CHAPTER 20

Fuel Handling and Storage

prepared by

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Summary:

CANDU® reactors are fuelled on a somewhat continuous basis while on-power. This fuelling capability is mainly performed by two remotely operated fuelling machines. CANDU®[1] 6 fuelling machines are part of the fuel handling and storage system, which is divided into three main sub-systems. New fuel transfer and storage involves the receipt, handling and storage of palletized crates of unirradiated, or new, fuel, the inspection and handling of individual new fuel bundles and the transfer of this fuel into a fuelling machine via a new fuel port. Fuel changing involves a pair of fuelling machines transporting new fuel from a new fuel port to the reactor face, loading and unloading fuel from a reactor fuel channel and transporting discharged irradiated fuel from the reactor face to a spent fuel port. Spent fuel transfer and storage involves the discharge of irradiated fuel from a fuelling machine and the transfer and storage of this irradiated fuel in water-filled bays until the fuel is transferred to dry storage.

Table of Contents

1 CANDU® (CANada Deuterium Uranium) is a registered trademark of Atomic Energy of Canada Limited (AECL) used under exclusive licence by Candu Energy Inc.

List of Figures

1 Introduction

1.1 Overview

This chapter provides an overview of a typical CANDU 6 fuel handling and storage system handling natural uranium fuel. It does not address the potential use and handling of alternative fuels. Although the fuel handling and storage systems of different CANDU 6 stations are almost identical to each other, there are some differences resulting from evolution over time. As a result, some of the equipment described herein, may not be applicable to all CANDU 6 stations. Although this chapter does not address the fuel handling and storage system of CANDU stations other than CANDU 6, the equipment and processes described herein share many similarities with their equipment and processes.

This chapter explains how the fuel handling and storage system is divided into three main sub-systems: new fuel transfer and storage, fuel changing and spent fuel transfer and storage. It discusses the structures, equipment and purpose for each sub-system, and provides descriptions of major components and system processes.

Section 3 covers the new fuel transfer and storage system, Section 0 covers the fuel changing system and Section 5 covers the spent fuel transfer and storage system.

1.2 Learning Outcomes

The principal learning objectives of this chapter are to gain a general understanding of the following aspects of a typical CANDU 6 fuel handling and storage system:

- The purpose of this system and that of its three main sub-systems: new fuel transfer and storage, fuel changing and spent fuel transfer and storage;
- The main structures and equipment of these sub-systems;
- The operation of these sub-systems.

2 Fuel Handling and Storage System Overview

The purpose of the fuel handling and storage system, depicted in Figure 1, is to provide on-power fuelling capability at a rate sufficient to maintain continuous reactor operation at full power. While fulfilling its purpose, the fuel handling and storage system is also required to maintain all fuel sub-critical outside the reactor core and in conditions preventing fuel damage and contamination by foreign materials. Refer to Chapter 8 for information on the main components of a CANDU nuclear power plant and Chapter 9 for information on the operating concepts of a CANDU nuclear power plant.

The main equipment necessary to achieve on-power refuelling capability, together with associated services and controls, includes:

- New fuel transfer and storage;
- Fuel changing; and
- Spent fuel transfer and storage.

On-power refuelling, which involves replacing discrete amounts of fuel in the core as required while the reactor is operating, is a major contributor to the high capacity factor of existing CANDU reactors. Other advantages of on-power refuelling include the following:

- Optimized burnup of natural uranium fuel and, therefore, lower fuelling costs.
- Low excess reactivity available, which reduces the requirement for reactivity control during operation.
- Flexibility to plan scheduled shutdown activities that do not have to include fuelling operations.
- Low levels of fission products in the heat transport system, by early detection and removal of failed fuel bundles.

The sequence of movements for typical fuel handling and storage operations is illustrated in Figure 2. The average equilibrium fuelling rate in the CANDU 6 reactor at full power is approximately 112 fuel bundles per week.

New fuel transfer and storage, described in Section 3, involves new, or unirradiated, fuel being received and stored in the new fuel storage room in the service building. New fuel is transferred to the new fuel loading room in the reactor building as required. There, fuel is loaded into one of two new fuel transfer mechanisms for transfer into one of the fuelling machines via the new fuel ports.

Fuel changing, described in Section 0, involves new fuel being received by a fuelling machine via one of the new fuel ports, fuelling machines travelling to the reactor face, new fuel being inserted into and irradiated fuel being removed from one of the 380 fuel channels by the fuelling machines, fuelling machines travelling from the reactor face, and irradiated fuel being discharged via one of the spent fuel ports.

Spent fuel transfer and storage, described in Section 5, involves irradiated fuel being received from fuelling machines via spent fuel ports and placed in water-filled fuel storage bays.

The fuelling machines, the new fuel transfer equipment and the spent fuel discharge equipment are normally operated remotely and automatically from the fuel handling control console in the control room. The automatic control system for the fuel handling and storage system uses one of the station computer-controllers and includes the fuel handling control console in the Main Control Room and local control panels specific to the fuel handling system.

Personnel are normally only required to enter the reactor building to load new fuel and to maintain the fuel handling system components. . Regular and frequent maintenance of fuel handling equipment, particularly the fuelling machines, is required to prevent or minimize unexpected breakdown of fuel handling equipment and to maintain or achieve station target capacity factors. Breakdown of fuel handling equipment at the reactor face and/or while manipulating irradiated fuel is particularly undesirable and problematic due to very high radiation fields.

The term ‘irradiated fuel’, which is common in the industry and is more precise, is used when referring to the fuel itself; however, the term 'spent fuel' is used when referring to applicable fuel handling subsystems and components per traditional fuel handling naming conventions for these subsystems. Refer to Chapter 17, for information about the fuel.

Note that the figures provided are for illustrative purposes only. Actual fuel handling and storage equipment may vary in appearance.

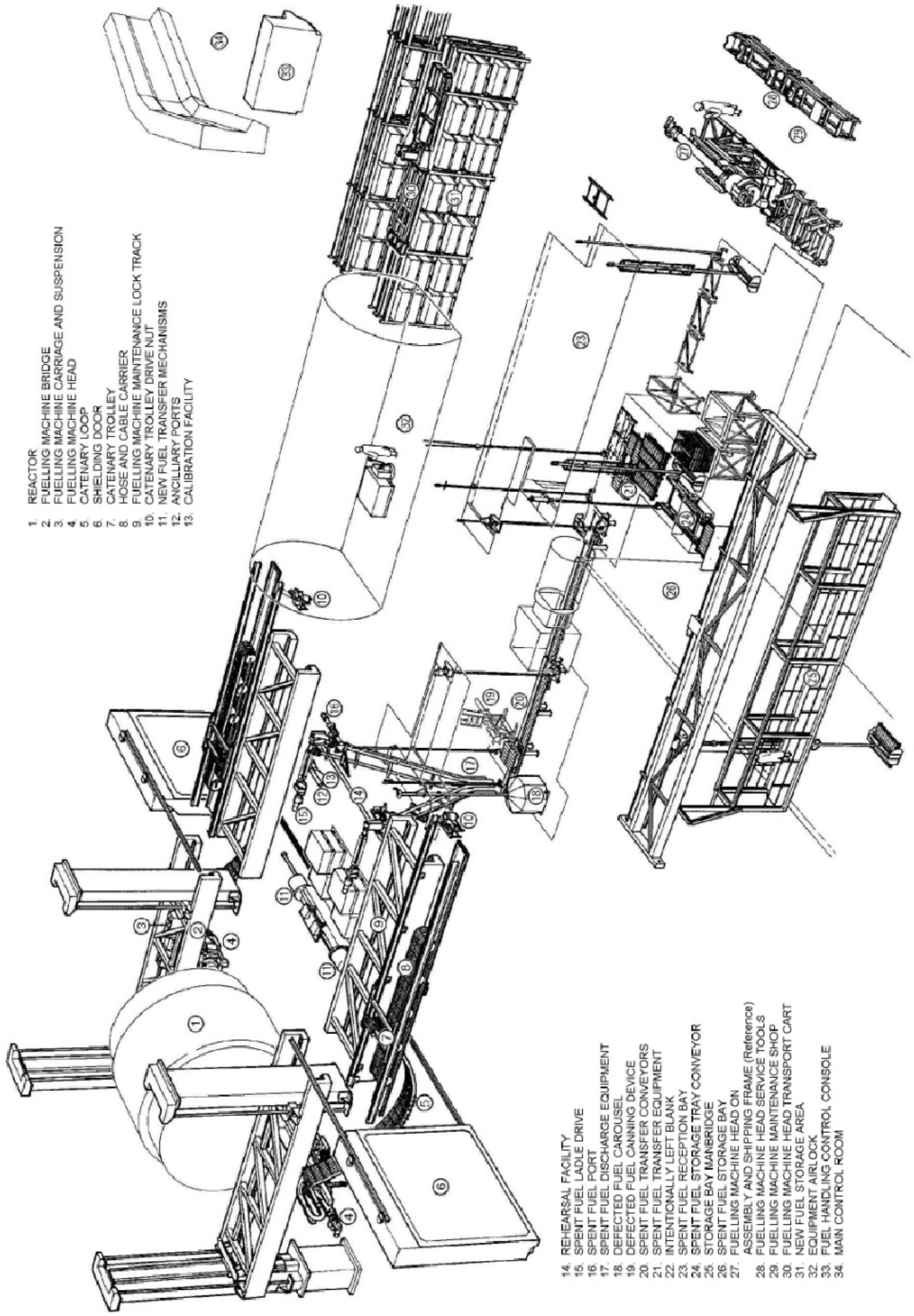

Figure 1 Fuel handling and storage system

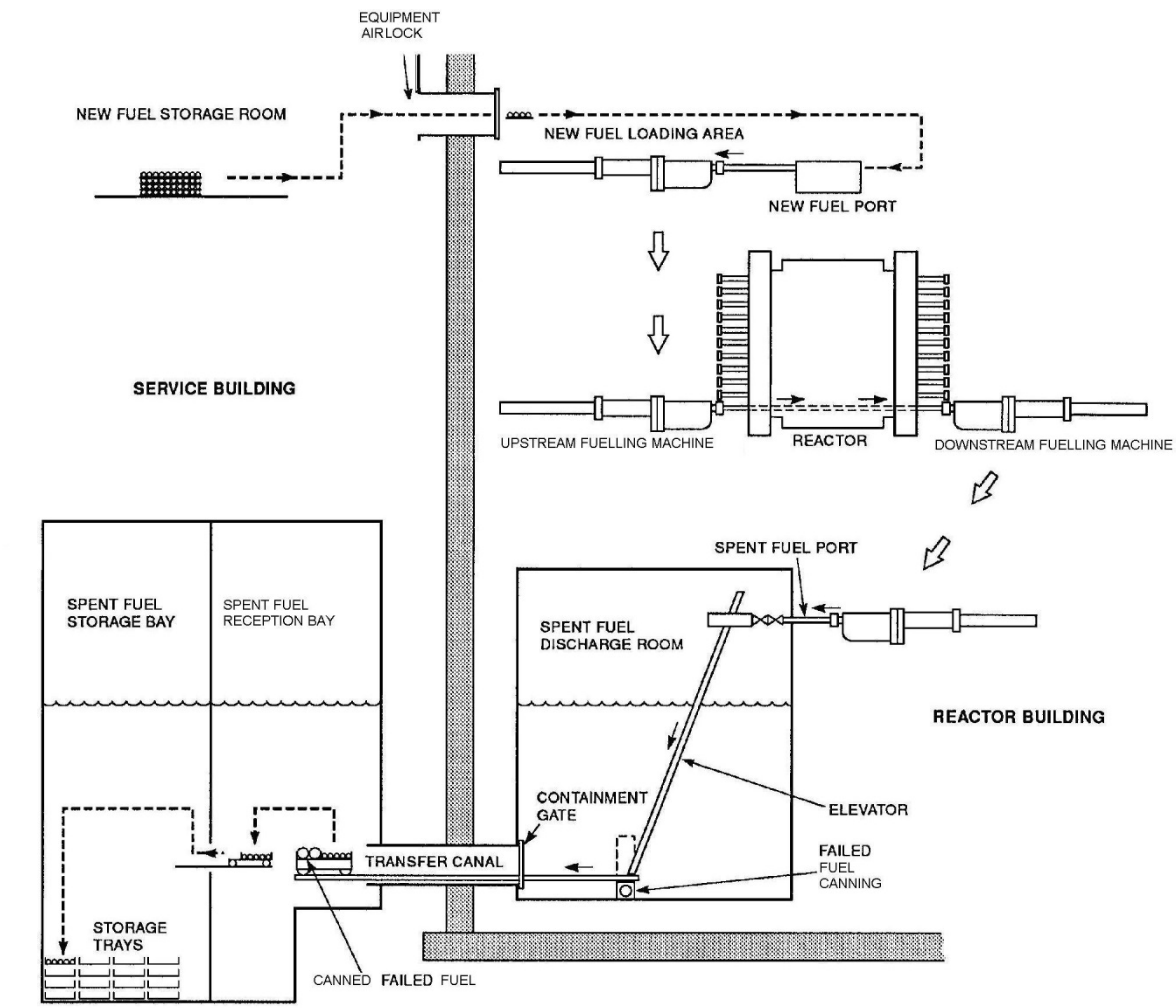

Figure 2 Fuel handling and storage sequence

3 New Fuel Transfer and Storage

3.1 System Description

The new fuel transfer and storage system covers the structures and equipment involved in receiving, handling and storing palletized crates of new fuel, inspecting and handling individual new fuel bundles and transferring these new fuel bundles into the fuelling machine.

New fuel transfer and storage equipment, shown on Figure 1, includes racks in the new fuel storage room, a fork lift truck, crane lifting attachments, a pallet cart and new fuel transfer equipment located in the new fuel loading room in the reactor building, just adjacent to the reactor vault and in between the two fuelling machine maintenance locks. The new fuel transfer equipment, shown on Figure 3, and located in the new fuel loading room, includes an air balance hoist, jib crane, fuel bundle lifting tool and fuel spacer interlocking gauge for handling and inspecting fuel bundles, and two new fuel transfer mechanisms for transferring fuel bundles into a fuelling machine magazine. Each new fuel transfer mechanism, shown on Figure 4, includes a new fuel port, a loading trough and loading ram, an air lock valve, a magazine, a shield plug, a transfer ram and drive and a magazine/port adapter. New fuel transfer auxiliaries use instrument air to power the new fuel transfer equipment. They also connect the new fuel transfer mechanism to the vapour recovery system and provide drainage for it. A local control panel located on each new fuel transfer mechanism allows semi-automatic control of the process for loading new fuel into the new fuel transfer mechanism magazine.

Up to 144 pallets each containing 36 fuel bundles can be stored on racks in the new fuel storage room as part of the normal storage capacity, which accommodates more than eight months of operation at equilibrium. Additional pallets of fuel can also be stored on the floor as part of the abnormal storage capacity.

3.2 Component Description

Major new fuel transfer and storage components are as follows.

New Fuel Storage Room Racks

Racks are available in the new fuel storage room in the service building for storing palletized crates of new fuel. Some of the racks are fixed while some of them are movable.

New Fuel Storage Room Lift Truck

A fork lift truck is available in the new fuel storage room to move the pallets of new fuel. It is an electrically operated, stand-up rider type, and has a capacity of one fuel pallet. This fork lift truck is also used to transport the pallets to the pick-up point for the service building crane during transfer to the new fuel loading room in the reactor building.

Crane Lifting Attachment

Two fork lifting crane attachments are available; one located in the service building for use with the service building crane, and one in the reactor building for use with the reactor building crane. Two pallets can be lifted at one time with these attachments.

Cart

A powered, pallet cart is available at the equipment airlock level to transfer up to two pallets at a time between the service building and the reactor building through the equipment airlock.

Air Balance Hoist and Jib Crane

The air balance hoist is mounted on a jib crane. This crane is pivoted from the building wall above the two new fuel transfer mechanisms and covers the area of the new fuel loading room through which new fuel bundles have to be moved. The air balancing hoist is free to travel along the length of the jib. It is air-powered and can be adjusted to balance the load from a control on the operator's handgrip.

Fuel Bundle Lifting Tool

The fuel bundle lifting tool is used with the air balance hoist to manually load fuel bundles into the new fuel transfer mechanism loading trough. The bundle lifting tool is a manually operated device which clamps around the end plates of the fuel bundles, through lifting adaptors. When the bundle is suspended, it is clamped securely by the toggle action of the tool linkage. The lifting adaptors are mounted on spherical bearings which allow the adaptors to align with the bundle end plates and permit the bundle to be rotated for inspection. The air balancing hoist used with the bundle lifting tool allows the operator to transfer the fuel bundles without damage and with a minimum of effort.

Fuel Spacer Interlocking Gauge

The fuel spacer interlocking gauge is used for checking the diameter of each fuel bundle over the central spacers before the bundles are loaded into the new fuel transfer mechanism magazine. This gauge is used while the fuel bundle is supported on the fuel bundle lifting tool. This gauge consists of two pivoted segments and a dial gauge having a shaded area which indicates the go/no-go range. The dial gauge is used to verify that the bundle has not changed shape during transit and that the pencil spacers have not interlocked. This is to verify that the bundle diameter has not expanded and that it will pass through the fuel handling tubes and the reactor channel without interference.

Loading Trough and Loading Ram

The loading trough and loading ram are provided for moving the new fuel into the magazine of the new fuel transfer mechanism. Two fuel bundles are normally loaded into the trough, and after the bundles are loaded, the lid is closed and the bundles pushed into the magazine by the loading ram. The trough is provided with a hinged lid which is interlocked to prevent operation of the ram unless the lid is closed. Limit switches are mounted in the trough and provide an indication to the control system when a fuel bundle is placed in the trough. The loading ram is in line with the top magazine station of the new fuel transfer mechanism. The ram is an oil/air operated, double acting cylinder, supplied from the new fuel transfer auxiliaries. Oil pressure is used to extend the ram to provide smooth ram operation and adequate lubrication.

Air Lock Valve

The air lock valve is pneumatically operated and is installed between the loading trough and the new fuel transfer mechanism magazine, to seal off the magazine whenever fuel is not being loaded into the magazine. This valve prevents the spread of contamination from the fuelling machine head, the maintenance lock or the fuelling machine vault, into the new fuel loading room. Limit switches indicate when the valve is in the open and closed positions.

New Fuel Transfer Mechanism Magazine

The new fuel transfer mechanism magazine assembly consists of a 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.

New Fuel Transfer Mechanism Shield Plug

The shield plug, which is normally installed in the new fuel port except when new fuel is being transferred to the fuelling machine, reduces radiation streaming into the new fuel loading room when a fuelling machine containing irradiated fuel passes the end of the new fuel port in the fuelling machine maintenance lock.

Transfer Ram and Drive

The function of the transfer ram is to remove and install the shield plug between the new fuel port and the transfer mechanism magazine and to push the new fuel bundles from the new fuel transfer mechanism 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. Ram position, for control of ram stopping and speed changing operation, is detected by a shaft encoder mechanically connected to the chain drive sprocket shaft.

Magazine/Port Adapter

An adapter assembly is bolted to the new fuel transfer mechanism front cover, at a bottom position in line with the respective magazine station and the fuel transfer ram. The adapter connects the magazine to the new fuel port and 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.

New Fuel Ports

The new fuel ports are mounted in embedments in the walls between the new fuel loading room and the fuelling machine maintenance locks. Each port is a tubular connection with an end fitting at one end extending into the fuelling machine maintenance lock and the other end engaging with the fuel transfer mechanism port adaptor. When loading fuel into a fuelling machine, the new fuel port becomes the passageway for bundle movement from the fuel transfer mechanism to the fuelling machine.

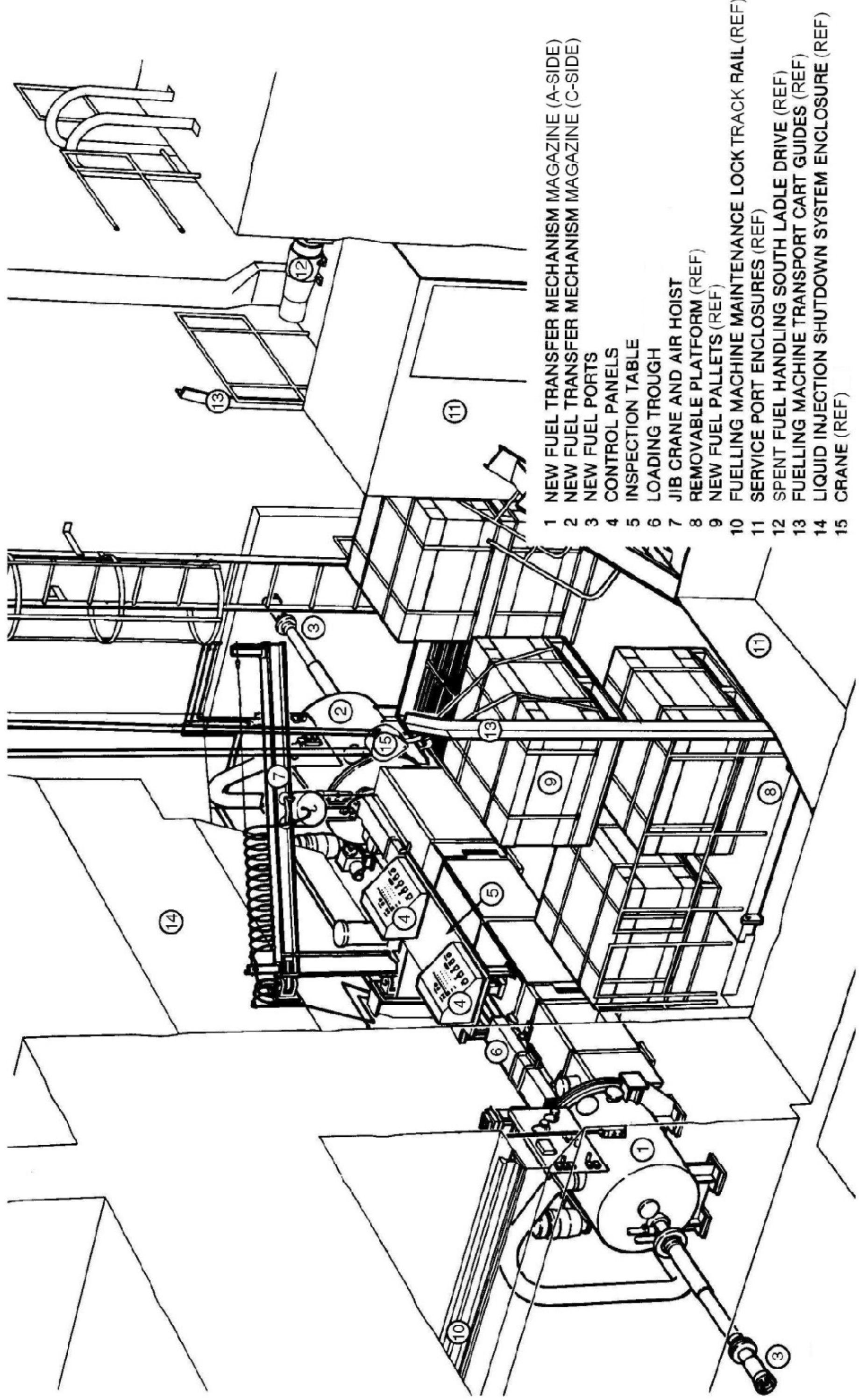

Figure 3 New fuel transfer equipment

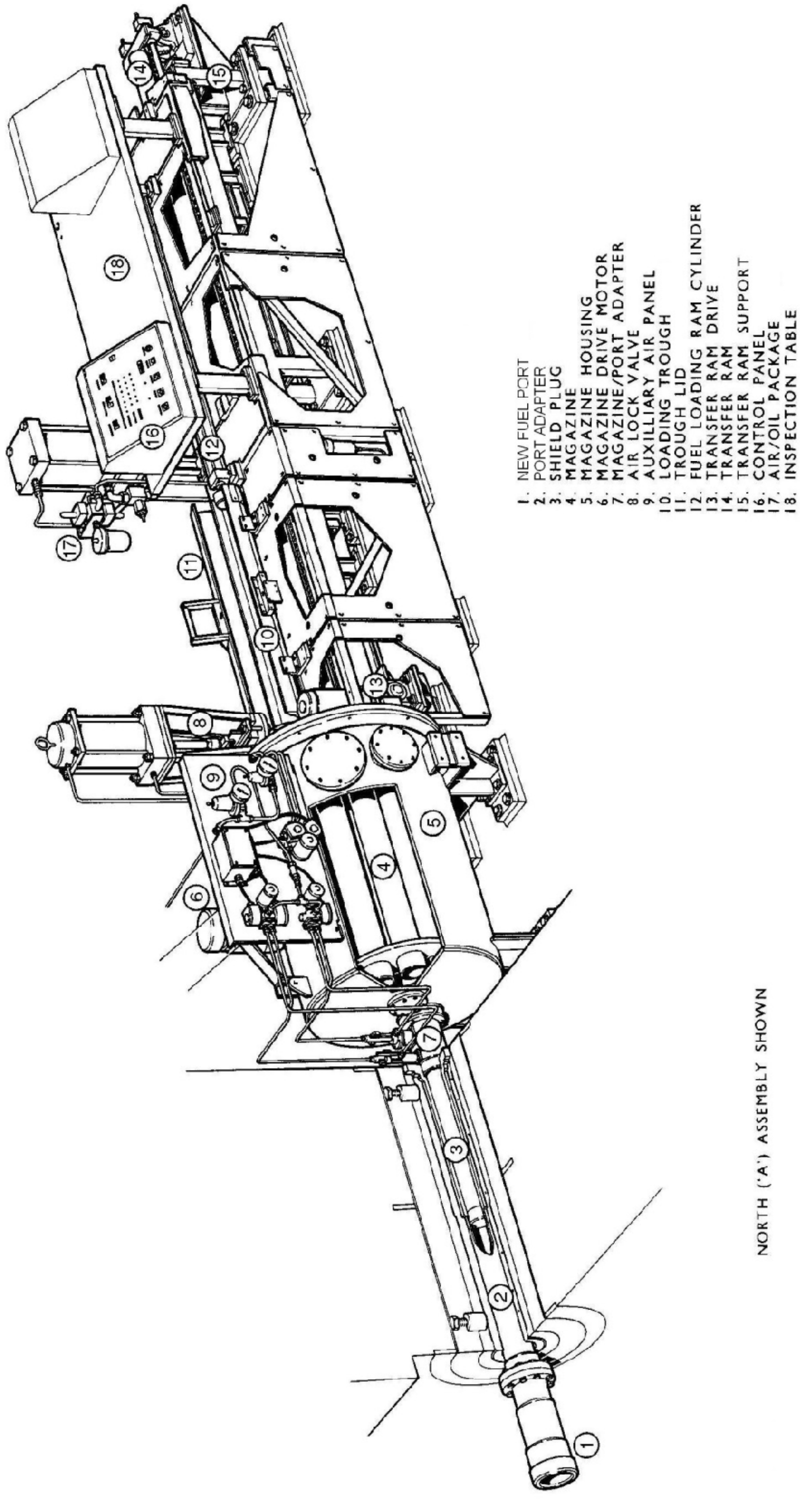

Figure 4 New fuel transfer mechanism

3.3 System Operation

New fuel is received on pallets and stored on racks in the new fuel storage room in the service building. When required, one or two pallets of new fuel are transferred to the new fuel loading room in the reactor building.

1) One new fuel pallet is removed from the new fuel storage room and transferred to the service building crane using the new fuel storage room lift truck. This is repeated for the second pallet.
2) Then the two new fuel pallets are lifted from the crane hall floor elevation and set on the floor of the equipment airlock using the main service building crane.
3) The two new fuel pallets are transported through the equipment airlock into the reactor building with the new fuel pallet cart.
4) From the air lock floor elevation, the two pallets are then lifted using the reactor building crane and set in the new fuel loading room.

Keeping the new fuel bundles on the new fuel pallet protects the new fuel from damage and contamination during transportation from the fuel supplier, during storage at the station and during transfer from storage to the new fuel loading room. The new fuel pallet has slots the fork lift has to engage into prior to lifting and thereby eliminates the chance of dropping the entire pallet.

The new fuel storage room is kept locked and access to fuel is restricted to people who have a valid reason to access or handle fuel. Security procedures are to be followed and the key to the new fuel storage room is controlled by the shift supervisor who authorizes all access to it. The serial number of each fuel bundle is recorded prior to loading into the new fuel transfer mechanism.

In the new fuel loading room, the new fuel pallet is opened and individual fuel bundles are manually unwrapped. One fuel bundle at a time is then picked up and moved onto the inspection table via the bundle lifting tool which clamps around the end plates of the bundle and which is attached to the air-balance hoist. The bundle size (the bundle diameter over the centre bearing pads) is carefully inspected with the fuel spacer interlocking gauge to ensure that it will pass smoothly through the fuel handling system. Each fuel bundle is checked to be free of abnormalities, damage or foreign matter prior to loading into one of the two new fuel transfer mechanisms. Experience from operating CANDU plants indicates that very few new fuel bundles have been rejected because of damage.

The new fuel loading room is heavily shielded and the spread of contamination, from the fuelling machine and the fuelling machine maintenance locks into the new fuel loading room, is prevented by the air lock valve, the shield plug, by maintaining a negative pressure at all times in the magazine of the new fuel transfer mechanism through a duct connected to the vapour recovery system, and by draining into the active drainage system any liquid which may accumulate in the magazine. The shield plug is not removed from the new fuel port unless the air lock valve is closed, and the air lock valve is not opened unless the shield plug is installed in the new fuel port.

New unirradiated fuel bundles, which are made up of natural uranium, have a very low level radioactivity, and can be handled safely by personnel without protective clothing (Note: gloves are normally worn).

Once the operator has manually placed two fuel bundles in the loading trough and closed the trough lid, the fuel bundles are pushed into the new fuel transfer mechanism magazine by the loading ram. The magazine is indexed, using the local control panel mounted on the new fuel transfer mechanism. This process is repeated until the magazine contains the required number of fuel bundles.

The transfer of fuel bundles from the new fuel transfer magazine to the fuelling machine magazine is normally performed under complete computer control, using a series of steps. Confirmation of the successful completion of each step, which is indicated by either a limit switch or a shaft encoder, is required prior to starting the following step. Prior to beginning the transfer sequence, the fuelling machine is clamped onto the new fuel port and its heavy water[2] level is lowered to just below the snout.

To ensure that the system is ready to begin the sequence, the computer memory is checked to confirm that the fuelling machine snout plug is stored in its magazine station and that the guide sleeve has been installed in the snout. Feedback must indicate that all rams are retracted to their home positions, that the air lock valve is closed, that there is new fuel in the new fuel transfer mechanism magazine, and that the new fuel transfer mechanism magazine is not in use. All conditions being satisfactory, the new fuel magazine is rotated to the shield plug station, the ram is advanced to remove the shield plug from the port, and then retracted to deposit the shield plug in the magazine for storage. The commands are then given to rotate the fuelling machine magazine to an empty station and the new fuel magazine to a full station. The new fuel transfer ram is then fully advanced to push two new bundles into the fuelling machine magazine station. The rams are retracted to their respective home positions, the fuelling machine and new fuel magazines are rotated to the next stations, and two more fuel bundles are transferred. This process is repeated until the fuelling machine magazine contains the required number of bundles. After completion of the fuel bundle transfer, the shield plug is re-installed into the new fuel port and locked in place. The fuelling machine then removes the guide sleeve from the new fuel port, installs its snout plug, raises its heavy water level and is unclamped from the new fuel port in order to traverse to the reactor face.

Normal handling of new fuel in air or light water does not pose criticality problems for natural uranium.

Note: New fuel bundles for the initial core are manually loaded into the fuel channels. Visual inspections of these new fuel bundles are performed on a loading platform at the reactor face.

2 Heavy water (D_2O) has deuterium atoms instead of hydrogen atoms and is approximately 10% heavier than light or regular water.

4 Fuel Changing

4.1 System Description

Fuel changing, depicted in Figure 5, involves the structures, equipment and activities required to transport new fuel from the new fuel port to the reactor, to load and unload fuel from the fuel channel, and to transport the discharged fuel from the reactor to the spent fuel port. This is mainly performed by two fuelling machine heads remotely operated from the Main Control Room.

Each fuelling machine head is suspended on a carriage, which moves horizontally along bridge rails in its respective fuelling machine vault and on tracks in its respective fuelling machine maintenance lock. A bridge assembly, adjacent and parallel to each reactor face, provides for vertical movement of the fuelling machine head and its carriage. Each bridge and carriage assembly allows a fuelling machine to access all 380 reactor fuel channels at the respective reactor face. The maintenance lock tracks align with the lowest bridge position to allow transfer of the fuelling machine and carriage between the fuelling machine vault and the maintenance lock.

The fuelling machine D_2O system supplies the fuelling machines with heavy water to cool irradiated fuel temporarily stored in the fuelling machines, operate associated fuelling machine mechanisms and generate injection flow. The oil hydraulic system supplies the fuelling machines and carriages with oil to operate and lubricate associated mechanisms. The catenary system conveys heavy water, hydraulic oil and electrical power and control signals to and from the mobile fuelling machine heads and carriages.

The fuelling machine heads are normally stored in two maintenance locks, where they can lock onto the new fuel ports to accept new fuel, onto the service ports for maintenance and rehearsal, or onto the spent fuel ports to discharge irradiated fuel.

Powered shielding doors separate the fuelling machine vault and the reactor from the maintenance locks and, when closed, provide shielding that allows personnel access to the fuelling machines in the maintenance locks while the reactor is operating.

The on-channel fuel changing operations are performed in the direction of coolant flow in the channel. Each fuel channel contains 12 fuel bundles. Typically, eight new fuel bundles are inserted at the upstream end of a fuel channel, and eight irradiated fuel bundles are removed at the downstream end. Since the coolant in adjacent fuel channels flows in opposite directions, for reasons of reactor symmetry, each fuelling machine is an upstream machine (carrying new fuel) and a downstream machine (carrying irradiated fuel) at different times.

4.2 Component Description

4.2.1 Fuelling Machine Head

The fuelling machine is a pressure vessel that comprises five major sub-assemblies, the snout, the magazine, two separators and the ram, which are necessary for it to perform its required functions. The fuelling machine head, shown on Figure 6, includes the fuelling machine mounted and supported in a cradle assembly as well as the guide sleeve and tool, and the ram adapter. The fuelling machine heads engage the end fittings at opposite ends of the same channel assembly for the purpose of fuel changing. The fuelling machine head contains heavy water and is designed to form an extension of the heat transport system pressure boundary to enable refuelling operations to be carried out with the reactor at full power.

Snout Assembly

The snout assembly, located at the front of the fuelling machine and shown in Figure 7, enables the fuelling machine head to clamp onto any reactor fuel channel and to seal the connection at high pressure and temperature. To achieve loading of new fuel bundles and the discharging of irradiated fuel bundles from the fuelling machine, the snout assembly is capable of locking onto the new fuel port and the spent fuel port. It is also capable of connecting to the service ports as required.

The snout assembly includes the centre support, the clamping mechanism, the snout emergency lock assembly, the head antenna and the snout probes. The clamping mechanism is engaged by oil hydraulic pressure. The snout emergency lock, a passive safety lock, prevents inadvertent removal of the snout assembly from an end fitting when the channel closure is not installed. When the fuelling machine is not attached to a fuel channel or port, the snout is sealed with a snout plug.

Magazine Assembly

The magazine assembly, as shown on Figure 7, includes a twelve-chamber rotor inside a pressure-retaining housing assembly for storing fuel bundles, channel closures, shield plugs, a snout plug, a ram adapter, a guide sleeve and tool, and a flow assist ram extension (FARE) tool.

It also includes a drive system, comprising an indexing mechanism driven by an oil-hydraulic motor for turning the magazine rotor, and the magazine emergency drive, a manual drive facility to rotate the magazine rotor if the oil hydraulic motor becomes disabled.

Ram Assembly

The ram assembly, shown in Figure 8, provides the necessary axial movements and forces required for the transfer and discharge of the fuel bundles, or the installation and withdrawal of various tools and plugs such as the guide sleeve, the channel closure plug, the shield plug, and the snout plug. The ram assembly consists of a B ram, a latch ram and a C ram. These rams are essentially concentric tube assemblies supported within a pressure-retaining ram housing. Each ram has a different head assembly to perform the necessary plug or fuel changing operation. Both the B ram and the latch ram are driven by oil hydraulic motors through a gear system and ball screws. The C ram acts as a multi-stage hydraulic cylinder and is powered by the fuelling machine D_2O system.

Separators

For each fuelling machine head there are two separator assemblies which perform identical functions and operate in synchrony. They are mounted in penetrations through the magazine front cover at points just forward of the magazine tubes and each assembly is oriented at 67.5° from the vertical. The separators sense the gaps between two fuel bundles or between a fuel bundle and ram adapter or FARE tool, provide a signal to the computer to stop the fuelling machine ram at the correct position, restrain the axial motion of the fuel column due to hydraulic forces from the fuel channel flow, push the bundles that have been separated from the fuel column into the magazine to allow clearance for magazine rotation, and verify the presence of the shield plug and the FARE tool during the refuelling operations. High pressure heavy water from the fuelling machine D_2O system is used to operate the separators.

Ram Adapter

The ram adapter, shown in Figure 9, attaches to the C ram head to provide a flat face for contacting the end plate of a fuel bundle and to centralize and support the C ram, which minimizes sagging of the ram. The ram adapter consists of five parts: the body, the sleeve, the stem, the inner spring and the outer spring. The ram adapter body provides the contact face with the fuel. The face is machined to simulate the end face of a fuel bundle, so that the gap between the ram adapter and the fuel is identical to the gap between two fuel bundles. The body is also machined to allow adequate cooling flow. The stem is screwed into the bore of the body and is contoured to connect with the C ram. The sleeve is spring-loaded by the concentric inner and outer springs and locks the C ram to the stem.

Guide Sleeve and Tool

The channel closure seal face in each fuel channel end fitting forms a step in the fuel channel, the bore of the channel being smaller than the bore of the end fitting. This discontinuity forms an obstruction to the smooth passage of fuel bundles and shield plugs. The guide sleeve provides a smooth bore for the passage of fuel bundles and shield plugs between the fuel channel and the fuelling machine.

The guide sleeve is moved between the fuelling machine magazine and the fuelling machine snout by the fuelling machine ram using a guide sleeve insertion tool. The guide sleeve and the insertion tool are locked together except when the guide sleeve is in position in the snout and end fitting. When not in use, they are stored together in the fuelling machine magazine and are held in the magazine tube by a locating tube and spacer.

Snout Plug

The snout plug, shown in Figure 10, is used to seal the fuelling machine snout when the fuelling machine is not attached to a fuel channel or port. It allows the interior of the fuelling machine to be maintained full of water at a controlled temperature and pressure, to maintain cooling of the irradiated fuel while in transit from the reactor fuel channel to the spent fuel port. The fuelling machine snout plug is composed basically of two parts, the latching mechanism and the seal assembly. The latching mechanism which makes up the rear half of the plug has four jaws which are extended by a spider mechanism. These four jaws locate the plug in a groove in the fuelling machine snout centre support. The front end of the snout plug is comprised of the seal assembly, which is screwed onto the latch assembly. The seal assembly contains a large elastomer O-ring seal and the associated mechanism required to expand and retract it.

4.2.2 Fuelling Machine Bridge and Carriage

Two fuelling machine bridge and carriage assemblies are provided, one at each reactor face. As shown in Figure 5, each bridge spans the face of the reactor and supports a carriage assembly, when the carriage is in the fuelling machine vault. The carriage assembly supports a fuelling machine head. Each bridge moves vertically on two guide columns, to provide vertical motion (y-motion) of the fuelling machine head. Carriage wheels ride on rails mounted on the bridge (when in the fuelling machine vault) and on the maintenance lock tracks (when in the maintenance lock) to provide horizontal motion (x-motion) of the fuelling machine. With the bridge in its lowest position, the rails on the bridge are aligned with matching rails on the maintenance lock tracks, enabling the carriage, with the fuelling machine head, to transfer between the fuelling machine vault and the maintenance lock.

Each carriage assembly consists of a drive unit assembly, and upper and lower gimbal assemblies, as shown in Figure 11. In addition to horizontal motion along the bridge and maintenance lock rails, the carriage assembly also provides fine vertical motion and motion toward and away from the reactor (z-motion) and allows a controlled amount of rotation of the head. It also provides a termination point for the catenary system.

The carriage also includes clamping mechanisms, which securely anchor the carriage to the bridge rails when the fuelling machine head is clamped to a reactor end fitting, to prevent excessive loads from being applied to the end fitting by the fuelling machine head during a seismic event.

4.2.3 Fuelling Machine D_2O System

The D_2O system supplies the fuelling machine with heavy water compatible with the heat transport system, and regulates the pressure and flow of heavy water to and from the various parts of the fuelling machine. Heavy water is used in the fuelling machine for the following functions:

- Cooling irradiated fuel stored in the fuelling machine magazine.
- Operating the C ram.
- Operating the separators.
- Preventing high temperature heat transport system water from entering the fuelling machine when the fuelling machine is coupled to a fuel channel.

The fuelling machine D_2O system is divided into the following major parts:

- Two valve stations that contain most of the control components of the stationary portion of the system.
- The mobile portion of the system located on each fuelling machine head.
- Catenary hoses that connect the stationary portion of the system with the mobile portion located on the fuelling machine head.

4.2.4 Fuelling Machine D_2O Supply System

The fuelling machine D_2O supply system can be divided into three subsystems:

1. The supply subsystem, which supplies pressure regulated, filtered heavy water, drawn from the primary heat transport system storage tank and/or the D_2O return subsystem, to the two D_2O system valve stations.
2. The D_2O return subsystem, which accepts the D_2O discharge from the fuelling machine head via the D_2O System, and cools and purifies it before returning it to the supply subsystem.
3. The D_2O leakage collection system, which collects the D_2O from all drain, leak and vent points in the system into two tanks.

4.2.5 Oil Hydraulic System

Each of the two fuelling machines is operated by an individual oil hydraulic system. The oil hydraulic system provides a continuous oil supply, at controlled conditions of flow, pressure and temperature, to the mobile fuelling machine head and carriage, via a catenary system. This oil supply is used to operate associated actuators on the fuelling machine head and carriage.

4.2.6 Fuelling Machine Head Accessories

Fuelling machine head accessories include the FARE tool, the pressure tube seal and latch assembly and the fuel grapple system.

FARE Tool

The FARE tool provides a restrictive element in low flow fuel channels, which develops the necessary coolant flow drag force to overcome the frictional resistance of the fuel bundles in the channel, in order to push the fuel column downstream when the fuelling machine ram cannot provide this force without entering the core. The FARE tool has an overall length of two fuel bundles and is handled like a pair of fuel bundles. For simplicity, it can be considered as a piston in a cylinder with a large amount of leakage.

The FARE tool is carried in the fuelling machine magazine and is pushed into the fuel channel in the same manner as the fuel bundles after the last new fuel bundle is inserted in the fuel channel.

After the irradiated fuel bundles are discharged from the fuel channel and the fuel string is returned to its normal in-core position, the C ram attaches to the FARE tool for its removal and return to the fuelling machine magazine.

Pressure Tube Seal and Latch Assembly

The pressure tube seal and latch assembly can be inserted into a fuel channel by the fuelling machine so that it stops the channel flow, thus enabling ice-plugs to be formed in the channel feeders by means of a freezing operation. This channel flow blockage is sometimes required to allow inspection of the channel or other possible fuel handling recovery scenarios. It is only used during reactor shut downs at low pressures. The pressure tube seal and latch assembly consists of a seal assembly with a mechanism for radially expanding an O-ring to seal the bore of the pressure tube and a latch assembly which is similar to a fuel channel shield plug.

Fuel Grapple System

The fuel grapple system enables the fuel channel to be defuelled from one end using a single fuelling machine when the other fuelling machine is disabled or when a channel is to be defu-elled. It includes a fuel grapple assembly, for latching onto a fuel bundle; grapple extensions, which attach to the grapple assembly or other extensions for grappling fuel bundles beyond the reach of the fuelling machine rams; a ram grapple adaptor, which allows the fuelling machine to operate latches on the extensions; and a grapple reset tool for releasing irradiated fuel bundles from the fuel grapple.

4.3 System Operation

To begin the fully automated fuel changing process, one of the two fuelling machines clamps onto the new fuel port, its water level is lowered to just below the fuelling machine snout, its snout plug is removed, the guide sleeve is installed and the fuelling machine typically accepts eight new fuel bundles from the new fuel port. The guide sleeve is removed, the snout plug re-installed and the water level is raised. Fuel bundles are received and stored in pairs.

With the shielding doors open, both fuelling machines travel along the maintenance lock tracks onto the fuelling machine bridges at each face of the reactor. The bridges are then raised and the fuelling machines positioned on the bridge so that the fuelling machines are located at opposite ends of the selected fuel channel. The fuelling machine with the new fuel is at the upstream end while the other fuelling machine, which contains no fuel, is at the downstream end of the same fuel channel.

Each fuelling machine then moves forward to home and lock onto the fuel channel end fitting to form a secure and pressure-tight joint with the channel. Figure 12 depicts a typical eight-bundle refuelling sequence.

The fuelling machines remove their snout plugs followed by the fuel channel closures. At this point, the fuelling machines become part of the heat transport system pressure boundary. The fuelling machine at the upstream end of the fuel channel removes the shield plug and typically inserts eight new fuel bundles, two at a time, into the channel. The downstream fuelling machine removes the shield plug and typically receives eight irradiated fuel bundles, two at a time, into its magazine. The remaining twelve-bundle fuel string is then moved back to the correct in-reactor position and the shield plugs and channel closures are re-installed in the fuel channel. The fuelling machines re-install the snout plugs in their snouts, the channel closures are checked for leaks and the fuelling machines are then retracted from the end fitting.

The fuelling machine containing irradiated fuel returns to the maintenance lock and discharges the irradiated fuel through the spent fuel port.

An eight-bundle refuelling sequence, from the time that one fuelling machine clamps onto the new fuel port to accept new fuel to the time that the other fuelling machine unclamps from the spent fuel port after discharging irradiated fuel, as described above, typically takes approximately two hours. This includes approximately 30 minutes at the new fuel port, a little over 50 minutes at the reactor face and approximately 35 minutes at the spent fuel port.

Other fuelling schemes are also possible. For example, an alternate scheme is available for the first refuelling visit to a fuel channel; it involves the fuelling machine at the upstream end of a fuel channel inserting eight new fuel bundles as usual, and the fuelling machine at the downstream end of this fuel channel receiving ten irradiated fuel bundles and returning the first bundle pair removed to the fuel channel. Although refuelling fewer than eight bundles at a time is favourable with respect to improving fuel economy; it increases wear and tear on fuel handling equipment, particularly on the fuelling machines. A fuelling machine can accommodate up to eight fuel bundles when carrying a FARE tool, up to ten fuel bundles without a FARE tool, and up to twelve fuel bundles when the reactor is shut down. Refuelling uneven numbers of fuel bundles is expected to be limited to abnormal situations.

Bundle movement is controlled by the downstream fuelling machine, assisted by the coolant flow inside the channel which moves the string of fuel bundles due to hydraulic drag.

The channel flow, however, varies depending on location. In the outer zone fuel channels where the flow is lower, a FARE tool is used to provide sufficient hydraulic drag force to move the fuel string under the reduced channel flow condition. The FARE tool is loaded at the end of the fuel string after new fuel bundles have been inserted by the upstream fuelling machine. The FARE tool is removed after the required number of irradiated fuel bundles is received by the downstream machine and the fuel bundle string is moved back to its correct in-reactor position. The FARE tool is used rather than the upstream machine ram so that the latter does not enter the core to become activated and contribute to the dose rate to maintenance personnel working on the machine. The FARE tool (which also becomes activated when it passes into the core) is discharged from the machine in the same manner as irradiated fuel bundles before maintenance work is started. The FARE tool is not required on inner zone channels.

The failed fuel detection and location system, which is part of reactor instrumentation and control, is used to detect and identify failed fuel in the reactor core. Its gaseous fission monitoring system detects the reactor loop in which the fuel failure has occurred. Its failed fuel location system, also referred to as the delayed neutron monitoring system, is then used to identify in which channel of the particular coolant loop, the fuel failure occurred and to find, in this particular channel, which bundle pair contains the failed bundle(s). It does this by monitoring delayed neutrons via a sample station. The delayed neutron count rate decreases sharply when a failed fuel bundle leaves the channel flow. Failed fuel bundle(s) are then identified via their fuelling machine magazine position. They are otherwise handled by the fuelling machine in the same way as undamaged fuel bundles.

The fuel changing system maintains irradiated fuel, temporarily stored in its magazine, at acceptable temperatures by keeping it submerged and accommodating adequate heavy water circulation in the fuelling machine magazine, except for the short period of time when fuel bundles are exposed to air for discharge via the spent fuel port. The temperature of the water in the fuelling machine magazine is monitored.

In order to prevent damage to fuel:

- Fuel changing mechanisms are normally operated automatically according to pre-defined sequences.
- Interlocks inhibit mechanism operations unless the configuration is acceptable.
- Fuel changing components that interface with the fuel such as the ram adapter and the separator assemblies are designed to limit the stresses in the fuel bundle to acceptable levels.
- When handling fuel, the ram forces are limited to prevent unacceptable axial forces on the fuel bundles.

The geometry of the fuelling machine maintains the fuel subcritical even with heavy water present.

Fuel changing operations are performed remotely to limit radiation exposure of site personnel. The fuelling machine shielding doors provide radiation shielding and a ventilation barrier between the fuelling machine vaults and maintenance locks when the fuelling machine heads and their carriage and suspension are in their maintenance locks to permit personnel access for their maintenance. The atmosphere in the maintenance locks can be purged.

Prior to the start of maintenance work on the fuelling machine, plugs and tools, such as the shield plug, ram adapter and FARE tool, which become activated when they enter the core, are discharged from the fuelling machine.

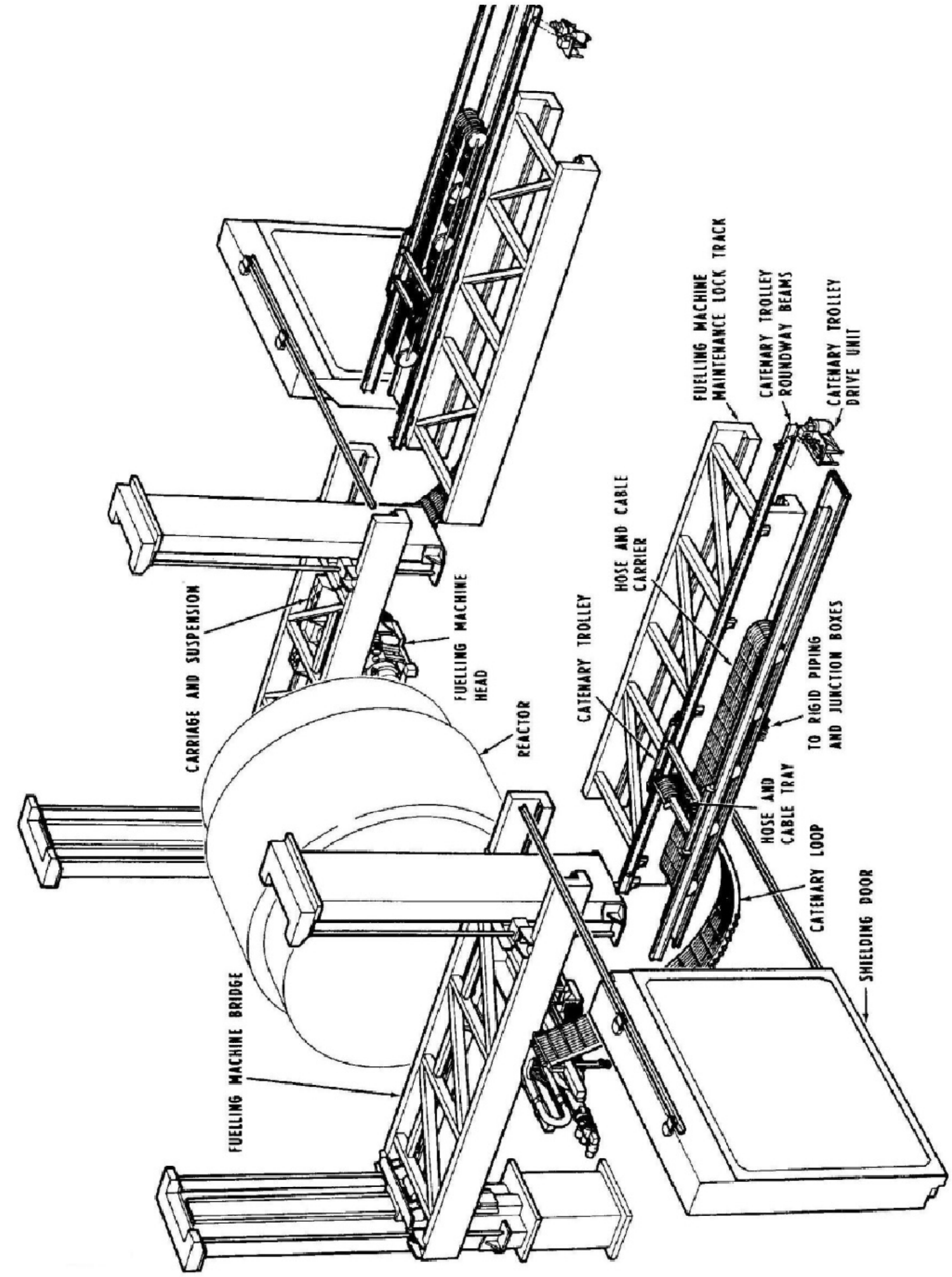

Figure 5 Fuel changing equipment

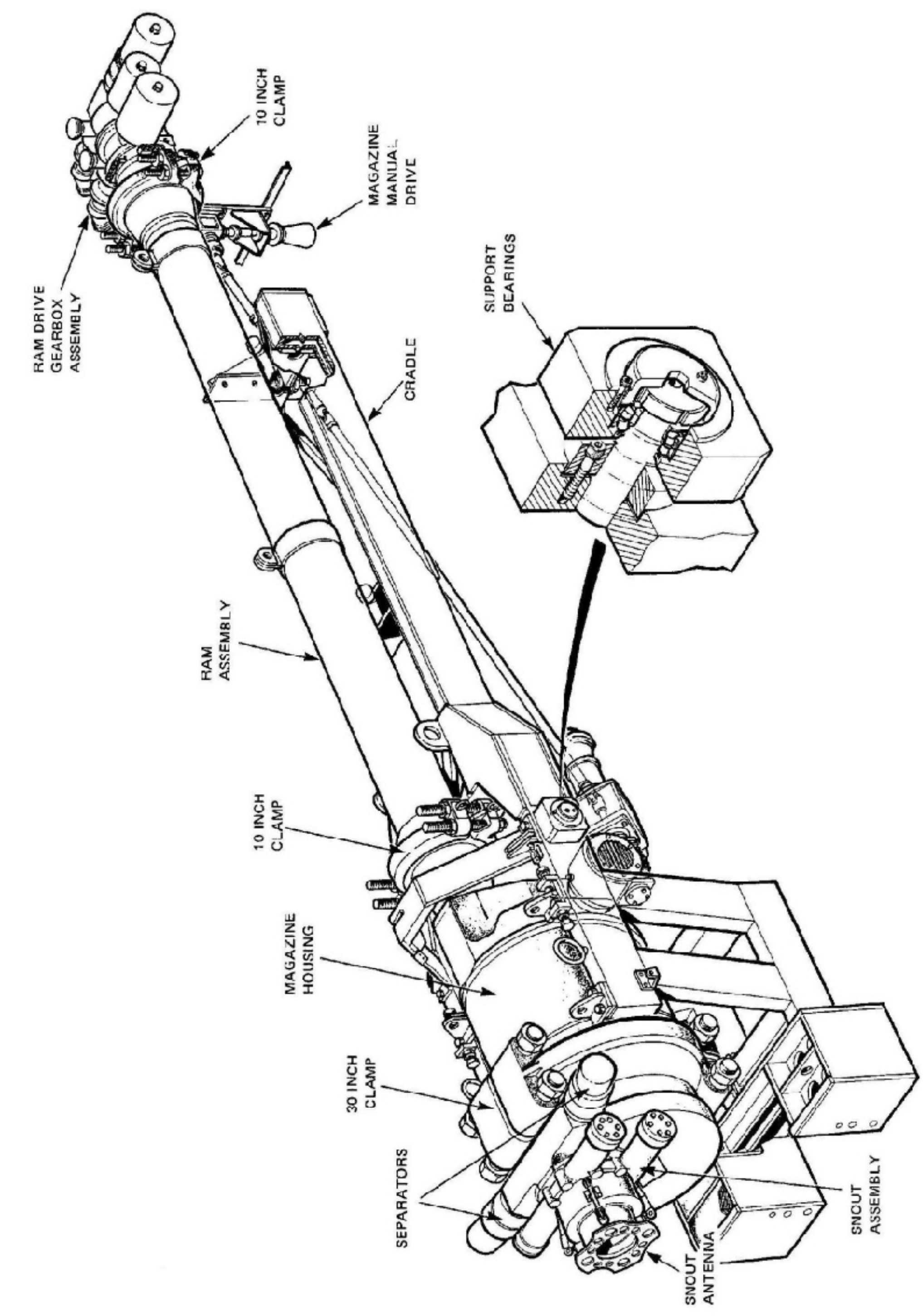

Figure 6 Fuelling machine head

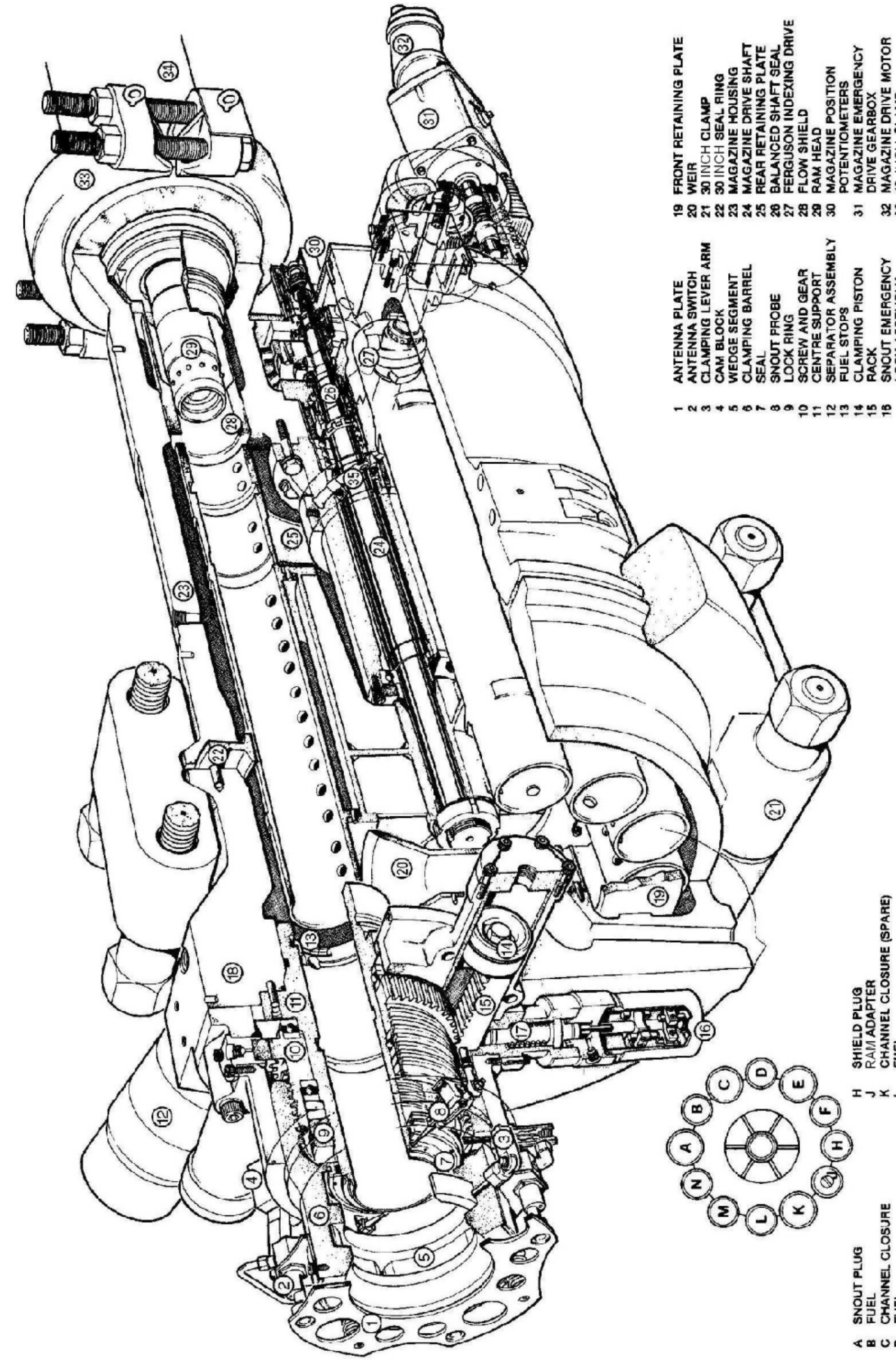

Figure 7 Front end of fuelling machine

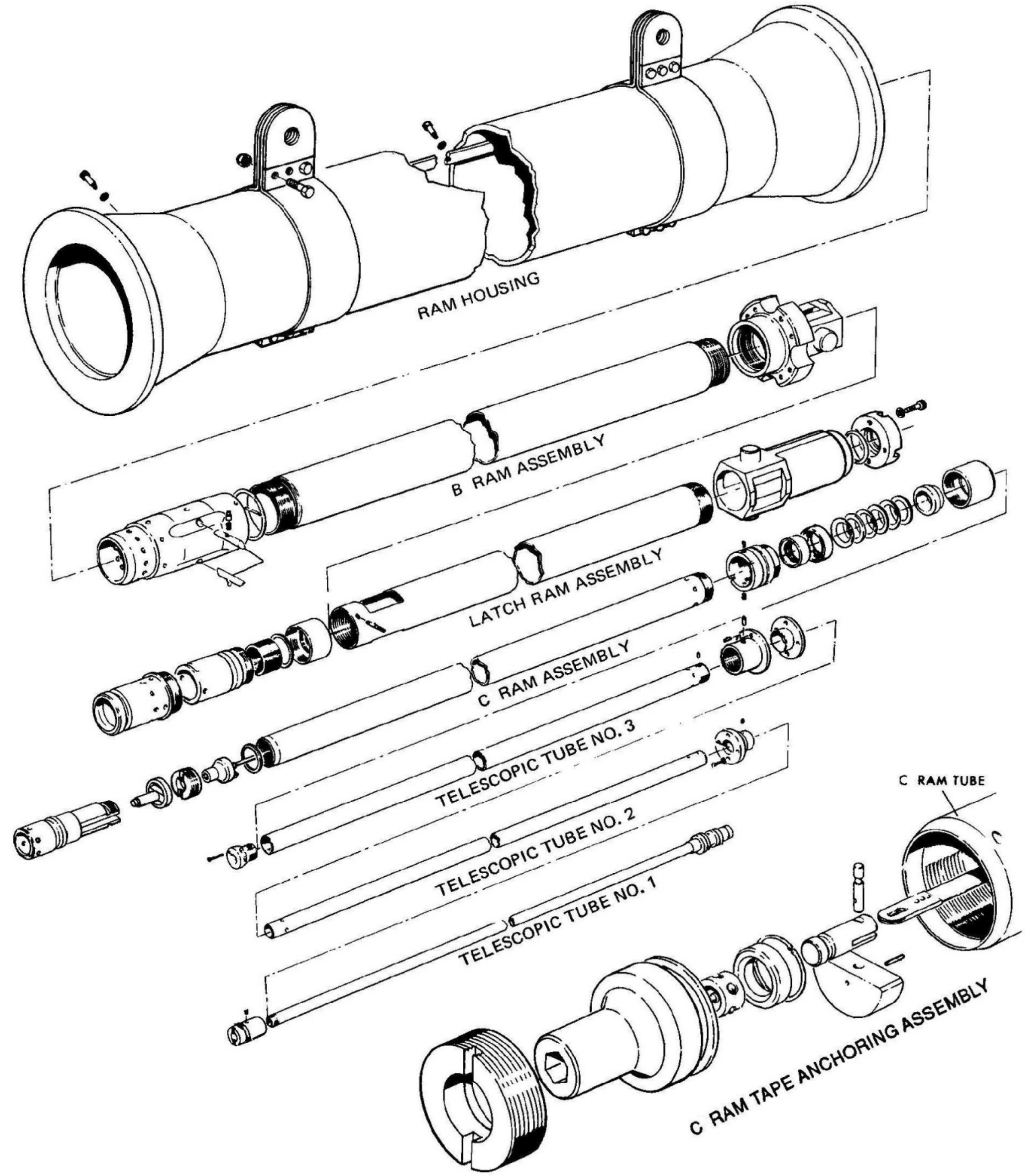

Figure 8 Ram assembly – exploded view

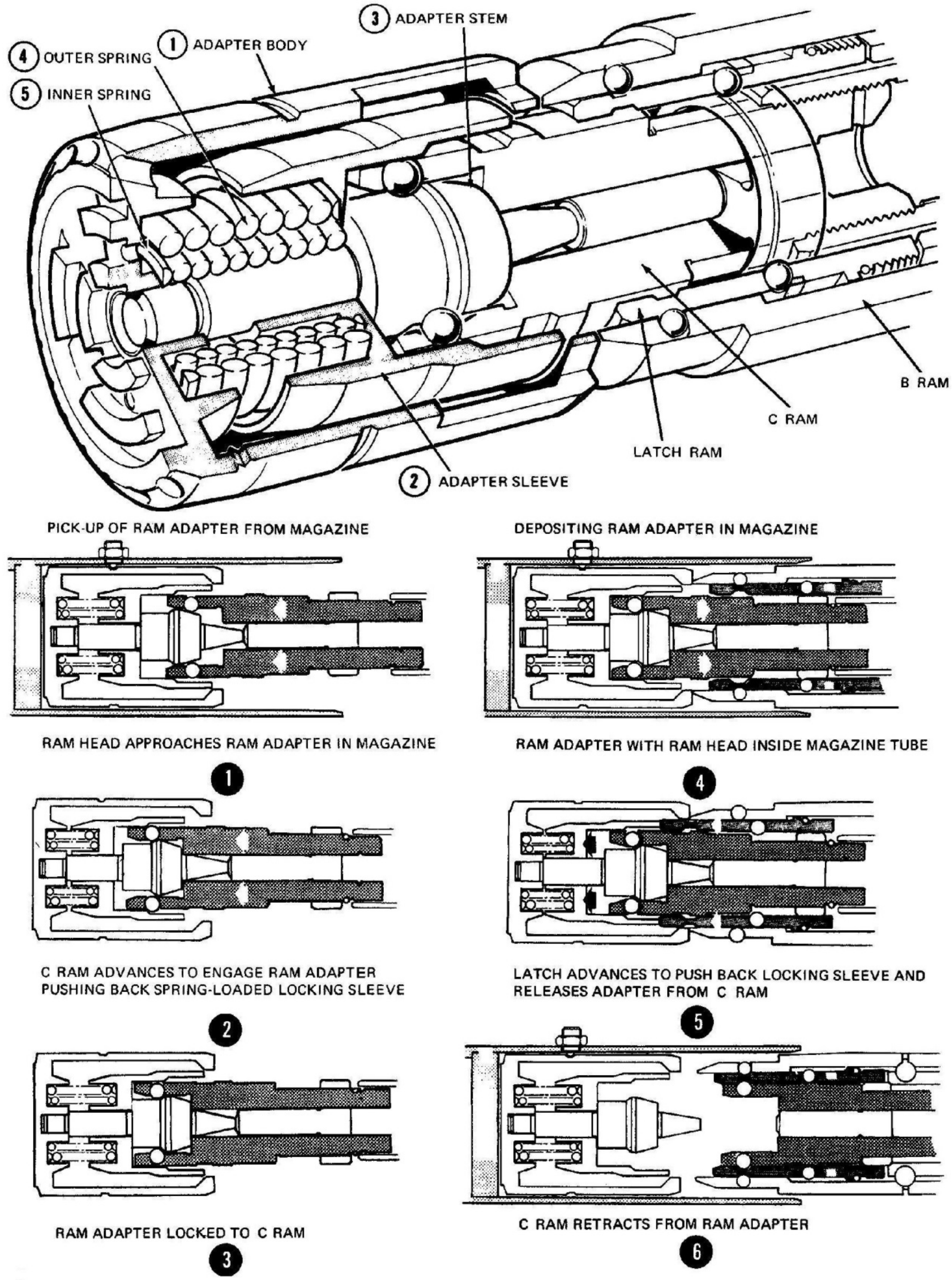

Figure 9 Ram adapter and operation

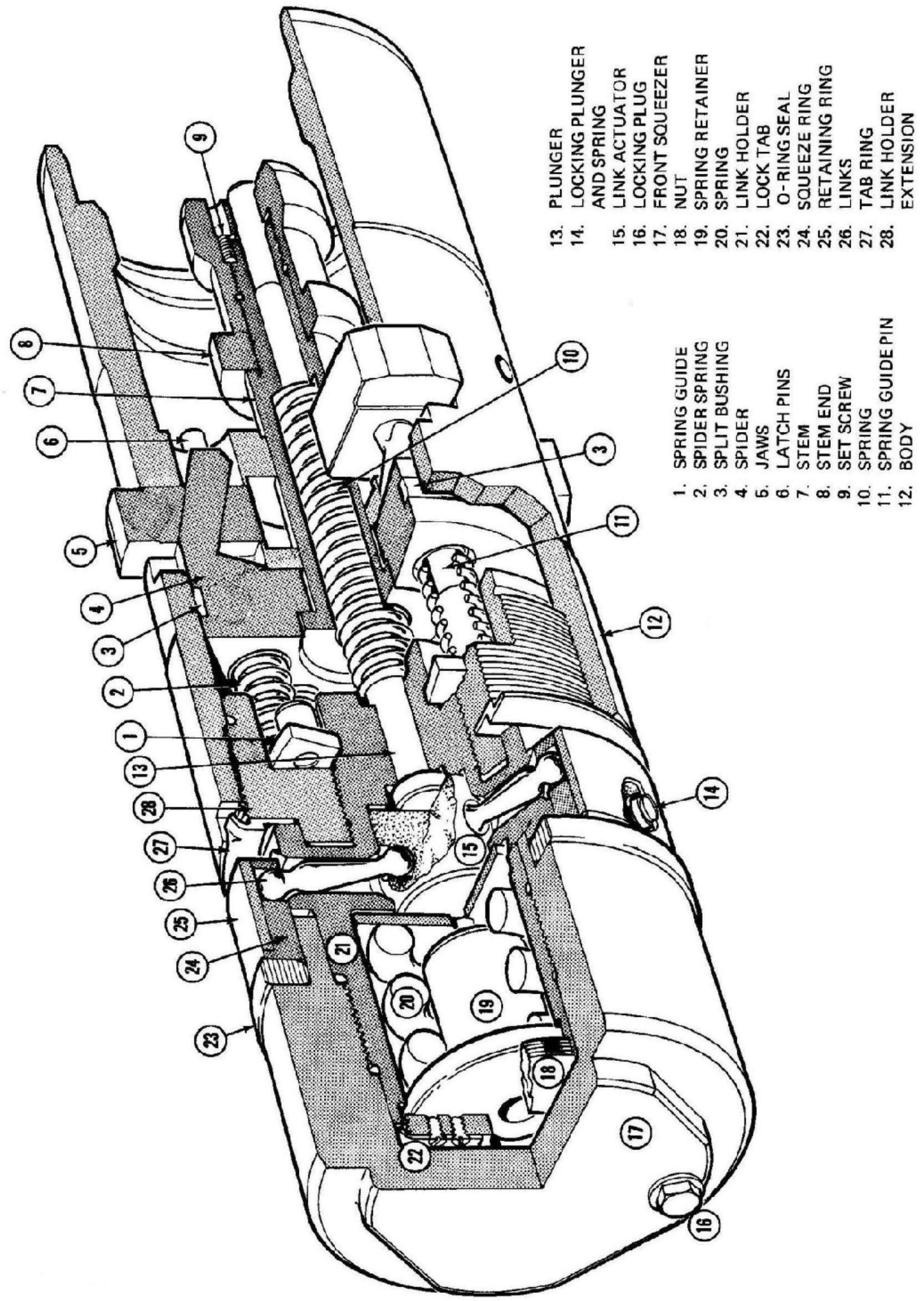

Figure 10 Fuelling machine snout plug

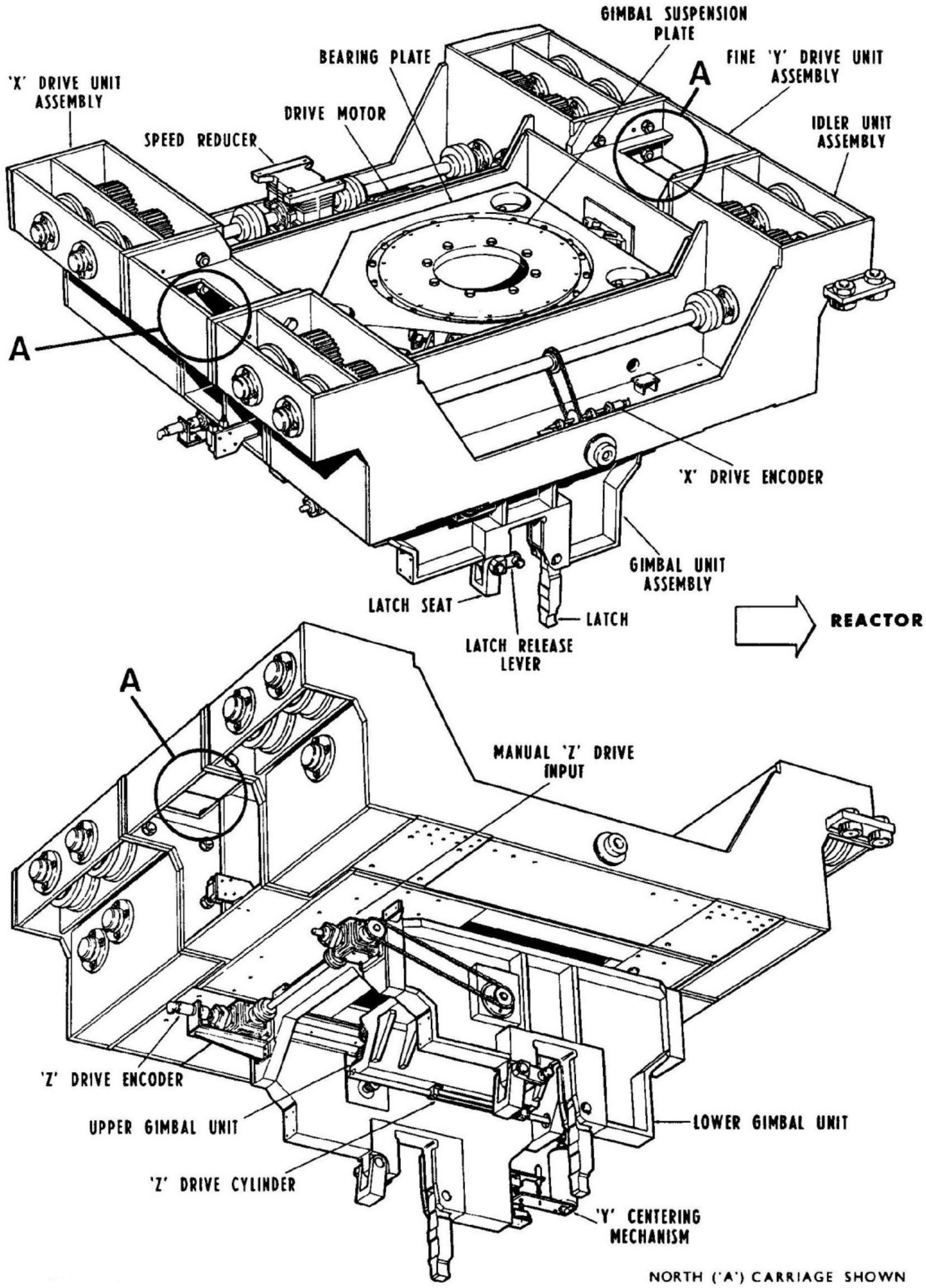

Figure 11 Carriage assembly

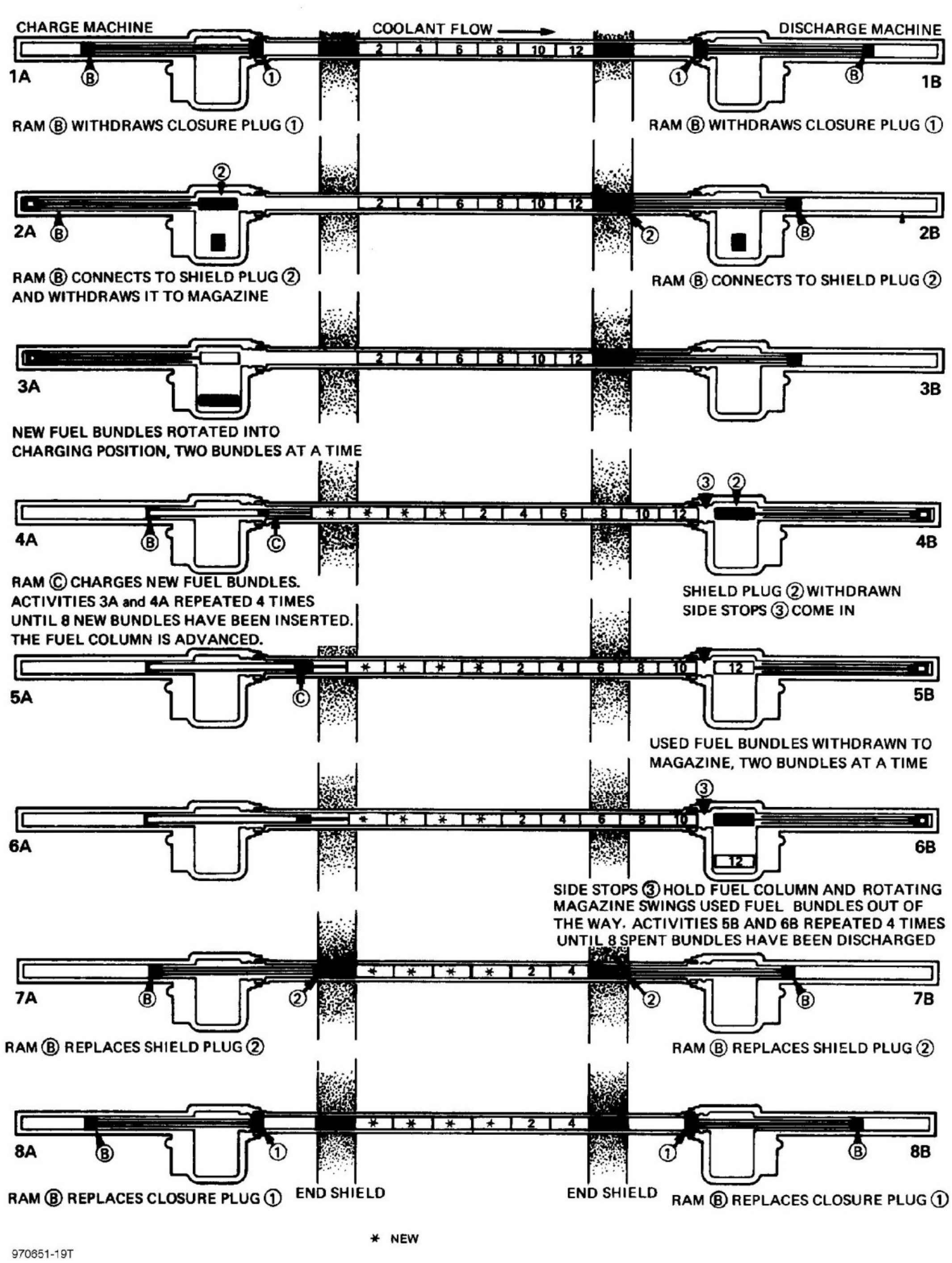

Figure 12 Fuel changing sequence

5 Spent Fuel Transfer and Storage

5.1 System Description

Spent fuel transfer and storage, which can be seen on Figure 1, covers the structures and equipment involved in the discharge of irradiated fuel from the fuelling machine and the transfer and storage of this irradiated fuel in bays until the fuel is transferred to dry storage. It consists of spent fuel discharge equipment, shown in Figure 13, spent fuel transfer auxiliaries, spent fuel transfer equipment, shown in Figure 14, and storage bay equipment. It also includes failed fuel canning equipment, shown on Figure 15, which is a subset of the spent fuel discharge equipment, and failed fuel handling equipment, which is a subset of the storage bay equipment. Spent fuel transfer and storage involves three bays filled with light, or regular, water: the spent fuel discharge bay, spent fuel reception bay and spent fuel storage bay (also referred to as the main storage bay).

The discharge equipment, which is located in the reactor building, receives irradiated fuel from the fuelling machines and lowers it into the discharge bay. It includes spent fuel ports that interface with the fuelling machines, and elevators to lower the fuel bundles into the water. It also includes the failed fuel canning equipment in the discharge bay, for handling and canning the small quantity of failed fuel.

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

The spent fuel transfer equipment provides for the transportation of irradiated fuel from the discharge bay in the reactor building to the reception bay and the storage bay in the service building. It includes the discharge and transfer canal conveyors, the storage tray conveyor, a conveyor rack and cart, as well as tools and accessories for manipulating the fuel in the reception bay. The transfer of irradiated fuel between buildings is under water through a containment gate and a transfer canal, which connects the reception and storage bays under water. The reception bay is connected under water with the main storage bay by the penetration for the storage tray conveyor.

The storage bay equipment provides for the storage of irradiated fuel in the reception and storage bays. It includes the storage bay man-bridge, the storage trays and their supports, a storage tray lifting tool and the failed fuel handling equipment for handling and storing canned failed fuel in the reception bay.

An irradiated fuel channel shield plug (with its jaws retracted by a locking mechanism) or FARE tool can be received from either fuelling machine and accommodated similarly to fuel bundles. Irradiated elements of the reactivity control mechanisms can be accommodated in the storage bay for underwater storage.

5.2 Component Description

5.2.1 Spent Fuel Discharge Equipment

Spent fuel discharge equipment, shown in Figure 13, includes the components described as follows, in addition to the failed fuel canning equipment described in Section 5.2.5.

Spent Fuel Ports

Spent fuel ports are mounted in port sleeves embedded in the walls between the spent fuel discharge room and the fuelling machine maintenance locks. Two ball valves are mounted in series on the bay end of each port to seal the port and maintain the containment boundary.

The ports are cantilevered from the discharge room end, via a flange on the port housing, to provide the degree of flexibility necessary for fuelling machine lock-up. A detachable stainless-steel liner tube is installed in the bore of the port housing, forming an annulus between the liner and the housing, for emergency cooling of irradiated fuel, if required. The liner has a row of 10 holes along the top and 5 holes radially around the fuelling machine end. The annulus connects to the standby cooling system water supply to provide adequate cooling water through the liner holes for cooling of any irradiated fuel bundles, which may, inadvertently, be held up in the port.

Elevators

Two elevator ladles accept the fuel bundles from the spent fuel ports and are electrically driven to lower them onto a conveyor 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 can be driven down to 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.

5.2.2 Spent Fuel Transfer Auxiliaries

The spent fuel transfer auxiliaries comprise a series of systems, which provide the fluid flows (air and water) for the spent 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.

Standby Cooling System

The standby cooling system can be initiated to provide cooling water to the spent fuel port via its liner tube and/or to the length of travel to the bay water via spray headers mounted parallel to the elevator ladle rails, to provide cooling to exposed irradiated fuel if the discharge process is delayed.

D_2O Leak Collection System

The D_2O leak collection system collects heavy water that leaks past the inner ball valve seals into the spent fuel port cavity between the inner and outer valves, during fuelling machine operations at the spent fuel port, when the fuelling machine and spent fuel port are filled with heavy water and pressurized. The D_2O leak collection system includes a pneumatically operated drain valve, which is connected to the cavity between the port valves and is opened to drain any heavy water into the D_2O system. At the same time, the cavity is supplied with air to assist in clearing any heavy water from the cavity.

Fuelling Machine Overflow Detection System

The fuelling machine overflow detection system includes a D_2O collection container located below the discharge end of the spent fuel port, and connected to the port. The container is drained into the spent fuel discharge bay through a removable orifice. If the level of heavy water in the fuelling machine fails to be lowered, a liquid level detector probe in the container actuates a transmitter.

Port Valve Actuating System

The port ball valve actuating system is used to operate the spent fuel port ball valves via pneumatic actuators.

5.2.3 Spent fuel transfer equipment

Spent fuel transfer equipment, shown in Figure 14, includes the following components.

Conveyor Rack

Each conveyor rack (also referred to as a transfer rack) can receive up to 12 fuel bundles from the spent fuel discharge elevator in two rows of 6; although 8 are normally carried. A conveyor rack can also accommodate canned failed fuel bundles.

Conveyor Cart

The conveyor cart (also referred to as a transfer cart) supports the conveyor rack and travels between the discharge bay and the reception bay on conveyors. The cart runs on eight stainless steel wheels which enable it to traverse the gap between the two conveyors. The cart engages drive chains on each conveyor.

Discharge Bay and Transfer Canal Conveyors

Two conveyors, the discharge bay and transfer canal conveyors (also referred to as spent fuel transfer conveyors), allow the conveyor cart to travel between the discharge bay and the reception bay. The transfer canal conveyor is sometimes also referred to as the reception bay conveyor.

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. A mechanical stop is mounted at each end of cart travel. The two conveyors are driven by electrical motors mounted above water on the discharge bay walkway floors, and vertical shafts used to drive the underwater gearboxes, conveyor sprockets and chain.

The discharge bay conveyor is mounted on a series of supports secured to embedments in the bottom of the reception bay. The conveyor is secured to the supports by captive screws and tapered alignment pins which facilitate conveyor removal and installation. The conveyor is also provided with lifting lugs.

The transfer canal conveyor is mounted on supports in the bay and also sits directly on the concrete in the transfer canal. It is located laterally and vertically by a slotted bracket assembly at the discharge bay end of the canal and is secured by captive screws and tapered alignment pins only at the reception bay end to facilitate removal and installation.

Fuel Transfer Canal Containment Gate

The fuel transfer canal containment gate is located at the entrance to the fuel transfer canal in the spent fuel discharge bay. The stainless steel gate is raised and lowered by a pneumatic actuator and includes a safety latch actuated by a second pneumatic actuator. It is closed and becomes part of the containment boundary when the spent fuel port ball valves are open during the discharge of irradiated fuel from the fuelling machine and through the spent fuel port. Otherwise the gate is normally open to permit water circulation between the bays. The containment gate opening permits passage of the conveyor cart with a full load of fuel.

Storage Tray Conveyor

The storage tray conveyor transports spent fuel storage trays, in any state of loading, between the reception bay and the storage bay. The manually driven storage tray conveyor has three superimposed frames, capable of telescopic extension. The bottom frame is bolted to the floor of the reception bay, while the other end extends into a rectangular opening in the wall between the reception bay and storage bay. The storage tray conveyor is manually operated from a handwheel located on the reception bay walkway and extended or retracted to the limit of its travel as required.

Tools and Accessories

Spent fuel transfer equipment tools and accessories are located in the reception bay. They enable fuel bundles to be transferred from the conveyor rack to a storage tray.

5.2.4 Storage Bay Equipment

Storage bay equipment, which can be seen in Figure 1, includes the following components in addition to the failed fuel handling equipment described in Section 5.2.6.

Storage Bay Manbridge

The spent fuel storage bay manbridge consists of an over-running, electric, travelling crane to which an under-slung walkway is attached. A 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 irradiated 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.

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 to support and separate the fuel bundles. The trays are stackable. Each tray is provided with two lifting plates corresponding to the pins on the storage tray lifting tool. Each tray is also provided with two tapered locating pins and two slots, the pins engaging with the slots of the next-higher tray in the stack.

Storage Tray Supports

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 raised pads.

Storage Tray Lifting Tool

This tool is similar to the storage tray lifting tool used in the reception bay, except for the length of the tool and the orientation of the handle to the head.

5.2.5 Failed Fuel Canning Equipment

The following failed fuel canning tools and equipment, shown on Figure 15, are available in the spent fuel discharge bay.

Carousel

A carousel provides temporary storage for failed fuel, for a decay period of up to two months after the bundle has been discharged from a fuelling machine. The carousel base is a weldment of angles bolted onto the bay floor. The outside walls consist of an octagonal lower section open at the bottom, with a removable conical hood also of octagonal shape covering the top of the tray. The 360° tray is divided into 12 sections, with each section capable of holding one failed fuel bundle. The maximum capacity of the carousel is 11 bundles, to allow an empty section to line up with the open portion of the carousel canopy. The carousel is manually operated from a handle located on the discharge bay walkway. A ventilation pipe connects the hood to the radioactive off-gas waste management system, to collect and purge active gases released by the failed fuel bundles in the carousel.

Failed Fuel Can

Each stainless steel failed fuel can is able to accommodate one failed fuel bundle after the necessary decay period in the carousel. The can has one open end for the bundle insertion, while other end is blanked and punched with a small hole to prevent pressure building up inside the can, during and after canning operations. The can is sealed by a lid, after the failed fuel bundle has been pushed into it.

Canning Device

The canning device consists of a can storage rack, a can support, a fuel bundle trough, and a bundle transfer ram. All these components are submerged and mounted on the canning device support frame.

Failed Fuel Bundle Lifting Tool

The failed fuel bundle lifting tool enables failed fuel bundles to be lifted from the conveyor rack into the carousel, and from the carousel to the canning device.

Lid Rack Handling Tool

The lid rack handling tool is used to transfer full lid racks from the ladle onto the canning device, and move empty lid racks back to the elevating table.

Elevating Table

The elevating table is a carbon-steel rectangular table, which can be hooked onto either of the elevator ladles. A rack of can lids can then be loaded onto the table and lowered into the bay by the elevator.

Can Handling Tool

This tool is used to move empty failed fuel cans between the elevator ladle and the can storage rack, between the rack and the trough, and to move full cans between the trough and conveyor rack.

Lid Handling Tool

This tool allows the failed fuel can lids to be picked up from the storage rack and placed in position in the canning equipment ram. The tool consists of a length of pipe, with a hook at the top and a contoured fork at the bottom.

5.2.6 Failed Fuel Handling Equipment

The following failed fuel handling tools and equipment are available in the reception bay.

Transition Table

The transition table is used to provide a transition point between the reception bay and the failed fuel storage area, which is lower, and to accommodate the tools of different lengths.

Can Handling Tool

Two can handling tools are provided for handling cans of failed fuel in the reception bay. These tools are similar to the can handling tool used in the discharge bay. Each tool consists of a handle connected to a double lifting hook by a length of pipe.

Failed Fuel Handling Storage Tray

These trays are of similar construction to the main storage trays, but can only hold 10 canned fuel bundles in a single row. These trays are also stackable.

5.3 System Operation

5.3.1 Normal Operation

Irradiated fuel bundles removed from the reactor remain immersed in heavy water within the fuelling machine until the fuelling machine magazine rotates to align the first pair of bundles with the spent fuel port. This raises the two bundles above the heavy water level inside the fuelling machine head and exposes them to air. This rotation starts a timer to measure the time the fuel bundles are exposed to air. The irradiated bundles will normally be exposed to air for less than two minutes.

After irradiated fuel is received, two bundles at a time from the fuelling machine via the spent fuel port, the elevator lowers the bundles into the water of the discharge bay, and deposits them on the conveyor rack, supported by the conveyor cart and correctly indexed under the elevator by the discharge bay conveyor drive, in position to receive pairs of fuel bundles.

If, due to a delay, the irradiated fuel remains in air longer than a predetermined time, an alarm is provided to the operator. In such a case, the operator would then select one of the following options to supply cooling water to the exposed fuel bundles, to prevent fuel bundle overheating and possible subsequent bundle failure.

If the fuel bundles are stuck in the port and the outer ball valve can be closed, the level of heavy water in the fuelling machine can be raised to flood the port with heavy water and cool the fuel.

The standby cooling system can be initiated to provide cooling water to the spent fuel port via its liner tube if fuel is stuck in the port such that the outer ball valve cannot be closed, and/or to the length of the elevator travel to the bay water via spray headers mounted parallel to the elevator ladle rails, if fuel is stuck on the elevator.

Once all fuel bundles are discharged onto the conveyor rack, the containment is sealed by closing the spent fuel port globe valves, and the containment gate is then opened. The conveyor cart then travels on the discharge bay conveyor up to the containment gate. Once the cart reaches the space between the two conveyors, one slotted bracket on the cart disengages the pins of the chain as the pins go around the sprocket of the first conveyor. This automatically aligns the other slotted bracket of the cart to engage the pins of the reception bay conveyor chain, which then moves the cart to the reception bay.

The fuel bundles are then transferred individually to a spent fuel storage tray. Full storage trays are moved onto the extendable storage tray conveyor for transfer to the storage bay via an opening in the wall between the two bays. Once in the storage bay, individual trays are lifted by a hoist on the storage bay manbridge and placed in stacks on a storage tray support. The storage tray conveyor then retracts until it closes the opening in the wall with its flow obstruction plate. This minimizes the movement of water between the two bays.

An operator on the manbridge manoeuvres all storage trays, and stacks them, using an electrical hoist and storage tray handling tool.

Irradiated fuel bundles are typically stored in the spent fuel bays for a minimum of six years prior to transfer to dry storage; this allows the heat of a natural uranium fuel bundle with maximum burnup to decay enough to allow for dry storage. The typical transfer of irradiated fuel to dry storage involves transferring irradiated fuel from storage trays into a storage basket, drying and seal welding the basket, transferring the basket, via a transfer flask, to one of the multiple storage cylinders within a concrete storage module. Fuel transfers are typically carried in batch processes where the inventory from approximately one year of irradiated fuel production is transferred to dry storage. The quantity of fuel baskets transferred to dry storage is selected to completely fill the storage cylinders involved. Refer to Chapter 19 for additional information on the dry storage of irradiated fuel.

The spent fuel storage bay can accommodate the storage of irradiated fuel in stacked spent fuel storage trays, in addition to the space required for equipment to prepare the fuel for dry storage. The storage capacity of the spent fuel storage bay accommodates the storage of irradiated fuel for a minimum of six years of wet-storage after removal from the reactor, the accumulation of inventory from at least one year of irradiated fuel production for transfer to dry storage, plus a half-core off-load (sometimes referred to as one loop) for emergency purposes.

Normal handling of irradiated fuel bundles in air or light water does not pose criticality problems for natural uranium fuel.

Operations are carried under water as much as possible and the amount of time irradiated fuel spends in air is minimized to maintain acceptable temperatures for the irradiated fuel and prevent fuel damage.

During handling, the fuel bundle is supported on at least two bands of its wear pads. Minor axial forces only are directly applied to the fuel sheaths via the endplates and endcaps.

Discharge operations are controlled remotely and the spent fuel discharge room is inaccessible to personnel while irradiated fuel is being discharged or when there is a high radiation field. The depth of water in the spent fuel bays has been calculated to limit exposure to any personnel in the area to well below allowable levels. Long-handled manual tools have markers to show safe operating lift heights. Fixed area monitors are permanently installed in the spent fuel transfer and storage areas and provide safe notification to personnel when radiation levels exceed allowables. Consequently, operators do not normally require personal protective equipment for radiation protection when handling irradiated fuel during normal operation.

5.3.2 Failed Fuel Handling

Once a failed fuel bundle has been detected, identified and removed from the reactor, it is discharged from the fuelling machine head and lowered on the spent fuel elevator in the same way as a normal fuel bundle. However, in the case of a failed fuel bundle, the conveyor rack is indexed two positions and the failed fuel bundle is removed from the rack and inserted into the carousel using the failed fuel bundle lifting tool suspended from the discharge bay monorail hoist. The carousel is then indexed to position the bundle under the carousel canopy.

The failed fuel bundle is retained in the carousel, where its radioactive gases are captured and directed to the radioactive offgas waste management system, for a period of up to two months, during which time radioactive gases will have decayed to safe levels.

Protective equipment is required when handling the small quantity of failed fuel.

If necessary, the failed fuel bundle is canned; otherwise, it is further handled as a normal bundle. A fuel bundle requiring canning is lifted from the carousel and placed in the trough of the canning device. A manually driven ram is then actuated to push the bundle into the can. A lid handling tool is then used to position the lid such that the ram can drive the lid into the tapered open end of the can.

The canned fuel bundle is then transferred via the discharge bay and transfer canal conveyors into the reception bay.

Canned failed fuel bundles are handled with a can handling tool and stored on failed fuel storage trays in a deeper area of the reception bay specially designated for failed fuel storage. A failed fuel storage tray lifting tool is used to maneuver and stack these trays. The failed fuel area of the reception bay can accommodate the small quantity of failed fuel.

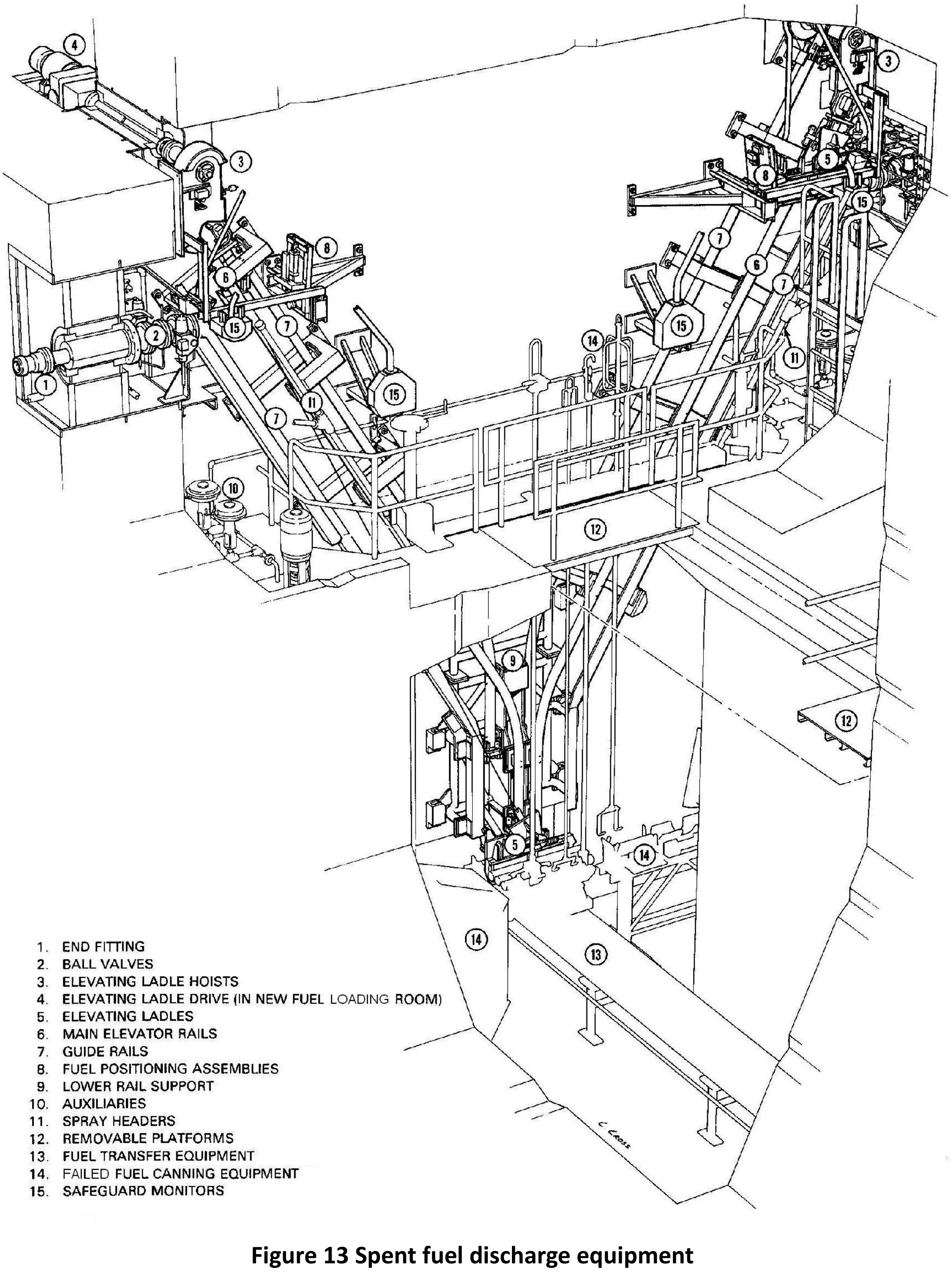

Figure 13 Spent fuel discharge equipment

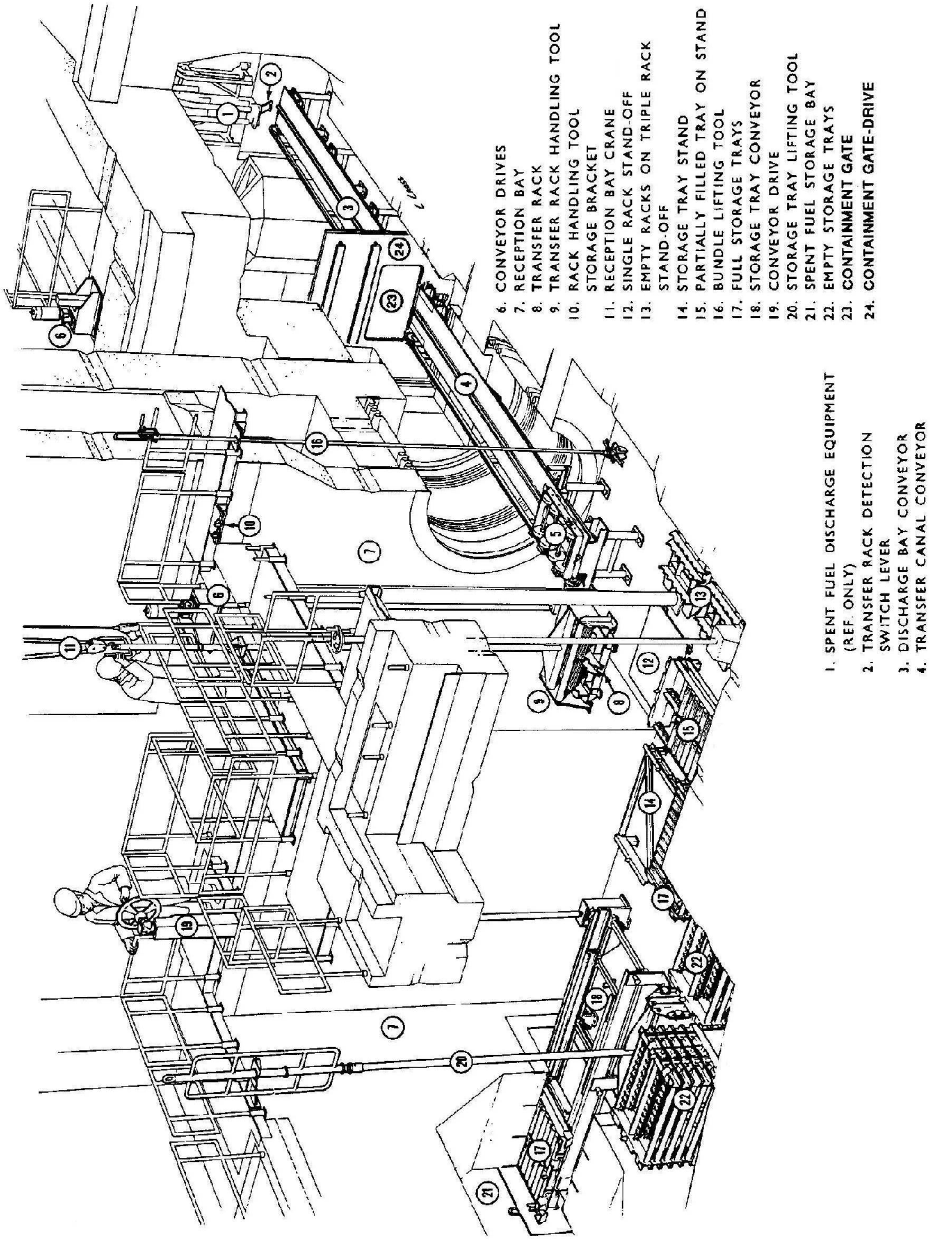

Figure 14 Spent fuel transfer equipment

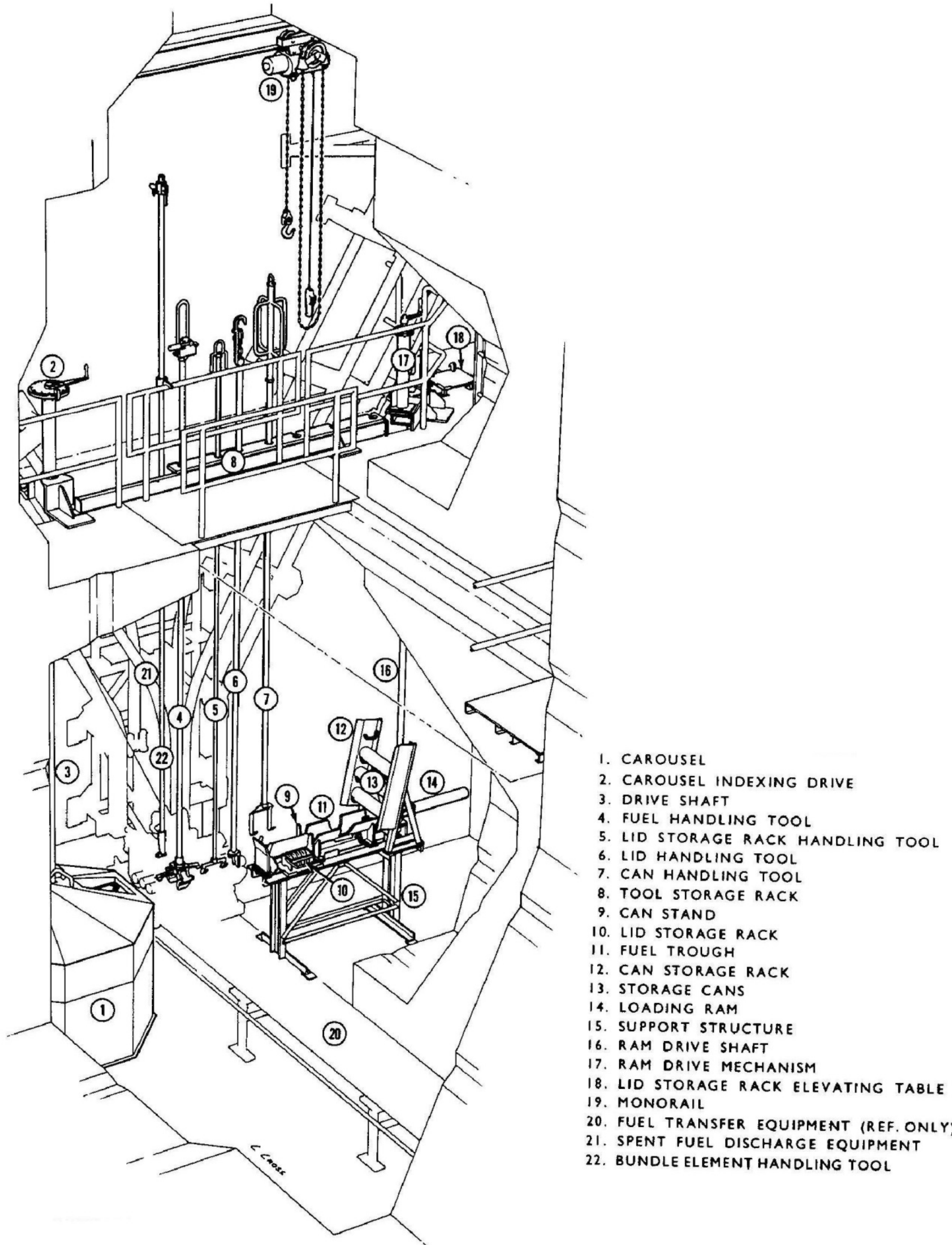

Figure 15 Failed fuel canning equipment

6 Problems

1. To accommodate eight months of reactor operation at equilibrium,
   a. Approximately how many channels are required to be refueled by the fuelling machines?
   b. Approximately how many fuel bundles need to be stored in the new fuel storage room?
   c. How many pallets of new fuel are required?
2. Estimate the minimum number of fuel trays that the spent fuel storage bay needs to accommodate, assuming that fuel is transferred to dry storage when an accumulation of fuel from approximately one year of production has decayed adequately for dry storage?
3. Describe the typical direction of on-channel fuel changing operations and the benefit(s) of operating in this direction.
4. Why does the level of water in the fuelling machine need to be lowered below its snout level for the transfer of fuel bundles to the spent fuel port and from the new fuel port?
5. What measures can be taken if a fuel bundle(s) is (are) stuck during spent fuel transfer?
6. What is the purpose of the snout emergency lock?

7 Further Reading

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