfer mechanisms from outside the reactor building.

The new fuel transfer mechanism consists of a loading trough and ram, a magazine and indexing drive, a single-stage transfer ram, a port and two port containment valves.

The new fuel magazine, similar to the CANDU 6 magazine, consists of a completely enclosed steel housing with a rotor. As in CANDU 6, there are six fuel stations and a station for the port shield plug. The magazine rotor is driven from an electric motor through a pinion and bevel gear. Indexing is controlled by a mechanical cam and roller drive indexing unit.

The fuel loading ram consists of a stainless steel rack with a ram head assembly. The ram is driven by a pinion and brushless servo motor.

An airlock valve, installed between the new fuel magazine and the loading trough, seals off the magazine whenever fuel is not being loaded into the magazine. This valve reduces the spread of tritium through the new fuel magazine into the new fuel room and enables the transfer mechanism and fuelling machine head to be pressurized during fuel transfer to the fuelling machine head.

The transfer ram is similar to the new fuel loading ram and consists of a ram tube with a latching ram head and a stainless steel rack. The entire ram is contained in a housing with a seal at the magazine housing. The ram is driven by a pinion with a sealed shaft.

The new fuel port is similar to the CANDU 6 component. This assembly locks the new fuel port shield plug in place and releases the transfer ram from the shield plug when needed.

The shield plug is normally latched in the new fuel port and performs the same function as on CANDU 6.

The new fuel port is mounted in an embedment in the reactor building wall between the new fuel transfer room and the fuelling machine lock. Because the new fuel transfer mechanism is fixed to the reactor auxiliary building, and the ports to the reactor building, the transfer mechanism is designed to accommodate differential settlement and building shifts due to seismic events.

The port containment valves are located between the port and the magazine housing. These valves are normally closed to maintain the containment boundary.

2.3.2 Operation

New fuel pallets are delivered from the new fuel storage room to the airlock level, and from there to the new fuel transfer room.

The new fuel bundles are inspected before loading into the transfer mechanism. The fuel bundles are lifted from the pallet using a fuel bundle lifting tool, suspended from an air balance hoist and a monorail. The bundles are placed on an inspection table and checked for interlocked element spacers, using a gauge, and vacuumed/air blown if needed.

Two bundles are loaded into the loading trough and the trough lid is closed. The airlock valve is opened and the bundles are pushed into the magazine by the new fuel loading ram. The ram is retracted and the magazine is indexed to the next channel position and two more bundles are loaded. This is repeated until the magazine contains the required number of bundles.

During new fuel loading, the magazine is opened to the ventilation system to maintain air flow from the new fuel loading room into the magazine.

To transfer fuel from the new fuel transfer mechanism into the fuelling machine, the fuelling machine clamps onto the new fuel port in the fuelling machine lock, within containment in the reactor building. The water level in the fuelling machine is lowered and the fuelling machine prepares the port for fuel transfer by installing the guide sleeve.

The new fuel transfer mechanism and the fuelling machine head are pressurized and the two port containment valves are opened. During the remainder of the transfer sequence, the pressure in the transfer mechanism and port is controlled by the new fuel transfer mechanism auxiliaries.

Until the containment valves are opened, the port and containment valves are the containment boundary and rest of the new fuel transfer mechanism is outside containment. After the containment valves are opened, the fuelling machine head becomes the containment boundary. The pressure in the transfer mechanism and head allow containment integrity to be confirmed and monitored.

To meet the regulatory requirements, the new fuel port and containment valves are Class 2, and the remainder of the transfer mechanism is Class 6.

Fuel bundles are transferred from the transfer mechanism into the fuelling machine head by the transfer ram. The transfer ram first removes the port shield plug and stores it in the new fuel magazine. The ram then pushes the fuel bundles in pairs from the new fuel magazine into the fuelling machine head. This operation is controlled remotely from the fuel handling console in the main control room.

3. DESCRIPTION OF IRRADIATED FUEL TRANSFER SYSTEMS

A paper presented at an earlier conference (1) defined the major design requirements for irradiated fuel transfer systems.

3.1 CANDU 6

The CANDU 6 irradiated fuel handling system consists of discharge and transfer equipment in the reactor building, and irradiated fuel reception and storage bays and equipment in the service building. (See Figure 1).

Irradiated fuel is transferred from the fuelling machine head to the discharge bay in air. The fuelling machine clamps onto the irradiated fuel port, prepares the port for transfer, and lowers the water level in the head. The two ball valves on the irradiated fuel port are opened and bundle pairs are pushed by the fuelling machine ram through the port and onto an elevator.

The elevator lowers the bundles into the discharge bay onto a conveyor cart, then returns to the port to receive the next bundle pair. This is repeated until all fuel has been discharged from the fuelling machine. There is one discharge bay conveyor serving both fuelling machines. The discharge conveyor transfers the cart to the reception bay conveyor.

During irradiated fuel transfer from the fuelling machine head, the containment boundary is at a containment gate at the end of the discharge bay canal. Earlier CANDU 6 units were not equipped with a containment gate and rely on the fuelling machine auxiliaries and the head of water in the discharge canal for the containment boundary. At all other times, the port valves are closed.

After fuel reaches the reception bay, the fuel rack is removed from the conveyor cart and placed in the reception bay. Fuel bundles are transferred to the storage bay trays using manual tools. Once the trays are full (24 bundles/tray), they are transferred to the storage bay and placed on storage tray supports.

The storage bay trays are stacked 19 high and sets of four stacks are secured with a covering frame. This assembly is sealed with an IAEA device.

For interim dry storage, bundles are transferred from the trays to cylindrical baskets. The baskets are then placed in dry storage concrete canisters.

3.2 DARLINGTON

The major differences between the CANDU 6 and Darlington systems are as follows:

The CANDU 6 irradiated fuel transfer system is 'above water' meaning that the irradiated fuel port is located above the water level in the bay. Darlington uses an 'underwater' concept wherein the port is located below the bay water elevation. An air-filled transfer chamber ('air chamber') is used. The bundles are transferred from D_2O in the fuelling machine head, to the air chamber, and finally into H_2O in the bay. In a CANDU 6 storage bay, irradiated fuel is stored in single-layer trays. In Darlington, it is stored in multi-layer modules. This introduces an additional indexing operation.

A description of the Darlington system follows. Figure 3 illustrates the system features.

The irradiated fuel port penetrates the containment wall 4.4 m below the surface of the bay water. An underwater air chamber is attached to the port from the bay side. Flooding the air chamber with bay water provides emergency cooling in case a bundle becomes stuck in the port. Defected fuel in the underwater chamber can be identified by drawing air from the chamber through a detector ('dry sniffing').

Irradiated fuel is discharged from the fuelling machine onto a shuttle in the irradiated fuel port. The shuttle is retracted through the port into the air chamber where it is supported on a ladle. The ladle and shuttle are lowered to transfer the shuttle onto a vertically travelling elevator. The elevator is lowered to align the shuttle with a chosen tube of the module, and the fuel is pushed out of the shuttle into the module. Horizontal indexing of the module combined with vertical indexing of the elevator make it possible to fill all tubes in the module.

Accurate indexing of the module conveyor is obtained by a Geneva mechanism. A telescopic water hydraulic cylinder provides smooth motion of the shuttle through the port. Shuttle position detection is by ferromagnetic sensors. Underwater equipment is driven, as far as possible, from above water by motorized drives. All motorized equipment has the capability of being driven manually.

The initial concept for handling defected fuel at Darlington was to separate defected fuel from sound fuel and, after inspection in the reception bay, place it in cans. Later experience indicated that the isolation of defected fuel in cans and containers was not necessary. A decision was made to place defected fuel directly into modules, with provisions for later removal of defected fuel from the modules for inspection.

3.3 CANDU 9

The fuel handling sequence for CANDU 9 is illustrated in Figure 4. The system minimizes the fuelling machine refuelling cycle time. This is achieved by temporarily storing the irradiated fuel in the port. Loading of the fuel into the storage bay takes place later, after the fuelling machine departs from the irradiated fuel port.

3.3.1 Description

The irradiated fuel transfer system, shown in Figure 6, is located primarily in the reactor auxiliary building. It consists of:

a) An irradiated fuel port mounted in the reactor building containment wall.
b) Two port containment valves.
c) A flexible port/magazine transition piece.
d) A totally enclosed irradiated fuel magazine and its drive assembly which is located in the storage bay

wall within the reactor auxiliary building.
e) An irradiated fuel transfer ram and drive.
f) A bay valve.
g) Associated air and water auxiliary systems.
h) Storage bay equipment which includes the indexing tray, storage ram, bundle tilter, 'basket modules', stacking frames and handling tools.

A paper published earlier (2) describes the 'basket module' and future considerations for the dry storage of CANDU fuel.

The irradiated fuel port assembly conforms to Class 2, Class 4 and Class 6 as appropriate. It has the flexibility and strength requirements to permit the homing and locking of the fuelling machine and to withstand high seismic loads. The port is sloped down towards the port magazine. D_2O carried from the head on the fuel bundles is collected to prevent its loss to the bay.

The irradiated fuel transfer mechanism spans two separate buildings; the reactor building and the reactor auxiliary building. These two buildings can move independently of one another under settlement and seismic actions.

The fuelling machine unloads irradiated fuel through its associated port which leads to one of the irradiated fuel storage bays located outside the reactor building containment wall. Each face of the reactor has one storage bay dedicated to it. The two storage bays are not interconnected.

The port/magazine transition piece provides the required flexibility between the buildings to allow these movements to be accommodated without loss of containment. This is achieved using two specially designed ball joints to accommodate the vertical, horizontal and axial displacements. The transition piece has a D_2O recovery circuit to recover D_2O vapour that evaporates or boils off the fuel bundle surface during fuel transfer in air. This D_2O recovery loop also contains provisions for 'dry sniffing' to detect defected fuel as it passes through the transition piece.

The irradiated fuel magazine (or port magazine) is located in a sleeve in the storage bay wall within the reactor auxiliary building. The end plate of the magazine housing is removable to enable maintenance to be carried out on the rotor assembly. Mounted on the end plate are the transition piece, the magazine drive assembly, the irradiated fuel transfer ram, and cooling water connections. The heat generated by the irradiated fuel bundles within the magazine is removed through a heat exchanger fitted internally in the magazine housing.

The magazine rotor consists of a stationary shaft, two end plates and six magazine channels. There are seven channel positions with one position used during maintenance only. This position is fitted with a hinged blanking plate to allow space for special tools (e.g. cleaning tools). The capacity of the magazine rotor is therefore six pairs of fuel bundles.

The CANDU 9 irradiated fuel transfer system is being designed to accommodate emergency recovery for all foreseeable failure scenarios in a manner that minimizes radiation and conventional risk to station staff, the public and the environment.

3.3.2 Operation

To prepare for fuel transfer, a pump is started to establish water circulation flow through the port magazine. The water flows over a weir for level control in the magazine. The irradiated fuel magazine and transition piece are pressurized with air. The fuelling machine homes and locks onto the irradiated fuel port and is pressurized. The two port containment valves are then opened and the port air pressure system regulates the pressure in both the port and the head.

The fuelling machine magazine channel, containing the fuel bundles to be transferred, is aligned with the port. The rams of the fuelling machine are used to push the irradiated fuel from the fuelling machine magazine into the port magazine, two bundles at a time. The rams are then retracted into the fuelling machine and both magazines index to the next position. This procedure is repeated until all the fuel has been transferred.

The irradiated fuel transfer takes place in air from the time that the fuelling machine magazine is indexed to align the fuel for transfer until the port magazine is indexed from the load position and the fuel is submerged below the water level in the port magazine. Fuel is then cooled in the circulating water in the magazine.

The control systems associated with the design ensure that the proper sequencing of the operation is achieved. Once the fuel transfer is complete, the two port containment valves are closed. The port is then flooded. In an emergency, the port and magazine can be flooded from a dump tank by gravity.

Irradiated fuel is now transferred from the port magazine to the storage bay by opening the bay valve. This operation equalizes the pressure in the port with the bay pressure. The bundles are pushed by the transfer ram, two at a time, from the magazine onto an indexing tray as it is moved automatically across the face of the irradiated fuel port. The tray has six positions for fuel bundles. Upon completion of transfer, the bay valve is closed.

A storage ram is then used to push the bundles, one at a time, into a bundle tilter designed to rotate the bundle into the vertical position. The tilter restrains the bundle during this operation and is fitted with a shock absorber to reduce impact on the bundle during tilting. A tool supported from the manbridge is used to transfer the irradiated fuel bundles from the tilter to the 'basket module'.

4. CONCLUSION

Major features of the CANDU 9 irradiated fuel transfer system design include commonality of equipment between the new fuel and irradiated fuel mechanisms and reuse or adaptation of technology used and proven at other CANDU plants. The transfer system design provides adaptability to a wide range of site conditions, low capital cost, short construction schedule, minimum system complexity, high system availability, low operating and maintenance cost, and a generic approach where many of the features can be applied to future CANDU designs.

ACKNOWLEDGMENTS

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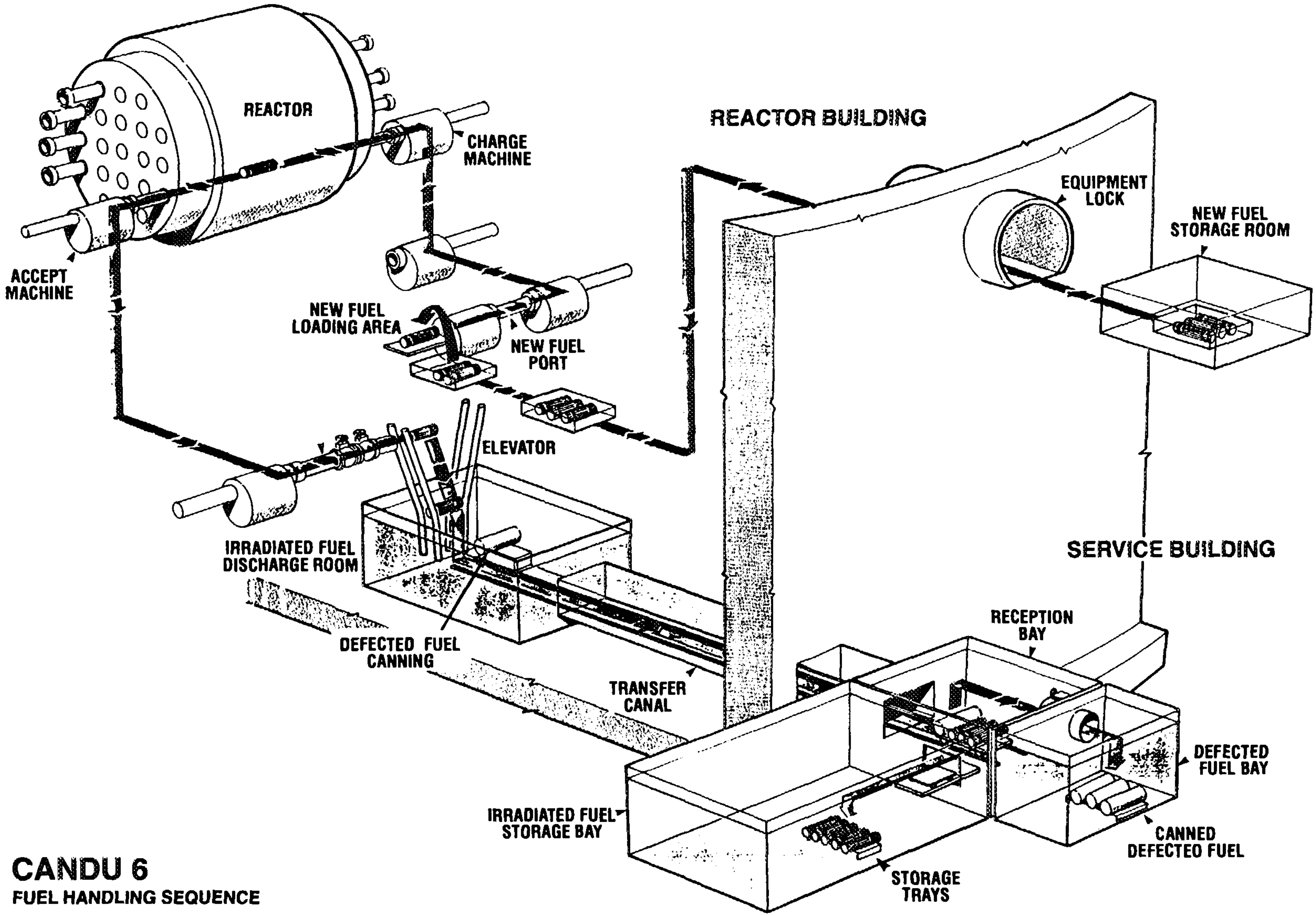
(2) NAKAGAWA R.K., "Standardized Approach to the Design of CANDU Used Fuel Receptacles", A Paper Presented at the Third International Conference on CANDU Fuel, Chalk River, Ontario, Canada, 1992 October 4-8.



CANDU 6
FUEL HANDLING SEQUENCE

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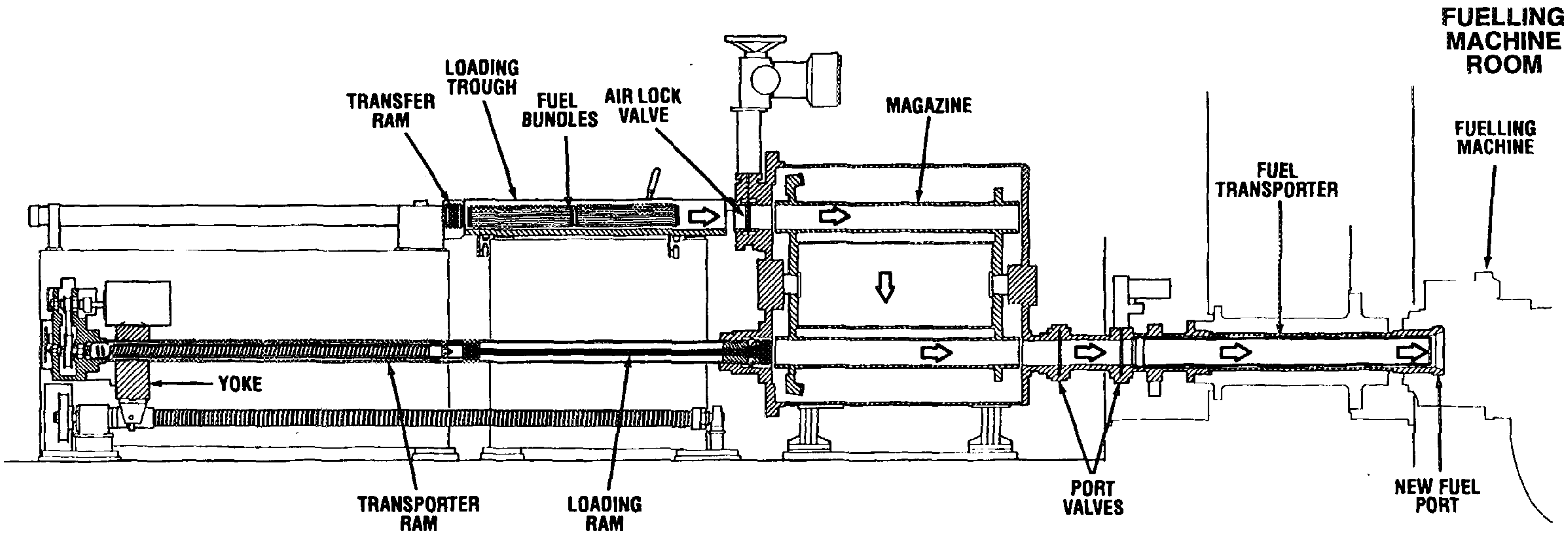
FIGURE 1

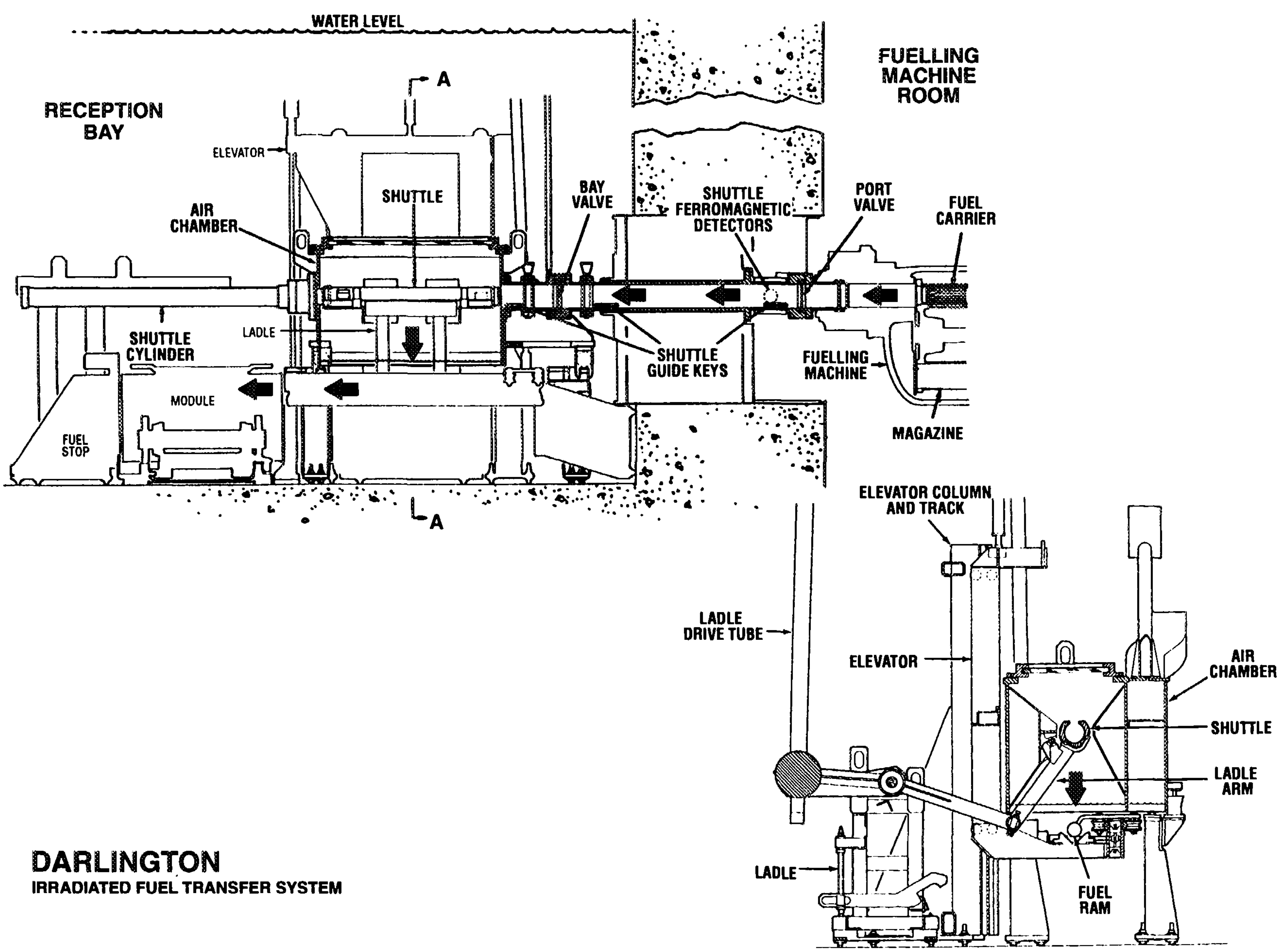


DARLINGTON

NEW FUEL TRANSFER SYSTEM

CG

FIGURE 2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FUELLING MACHINE ROOM
A
RECEPTION BAY
ELEVATOR
SHUTTLE
AIR CHAMBER
BAY VALVE
SHUTTLE FERROMAGNETIC DETECTORS
PORT VALVE
FUEL CARRIER
LADLE
SHUTTLE CYLINDER
SHUTTLE GUIDE KEYS
FUELLING MACHINE
MODULE
FUEL STOP
MAGAZINE
A
ELEVATOR COLUMN AND TRACK
LADLE DRIVE TUBE
ELEVATOR
AIR CHAMBER
SHUTTLE
LADLE ARM
LADLE
FUEL RAM
DARLINGTON
IRRADIATED FUEL TRANSFER SYSTEM
CG
SECTION A-A

FIGURE 3

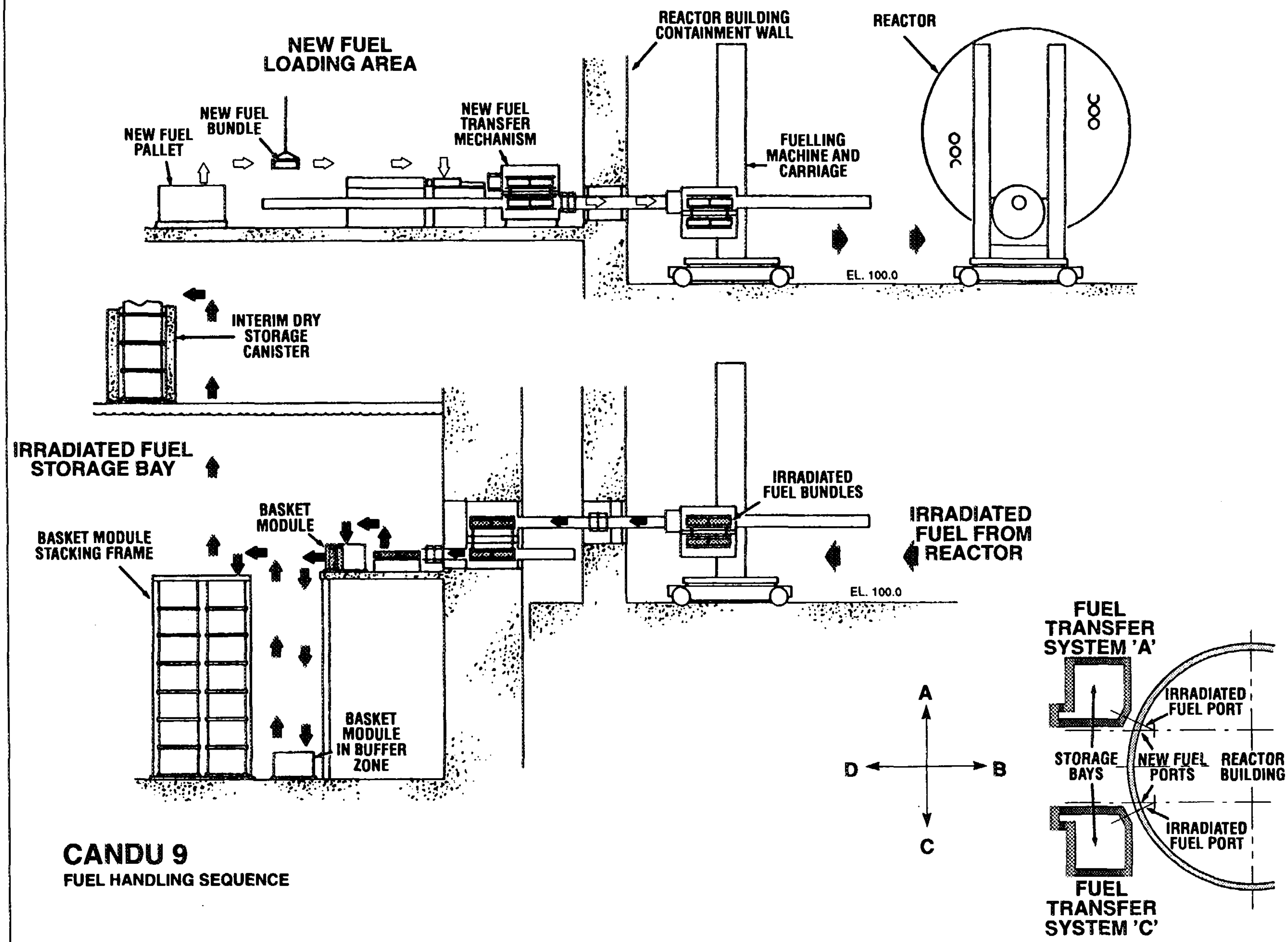

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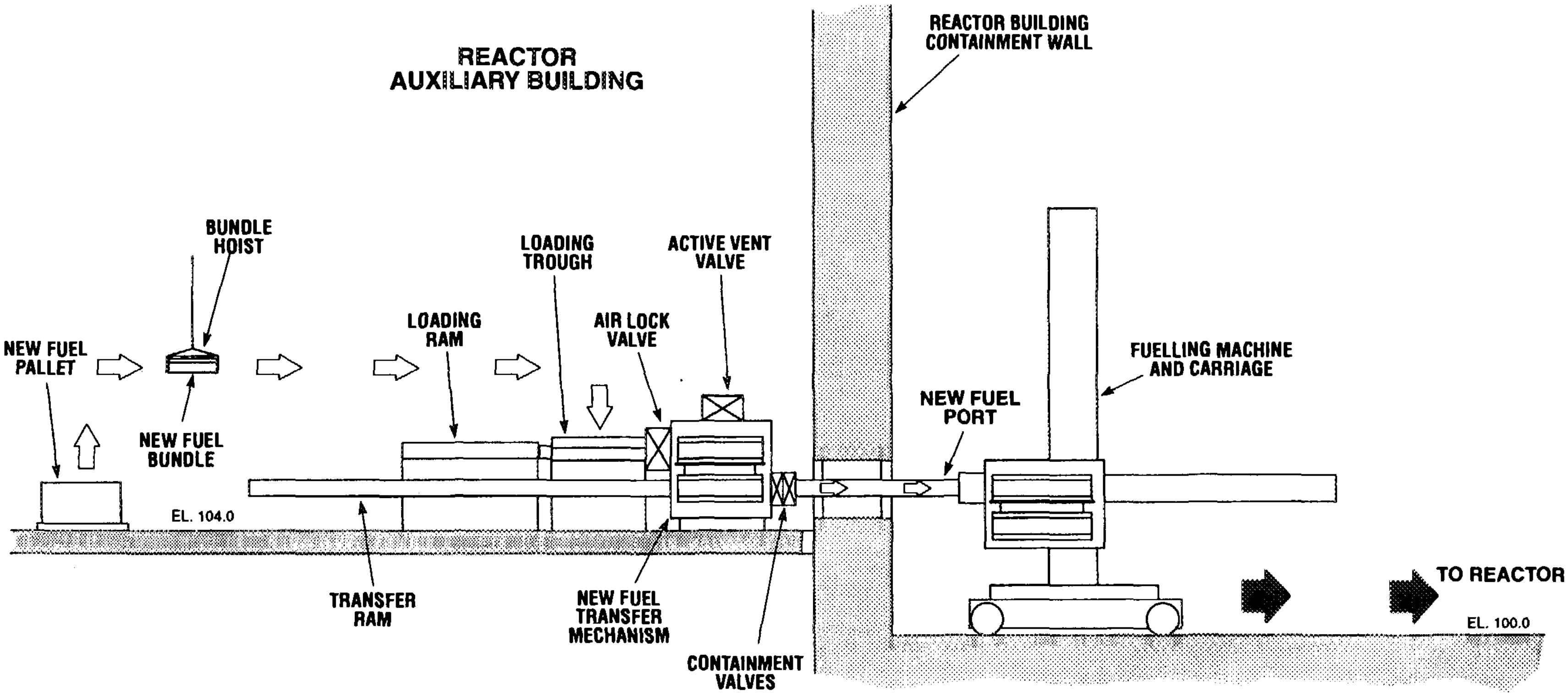
FIGURE 4

TWO BAY LAYOUT



CANDU 9
NEW FUEL TRANSFER SYSTEM

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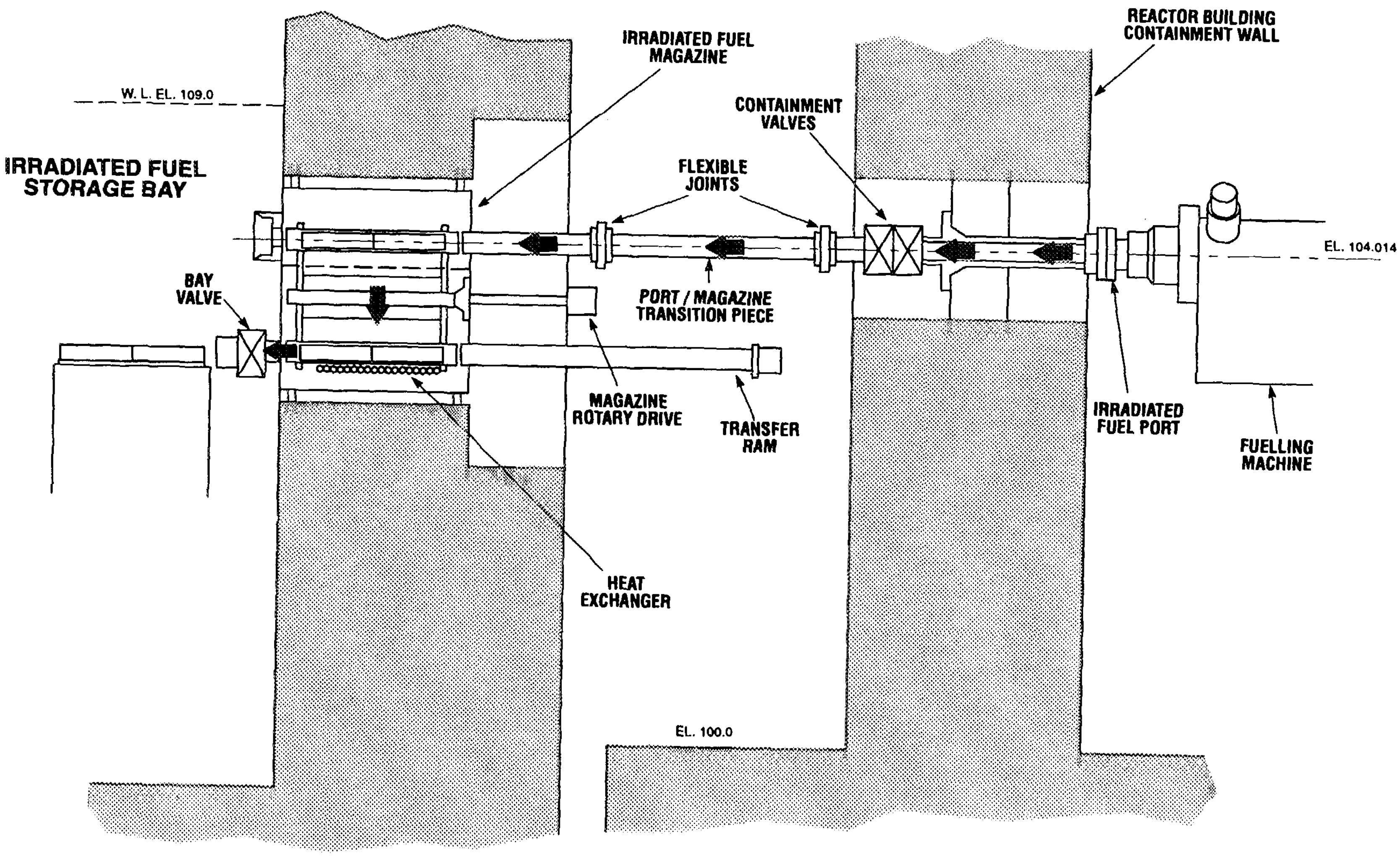
FIGURE 5



CANDU 9

IRRADIATED FUEL TRANSFER SYSTEM

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FIGURE 6