

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.

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.

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

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 D₂O in the fuelling machine head, to the air chamber, and finally into H₂O 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. D₂O 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 D₂O recovery circuit to recover D₂O vapour that evaporates or boils off the fuel bundle surface during fuel transfer in

air. This D₂O 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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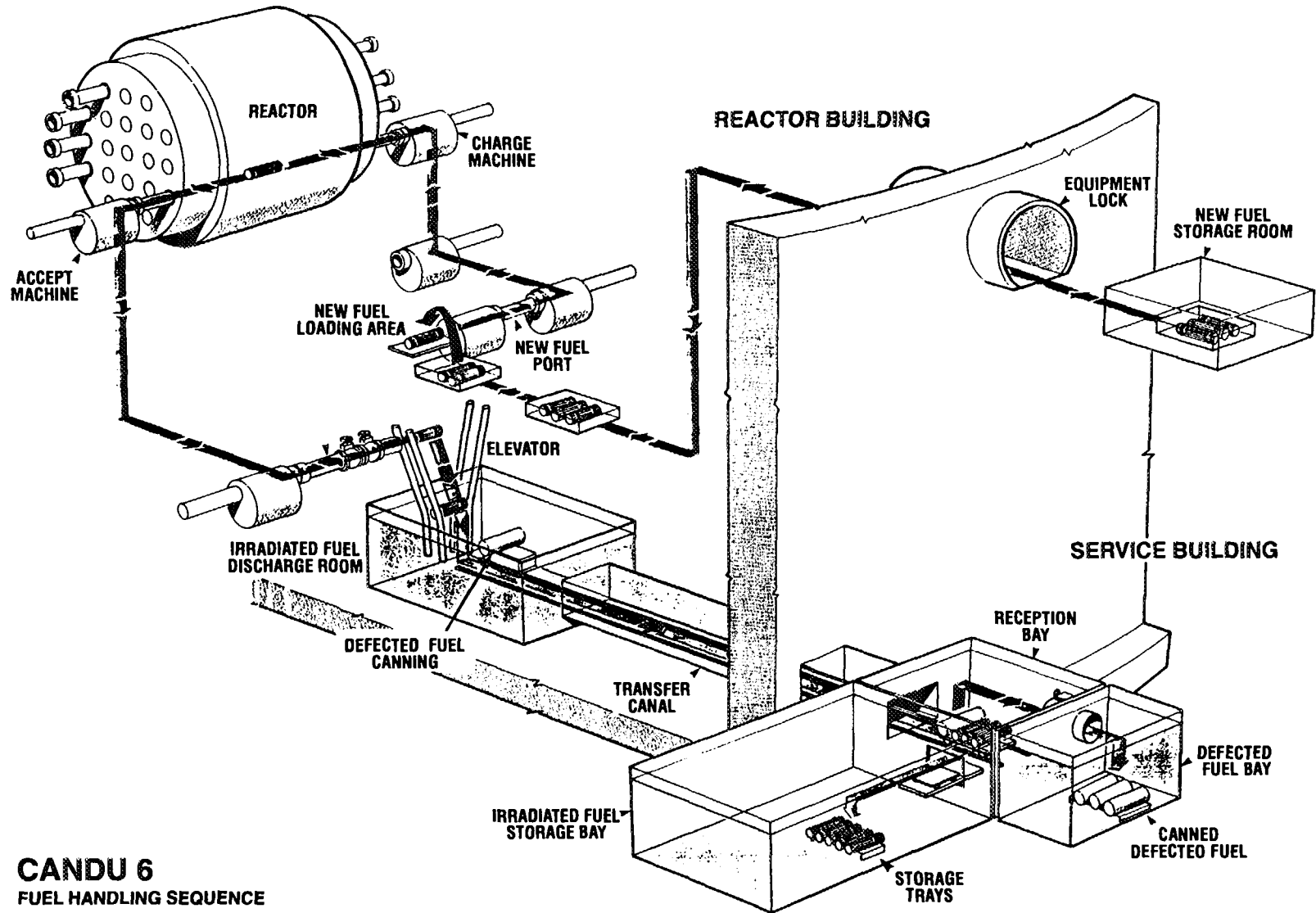
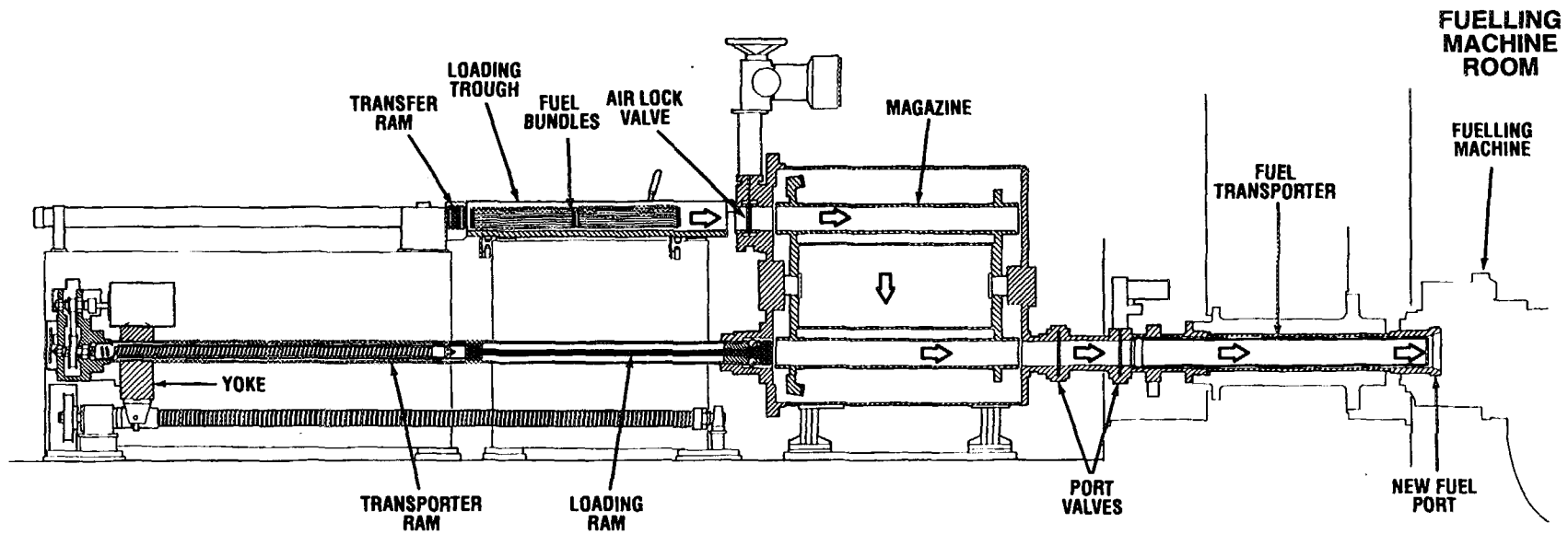
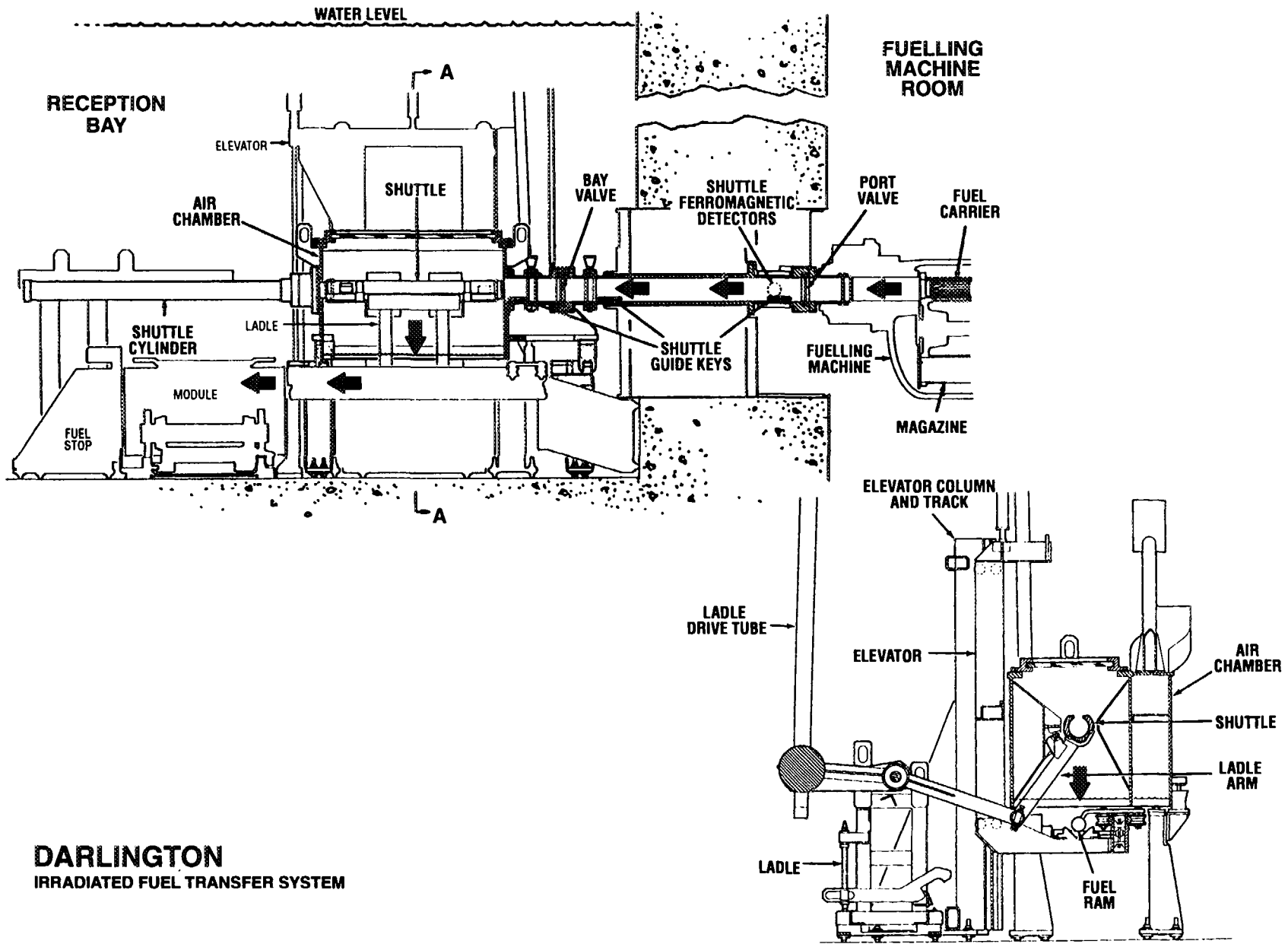


FIGURE 1



DARLINGTON
NEW FUEL TRANSFER SYSTEM

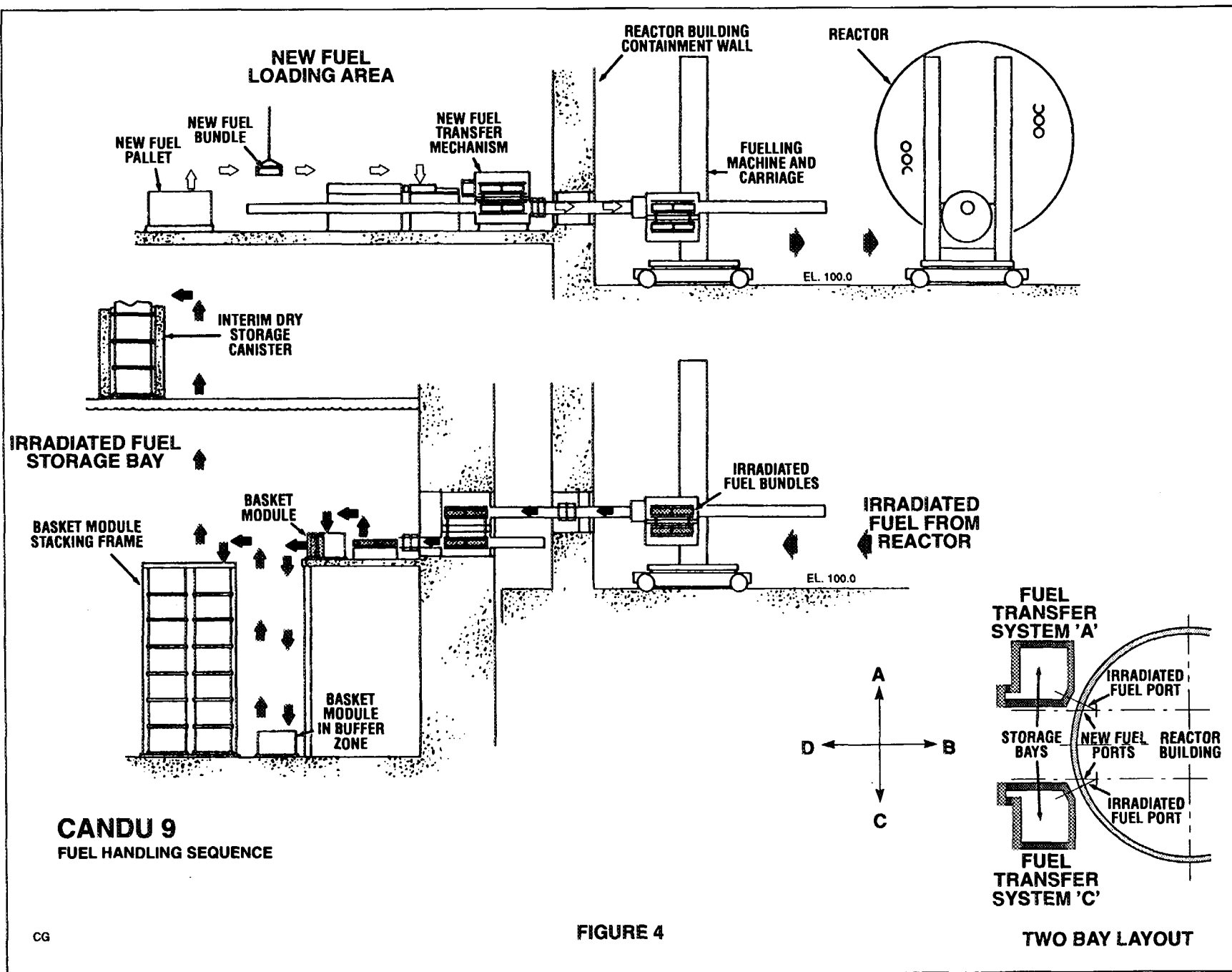
FIGURE 2

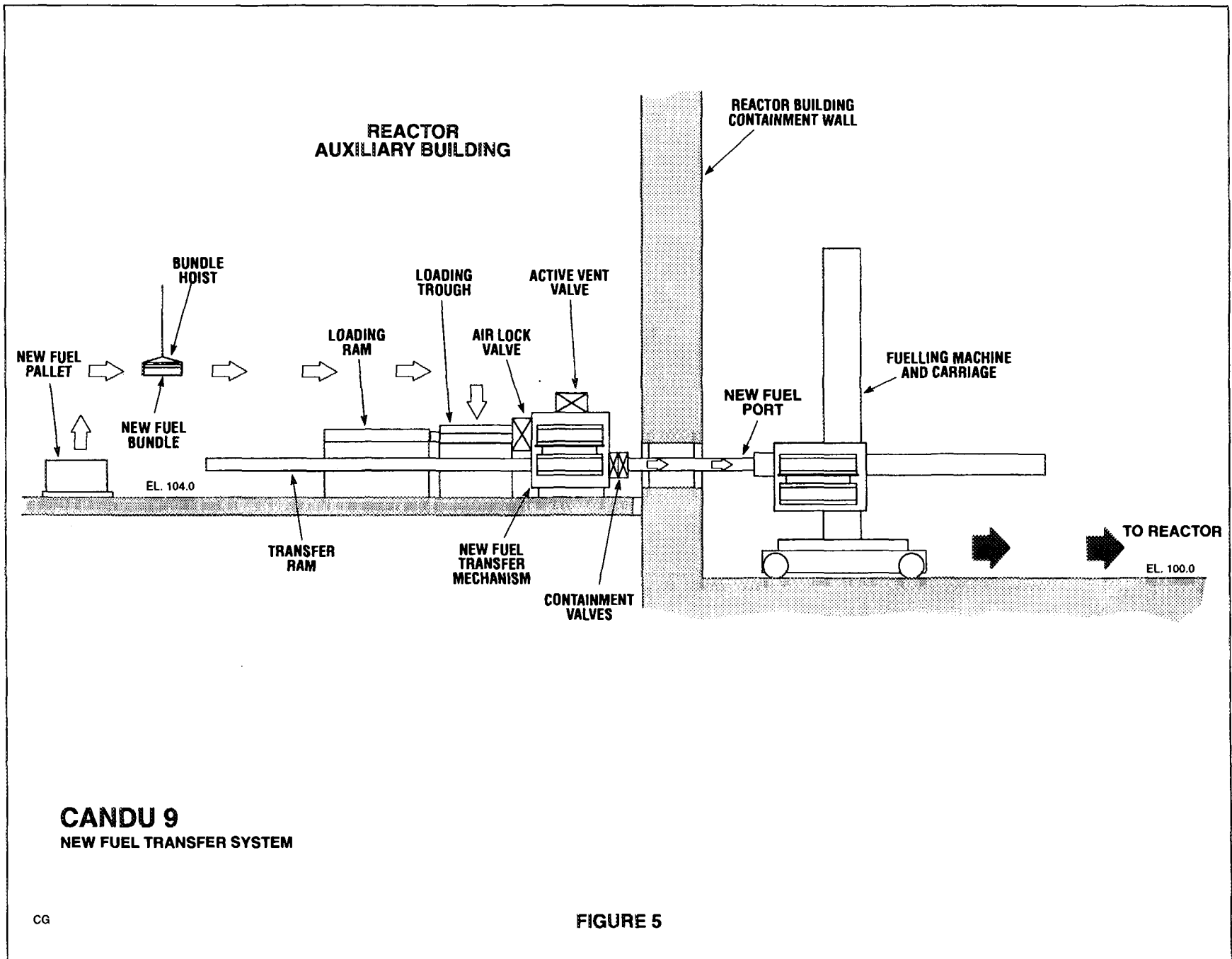


DARLINGTON
IRRADIATED FUEL TRANSFER SYSTEM

FIGURE 3

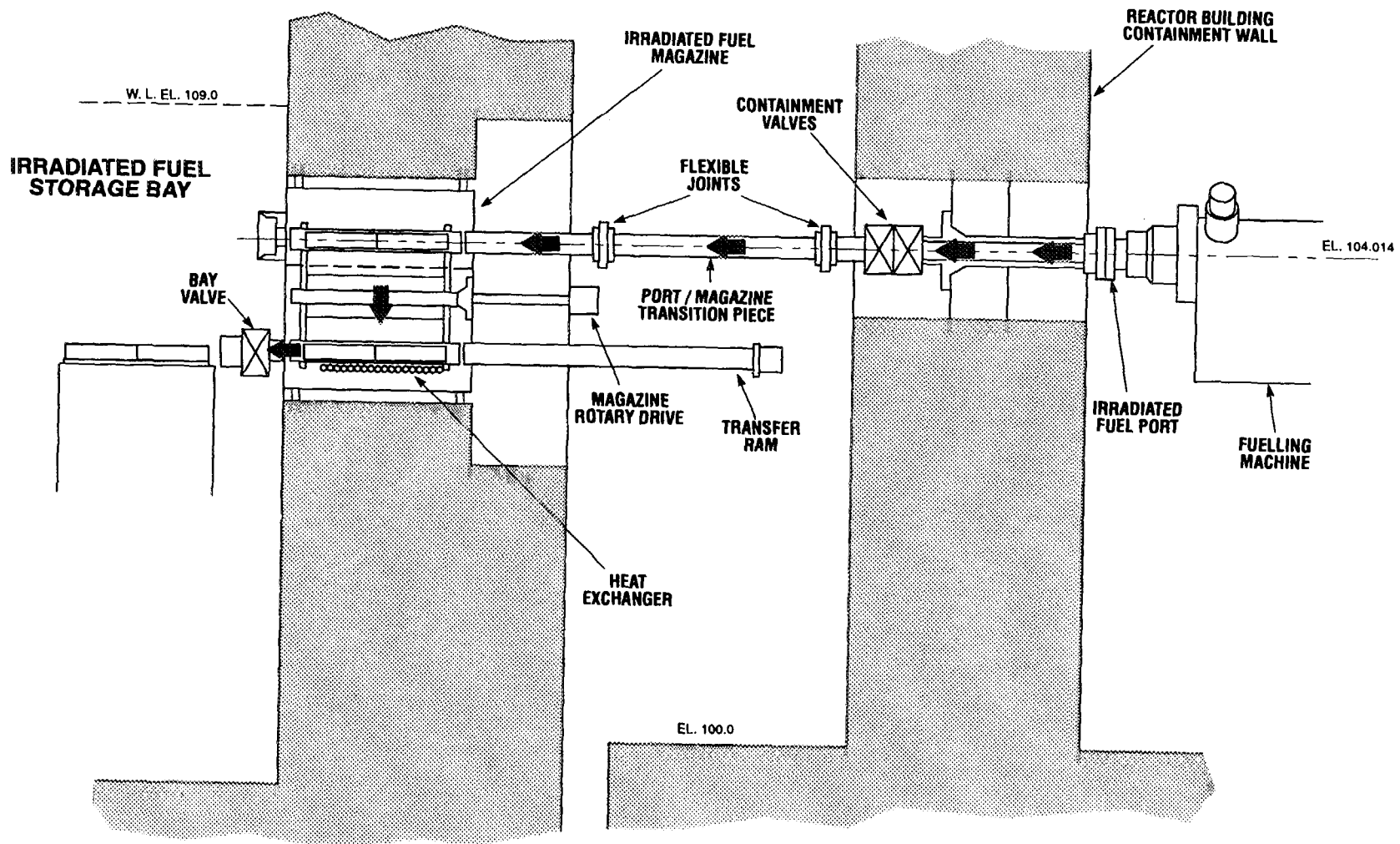
SECTION A-A





CANDU 9
NEW FUEL TRANSFER SYSTEM

FIGURE 5



CANDU 9
IRRADIATED FUEL TRANSFER SYSTEM

FIGURE 6

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