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THE TECHNOLOGY OF CANDU ON-POWER FUELING

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EXECUTIVE SUMMARY

INTRODUCTION

The Canadian designed CANDU (CANada Deuterium Uranium) nuclear reactor is based on a heavy water moderated and cooled reactor that currently operates on a once-through natural uranium fuel cycle in a horizontal Fuel Channel/Pressure Tube Core. There is no need for enriched fuel in the CANDU system.

On-power fueling of CANDU reactors is a major contributor to the proven high capacity factors achieved.

Further advantages of on-power fueling are:

a. optimized burnup of natural uranium and, therefore, lower fueling costs

b. fewer fission products in the primary heat transport system, by enabling early removal of defected fuel bundles

c. more flexibility to plan scheduled shutdown activities that do not have to include fueling operations

d. less excess reactivity available which minimizes the requirements for reactivity control during operation.

On-power fueling of CANDU reactors originated with the 20 MW(e) Nuclear Power Demonstration (NPD) reactor which entered service in 1962. It was recognized at an early stage that CANDU reactors, burning natural uranium fuel with inherently low excess reactivity margins, would be more economical to operate if they utilized on-power fueling. This was further demonstrated with on-power fueling of the 200 MW(e) Douglas Point reactor in 1968. These early fuel handling systems formed the basis for design and development of equipment used in the successful commercial units.

Commercial power plants have been built in single-unit and multi-unit stations. Some of the multi-unit stations are equipped with dedicated fueling machines (F/Ms) for each reactor unit, whereas others are equipped with a shared system.

Double-ended fueling requires the coordinated action of two F/Ms for fueling the present commercial units. Fuel handling design of CANDU 3, that is presently under development, was derived from present proven CANDU systems, but unlike the present commercial units, single-ended fueling using one F/M and a hydraulic fuel pusher system is incorporated. Improvements that have been developed in the past will be incorporated in the CANDU 3 design. For example, electric motor drives will be used in lieu of oil hydraulic motor drives to eliminate oil leakage problems and the potential of a fire hazard.

There are variations in the method used to achieve the basic on-power fueling capability. The different methods that have been successfully developed and incorporated in the operating stations are discussed to provide an insight to on-power fueling.

For descriptive purposes, this report focuses on the CANDU 6 design. These are single unit stations (620 to 680 MW(e)) licensed and operating at Gentilly, Quebec and Point Lepreau, New Brunswick in Canada, and Wolsong, Korea and Embalse, Argentina.

Figure 1 shows the CANDU 6 reactor building cutaway.

Schematics of the CANDU 6 fuel handling sequence and the CANDU 6 F/Ms are shown in Figures 2 and 3 respectively.

The subject matter covers CANDU specific fuel handling requirements, on-power fueling history and F/M history, giving examples of actual case histories. This is followed by fuel design, physics interface and safety analysis. The report concludes with a section on the CANDU 3 design that is presently in an advanced stage of development.

CANDU SPECIFIC ON-POWER FUELING REQUIREMENTS

The purpose of the fuel handling system is to provide on–power fueling capability at a rate sufficient to maintain continuous reactor operation at full power.

The fuel handling system and equipment are designed for enhanced reliability and maintainability to facilitate maintenance between fueling operations and to minimize the contribution to overall incapability of the station due to fuel handling equipment unavailability. The access and maintainability are designed with the principle of reducing radiation exposure to operators and maintainers following the ALARA principle. All equipment is designed to withstand floor response spectra based on ground motion earthquake conditions appropriate to the station site.

A series of Canadian Standards Association (CSA) standards has been produced to provide uniform rules for the design, fabrication, examination and inspection of pressure-retaining systems and components in CANDU nuclear power plants. These rules are needed to complement those specified in the ASME Boiler and Pressure Vessel Code. Modification of the ASME rules, as well as additional rules, are required to address both administrative systems and the design concepts, which are uniquely Canadian.

During on-power fueling, the F/M head becomes an extension of the reactor fuel channel end fitting and is subjected to the pressure in the primary heat transport system. The F/M is designed as a reliable high integrity device. Portions of it are equivalent to static pressure vessels and meet the requirements of the ASME Boiler and Pressure Vessels code, Section III Class 1.

Since the F/M must visit different reactor fuel channels, the fuel transfer port and auxiliary ports, its support system must provide the required transport mobility, whereas the requirements for ASME pressure vessel supports generally address static structural components.

As an example, an elevating bridge and carriage is commonly used to move a F/M from one reactor channel to another for on-power fueling. A mechanism such as a ball screw and nut assembly is often used to produce bridge and carriage motion and to provide support. Rules primarily cover the construction of these mechanisms and the control and interlock requirements necessary to prevent over-stressing of the pressure boundary, or its support, caused by inappropriate support movement. Rules for a safety lock on each channel closure to prevent it from being unintentionally released from a fuel channel are covered as well as a F/M safety lock to prevent uncoupling of the F/M from the reactor fuel channel when the channel closure is removed and the reactor is pressurized. Elastomeric hoses, the failure of which results in release of fluid, are also covered. These are all designed to CAN/CSA-N285.2-M89, Requirements for Class 1C, 2C and 3C Pressure Retaining Components and Supports in CANDU Nuclear Power Plants.

Additionally, the on-power fueling concept requires the F/M pressure boundary and its support structure to be seismically qualified to the requirements of CAN3-N289.3, Design Procedures for Seismic Qualification of CANDU Nuclear Power Plants.

DESCRIPTION OF CANDU 6 ON-POWER FUELING

On-power fueling on CANDU reactors involves the exchange of new fuel with irradiated fuel by the fueling machine while the reactor is on power.

New fuel that is shipped in pallets is loaded manually into the new fuel loader that transfers it automatically into the F/M. Irradiated fuel is discharged automatically by the fueling machine into the storage bay.

The reactor building containment is an envelope provided to enclose the nuclear components of the reactor in order to prevent the release of radioactivity to the public in case of reactor component failure.

The fuel transfer port penetrates the containment boundary and is equipped with double valves in series. When the F/M clamps onto the fuel transfer port during fuel discharge, it becomes a part of the reactor building containment boundary.

When the F/Ms are connected to the reactor fuel channel end fittings during fueling, they become extensions of the primary heat transport system, when the channel closures are removed. Thus the F/M pressure boundary is designed in accordance with CAN/CSA -N285.0 series and the ASME Pressure Vessel Code, Section III Class 1 requirements. While in transit from reactor to fuel transfer port, the F/M utilizes its own cooling system.

The normal fueling rate for a CANDU 6 reactor is 112 bundles or 14 channels per week under normal steady state fueling conditions. Fueling normally consists of charging and discharging eight fuel bundles on each fuel channel visit.

The F/M basically comprises a snout, separators, magazine and a ram assembly. The snout allows the F/M to clamp on and seal to the reactor fuel channel end fitting. The magazine provides a number of rotor stations to house fuel bundles and the F/M and fuel channel hardware components, such as channel closures, shield plugs, ram adaptor and other items, that are required to carry out the fueling operation. The ram assembly provides the mechanical actuation of the fuel channel and F/M hardware components. Two of the ram motions are provided by water lubricated ballscrew mechanisms that are supported on water lubricated anti-friction bearings. The ram and magazine drive shafts penetrate the pressure boundary and are driven by oil hydraulic motors. A third ram incorporates a water-actuated telescopic mechanism.

The separator assemblies monitor the fuel string location during fuel changing, and can hold back the fuel string against the hydraulic drag of the coolant in the fuel channel during fuel bundle separation and magazine rotor indexing.

The F/M and its support system is designed to meet the seismic requirements pertaining to each reactor site. This is to ensure the integrity of the pressure retaining components during a seismic event. Analysis covers both the attached and unattached cases, relative to the reactor fuel channel. Some of the analytical models have been validated by actual tests in the engineering test facilities. The equipment is designed to withstand a design basis earthquake (DBE) without pressure boundary failure to preclude fission product release but not necessarily to remain fully operational, except for maintaining fuel cooling capability.

Used fuel is placed in the wet storage bay that is located in a building adjacent to the reactor containment building. After a minimum of five years, used fuel is placed in dry concrete storage cannisters that are located outdoors at the site for continued interim storage.

Permanent disposal of used fuel is expected to take place in an underground vault in granitic rock commencing in 2035, when there will be sufficient inventory to achieve economical operation. Permanent disposal is not within the scope of this report and is covered separately.

ON-POWER FUELING HISTORY

Continuing development programs serve to further advance the technology of the CANDU fuel handling system. Station incapability due to fuel handling may result if it becomes necessary to derate the reactor as a result of insufficient reactivity due to inability of the fuel handling system to maintain on-power fueling as required. Improvements have been made to enhance equipment performance and increase fueling capacity so that there will be more time available for maintenance.

As part of the CANDU program, a fuel handling technology that involves the design of corrosion resistant water lubricated mechanisms and high pressure shaft seals has been highly developed at AECL CANDU. In conjunction with this technology, substantial test data on galling and wear resistance between different mating materials in water have been accumulated over a number of years. Successful performance of F/M components such as gears, anti-friction ball bearings, shaft seals and ballscrews operating in a water environment developed over the past 25 to 30 years is applied to the operating F/Ms as well as those under development.

The CANDU 6 F/M head is a derivative of the Pickering machine and much of the modular components are nearly identical. Hence, a common development program embraces the two systems. Although the Bruce/Darlington F/Ms are different, there is commonality in the basic technology. This also applies to the different fuel transfer and storage systems that are tailored to meet the different station layout and performance requirements. CANDU 6 is a single unit station, whereas Pickering and Bruce/Darlington are multi-unit stations.

In mature operating stations, reactor operation may be affected due to pressure tube In-Service Inspection Programs. Such programs often require the use of some of the fuel handling equipment.

FUELING MACHINE RECOVERY

In the event that a malfunctioning F/M is required to be recovered from the reactor end fitting while ensuring the fuel remains cooled and maintenance personnel are not exposed to radiation, provision is made by built-in redundancy and manual drives that can be driven with tools working through penetrations into the reactor vault shielding. Grapples are used in a functioning F/M to defuel a channel with the reactor shut down, working from one end of the channel with the other F/M or special tooling, including removal of fuel from the disabled F/M head. For F/M recovery, experience has shown that tooling can be built as required at the time, rather than to have a number of tools on hand to meet postulated events.

For single-ended fueling as in CANDU 3, recovery of a malfunctioned F/M from the reactor must be readily carried out where possible without grappling the fuel string and bundles trapped in the channel or F/M magazine, working from the outlet end of the fuel channel. A more involved recovery scheme using special tooling is required to grapple fuel from the inlet end of the fuel channel. This has been thoroughly investigated and the recovery scenarios are fully documented. To assist in achieving this aim, limited shielding that envelops the F/M magazine housing is provided. Defueling will be possible using a special flask that can be used from the other end of the fuel channel.

This chapter provides detailed descriptions of these aspects of the CANDU fuel handling system. Examples are given to show how significant malfunctions have been resolved in the past. Subsequent to these occurrences, modifications have been incorporated into the F/M to preclude recurrence. For example, in one instance, the F/M snout became stuck on the reactor end fitting due to hydraulic lock-up in the actuating system when the temperature of the hydraulic fluid increased. The return line was remotely severed to reduce back pressure and the actuating pressure was increased to free the snout from the reactor. This was subsequently rectified by a modification to the oil hydraulic system.

Other modifications that were carried out after significant malfunction include addition of an obstruction in the guide sleeve station in the F/M magazine rotor to prevent a fuel bundle from entering this position. Difficulty would be encountered in pushing a fuel bundle from the larger bore to the smaller bore because the guide sleeve station bore is larger than that of fuel bundle stations.

INTERACTIONS OF ON-POWER FUELING WITH REACTOR PHYSICS AND FUEL DESIGN

The CANDU reactor design was predicated on the basis of capability to use natural uranium as fuel. This means that even with the use of heavy water as moderator and coolant, the excess reactivity of a fresh core is quite small. Consequently, on-power fueling is necessary to achieve a reasonable energy production per unit mass of fuel. The capability to replace fuel on-power, combined with constructing the fuel in the form of short bundles of elements, provides the flexibility in fuel management to achieve maximum fuel utilization.

Analytical studies show that an ideal reactor from the point of view of fuel utilization is one which is continuously fueled and hence operates on the average with very little neutron absorption in non-fuel components such as control rods. The original CANDU design concept approximated this ideal by use of fuel bundles only 0.5 m (20 in.) long and designing the fuel handling system to push these bundles through the channels in opposite directions in adjacent channels. This bi-directional scheme would ensure a symmetric axial power distribution in the global sense. This was easy to accomplish by providing a F/M at each end of the reactor. One machine inserted fresh fuel at one end of the channel and the other would receive irradiated fuel discharged from the other end. It was originally thought that a maximum of two bundles should be replaced upon each visit to a channel to well approximate the continuous fueling model. Therefore the F/Ms were designed to replace two bundles in one operation.

With the development of software able to simulate discrete bundle movements, it was possible to evaluate the advantages and disadvantages of replacing more than two bundles per visit to a channel. It was found that the penalty on fuel utilization was not very large even if eight of the twelve bundles in a channel were replaced each channel visit. Therefore, CANDU reactors operate today with replacement schemes of four or eight bundles per visit (referred to as four or eight bundle shift fueling schemes).

The number of bundles replaced per visit affects the physics in that as the number increases, the local perturbation in power caused by the fueling operation also increases. This is called "fueling ripple". The fueling scheme also affects the axial power distribution. For example, use of an eight-bundle shift scheme causes some flattening of the distribution.

The ability to change fuel in any channel at any time provides the option to use the fueling strategy to control the radial power distribution very effectively. Therefore the CANDU design assumes this method of power shape control is utilized. This means that except for an initial transition period from an all-fresh core to one with a distribution of fuel irradiations, the power distributions and physics characteristics remain constant in a global sense. This is described as a core at "equilibrium" burn-up.

The CANDU 3 reactor is designed to be fueled from one end only. This requires the complete channel to be emptied into the machine, and then some of the fuel re-inserted together with some new fuel. This affords the option of controlling axial power distribution by the choice of where the new and old bundles are placed in the channel. This chapter contains a brief summary of the physics, reactivity control, and fuel management implications of single-ended fueling.

There are also aspects of fuel detail design which require taking into account phenomena unique to on-power fueling. These include loading from flowing fluid and F/M imposed motion and power level changes due to fueling.

SAFETY ASSESSMENT OF FUEL HANDLING

Safety assessment of fuel handling events for CANDU reactors involves a review of past fuel handling accidents, a probabilistic assessment of the frequency of various failure modes, and deterministic analysis of postulated failures or misoperation of the fuel handling system.

Besides accidents with some release of radioactivity, incidents occurred which incapacitated the fuel handling system, without activity releases, resulting merely in economic consequences. A detailed review of malfunctioning of CANDU fuel handling systems, whether the events represented only economic or also safety concerns, and of the ensuing corrective measures, is presented.

With an accumulated experience of about 250 years of CANDU reactor operation with on-power refueling by 1990, the assessment of fuel handling safety starts with a review of past encounters, which had safety implications.

Some events occurred with fuel failures which resulted in some small activity release within the containment building. In the early CANDUs some coolant hoses failed and had to be redesigned. To prevent overheating of irradiated fuel in a F/M with impaired cooling, the reactor operators learned to rotate the magazine, so that the fuel bundles can be cooled alternately by the water remaining in the F/M. Also, it was possible to speed up the discharge of fuel from a F/M with impaired coolant flow.

An accident in a multi-unit CANDU reactor involved a stuck irradiated fuel elevator, where an air-cooled irradiated fuel bundle overheated and disintegrated. Spray cooling was subsequently retrofitted to the elevator. In another incident in a multi-unit CANDU, a F/M bridge moved after a F/M was clamped on a fuel channel end fitting for refueling. The displacement caused some leakage of primary coolant. Improved interlocking in the computer control system resolved this issue. In the early KANUPP reactor, an incident of shearing a fuel bundle occurred within the F/M. Improved position sensors and magazine indexing locks will preclude recurrence of a similar event.

Detailed fault tree analysis is performed of the F/M system to identify possible modes of occurrence of undesired events and by probabilistic analysis the expected frequencies of such events are assessed. This analysis depends on statistical data on component, system and human reliability. Where such data is not sufficient from experience or development tests, conservative assumptions are made. Unless the probability of an accident is very low, the possible consequences are evaluated by analytical simulations of the events, and when needed supported by separate effect tests.

The deterministic analyses are performed on postulated event sequences with possible release of radioactive fission products, from overheated and failed fuel or from primary coolant with its inherent radioactivity.

Loss-of-coolant accidents (LOCA) from the F/M were analyzed for cases with the F/Ms being attached to a fuel channel, that is, while the F/Ms are "on" reactor, and for cases when the F/Ms are not attached to the reactor, that is, "off" reactor. In an "on" or "off" reactor, the worst cases considered were either a break of all hoses to the F/M or a failure of the F/M snout-to-end fitting connection ("on") or merely a snout failure ("off").

The consequences of these F/M related accidents were found to be within more severe accidents analyzed for the primary coolant system. The combined hose breaks are less severe than a small break LOCA (e.g., a feeder break). In a failure of snout connection or closure, the ejections of fewer and more decayed fuel bundles are less severe than in a postulated end fitting failure, in which case all twelve fuel bundles from a channel are assumed to be ejected from a fuel channel with instantaneous release of their fission product inventories.

In an "on" reactor LOCA, the discharge of the primary coolant via the F/M alleviates the fuel heat up in a magazine. In "off" reactor accidents the affected fuel is decayed at least 10 to 20 minutes longer than in "on" reactor events. The results of studies with break of all hoses also apply to other causes of loss of cooling within the F/M, for example, by loss of electrical power, by pump or motor failure or by jammed or plugged components. In such a case the fuel bundles stored in the magazine of the F/M can overheat only after evaporation or leakage of coolant to a level lower than that of the irradiated fuel. This transient heat up and the release of any fission products from failed bundles are calculated. The release of fission products from the F/M is slowed down by the lack of a powerful blowdown and by fission product plating out on the structural components within the F/M.

After a postulated failure of snout to end fitting connections or of snout closure, there is a possibility of some fuel bundles being ejected to the floor. The heat up of the fuel and any fission product releases in these events were treated as in an end fitting failure.

Although tests were performed to ascertain that fuel elements of a bundle can survive the impact on the floor after an ejection, bundle failure by subsequent lack of cooling is still a possibility. The thermal consequences of such events were investigated by tests on electrically heated fuel bundles on concrete slabs. The test results were well simulated by analyses. The thermal studies combined with established fuel failure and activity release models predict the consequences of either fuel bundles heating up on the floor or in a F/M magazine or port. The predicted fission product release rates were found to be, as expected, less severe than in some LOCAs hypothesized for the primary coolant system.

The expected event frequency of a breached F/M head is very small, but in any case, the consequences of this event would also be bounded by those of a fuel channel end fitting failure.

The safety analyses predict the release of fission products for single failure [...]nts as outlined above, and also calculate activity releases from the containment and doses [...]e population and to the most affected individual after dual failure accidents, such as [...]cident containment impairment. In all these cases the estimated doses were found [...]ptable. This chapter of the report provides analytical methods, results, and acceptance criteria for some of the limiting analysis performed for the CANDU 6 reactors.

CANDU 3 SPECIFIC FEATURES

The CANDU 3 fuel handling system is based on proven CANDU technology utilizing one F/M and a hydraulic fuel pusher system, updated with improvements resulting from on-going development and operating experience.

The CANDU 3 design is based on the following requirements:

a. single-ended fueling, one F/M and fuel transfer system

b. applied proven CANDU technology

c. competitive capital and operating cost and implementation schedule.

Previous CANDU plants carry out fueling by the coordinated operation of two F/Ms, one accepting used fuel, the other inserting new fuel at opposite ends of a selected fuel channel. CANDU 3 single-ended fueling permits fueling with an upstream hydraulic fuel pusher moving the fuel string to only one F/M, at the downstream end of the fuel channel. This results directly in significant capital cost saving, higher reliability with less equipment and indirectly to a smaller reactor building while retaining all the safety features of the CANDU 6 plant.

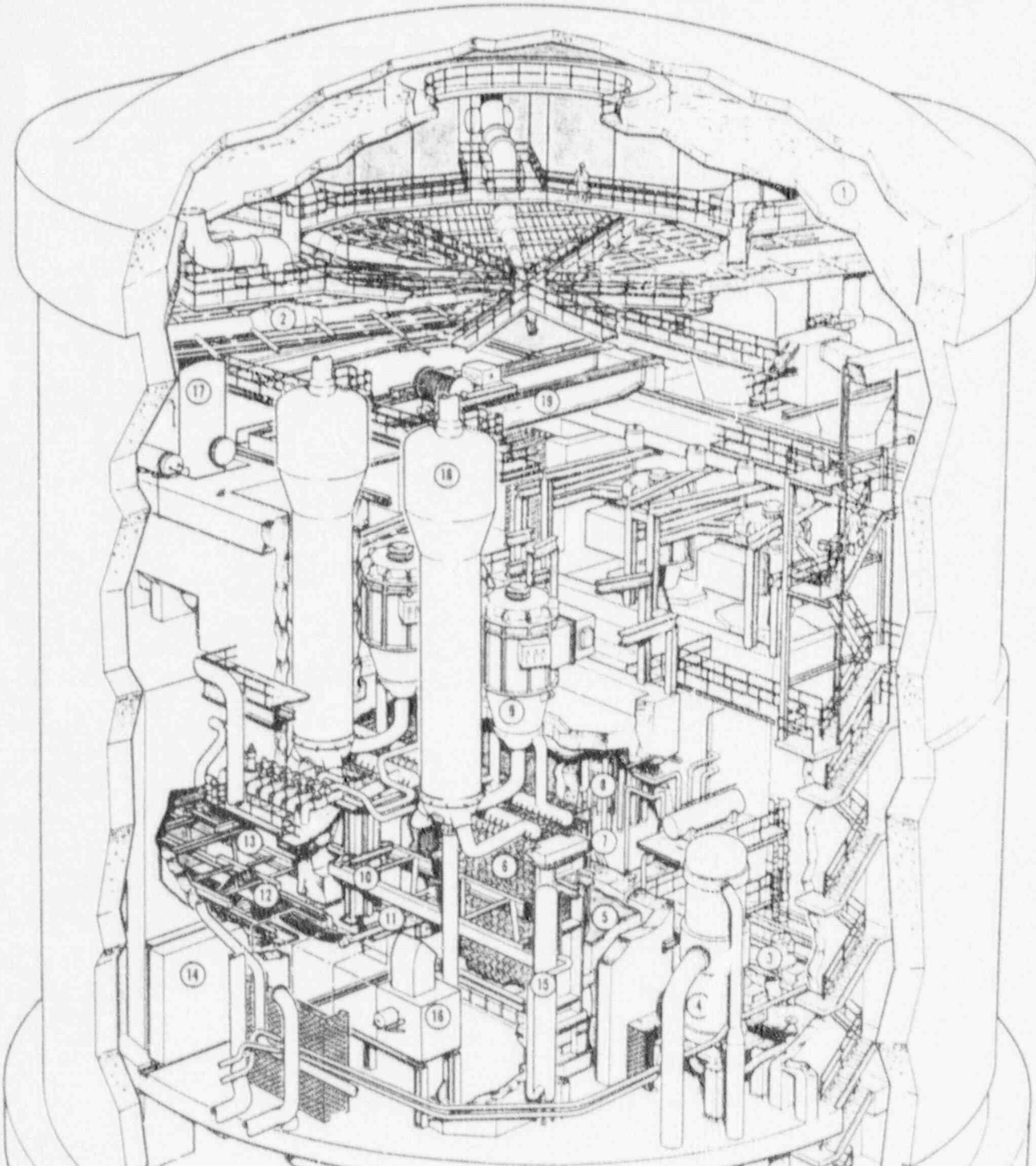
With double-ended fueling systems, the upstream F/M inserts new fuel bundles into the channel. In the central core high-flow channels, hydraulic drag on the fuel bundles is sufficient to move the fuel string along the channel. In the outer, low-flow channels, a flow-assist ram extension (FARE) tool, which is basically a free piston, is inserted by the upstream F/M to create the required impedance to move the fuel string towards the downstream F/M which accepts the used fuel.

With CANDU 3 single-ended fueling, each upstream fuel channel end fitting is provided with a resident fuel pusher, which is basically a modified version of the FARE tool, to create the impedance required to move the fuel string. The fuel channels have balanced flow adjusted for equal enthalpy and all channels have a fuel pusher to provide the required impedance to move the fuel string downstream. The outlet end fitting is provided with a shield plug and a channel closure operable by the F/M, as in the previous system, to perform on-power fueling.

Magazine capacity is arranged to suit single-ended fueling, allowing the operation to be carried out during a single visit to a fuel channel. Adaptation of the existing proven CANDU F/M head has been accomplished by incorporating modifications restricted mainly to the magazine rotor capacity to handle the complete fuel string, plus up to eight new fuel bundles.

Single-ended fueling and the equipment integral with the fueling operation, as well as modifications based on proven CANDU reactors incorporated to expedite maintenance and associated single-ended fueling operations are described.

With single-ended fueling, the recovery scenarios will be based on experience from existing CANDU systems. Additional features have been incorporated on the CANDU 3 design to ensure that recovery capability will not be compromised.



1 DOUSING WATER TANK
2 DOUSING WATER VALVES
3 MODERATOR PUMP
4 MODERATOR HEAT EXCHANGER
5 FEEDER CABINETS
6 REACTOR FACE
7 REACTOR
8 REACTIVITY MECHANISM
9 PRIMARY HEAT TRANSPORT SYSTEM PUMP
10 FUELING MACHINE BRIDGE
11 FUELING MACHINE CARRIAGE
12 FUELING MACHINE CATENARY
13 FUELING MACHINE MAINTENANCE LOCK
14 FUELING MACHINE MAINTENANCE LOCK DOOR
15 END SHIELD COOLING WATER DELAY TANK
16 VAULT COOLER
17 PRESSURIZER
18 STEAM GENERATOR
19 CRANE

FIGURE 1 CANDU 6 REACTOR BUILDING CUTAWAY

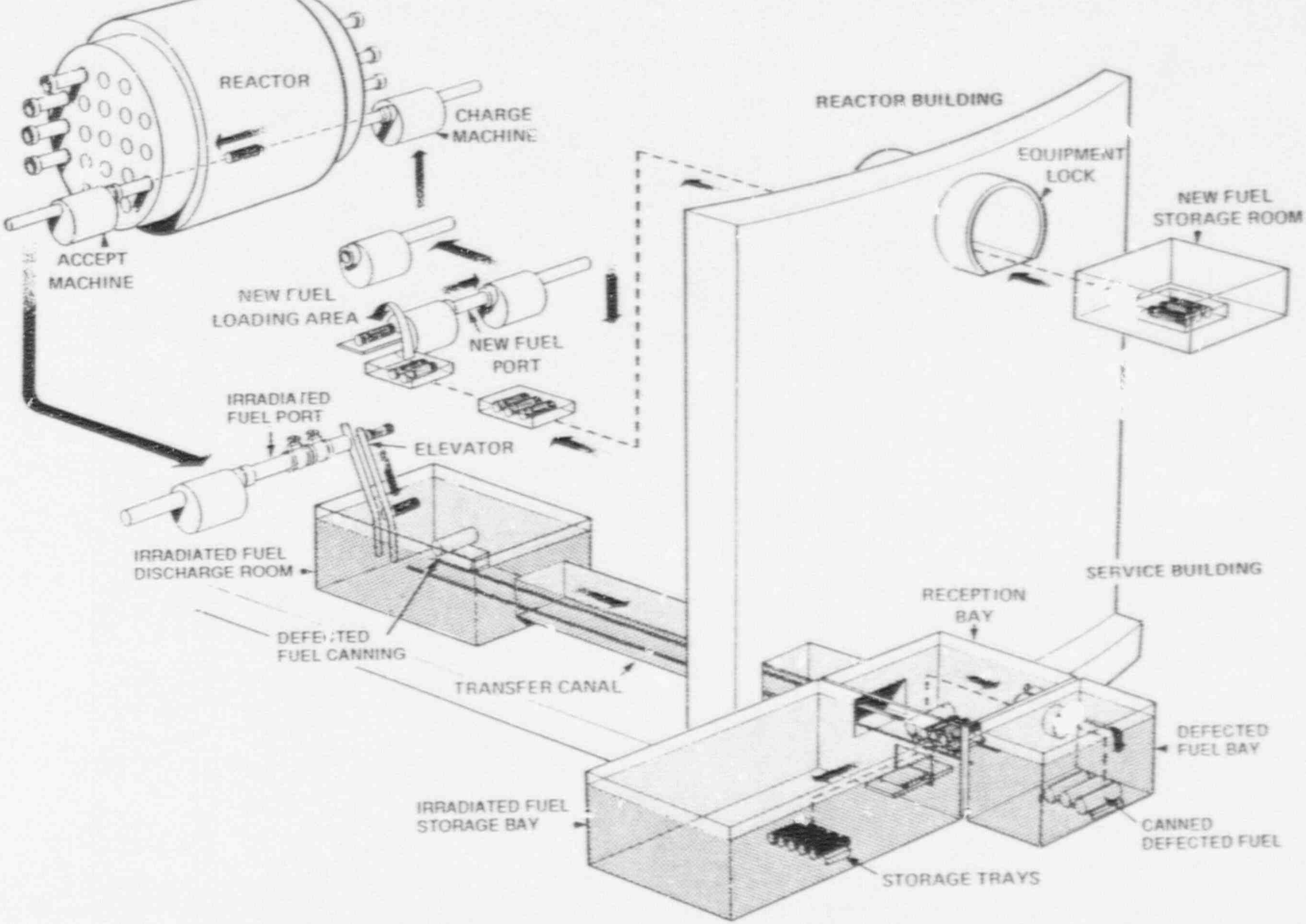


FIGURE 2 CANDU 6 FUEL HANDLING SEQUENCE

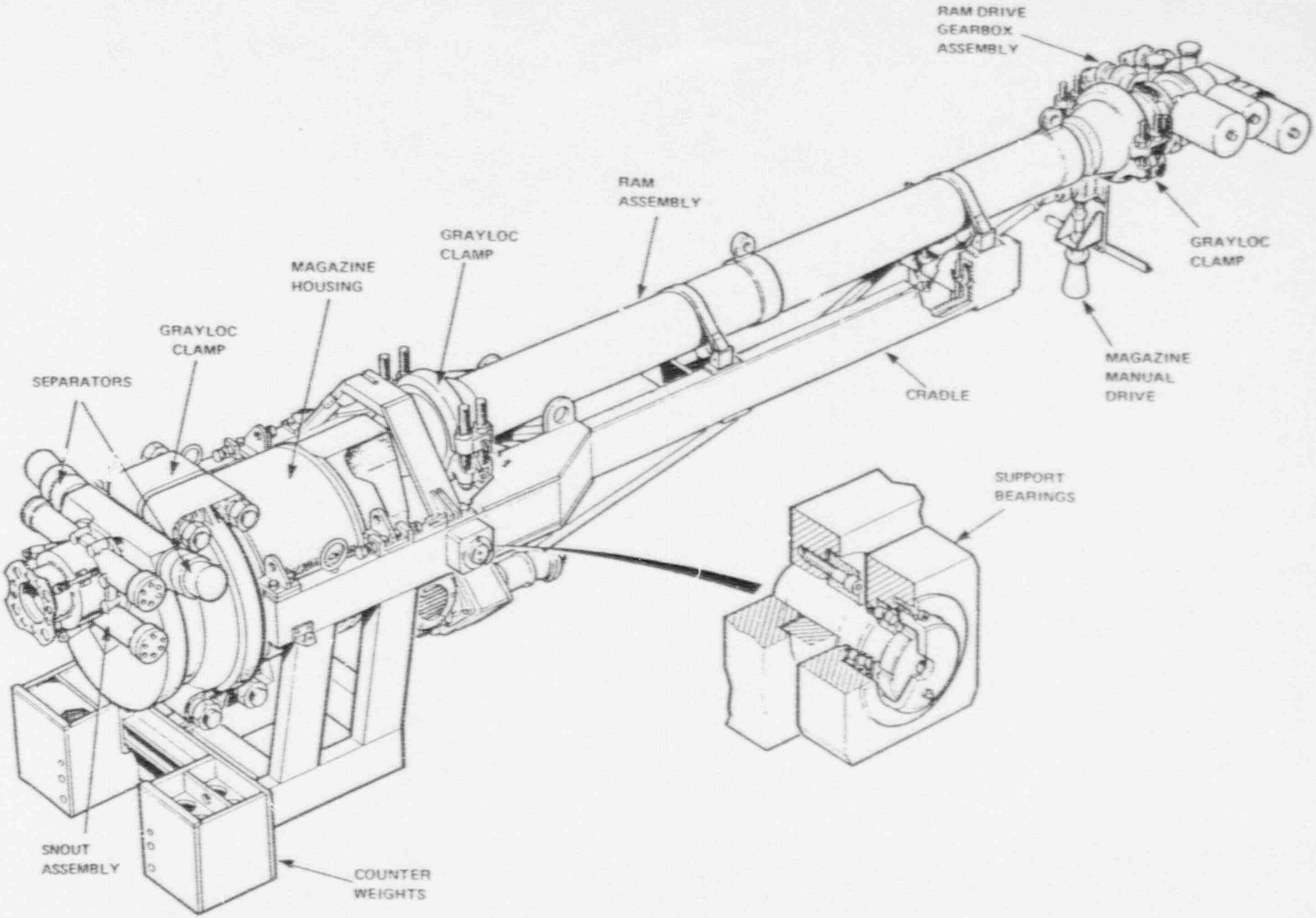


FIGURE 3 CANDU 6 FUELING MACHINE HEAD

ABSTRACT

On-power fueling is an integral feature of the CANDU nuclear power plants.

Two basic fuel changing processes have evolved from the original Nuclear Power Demonstration and Douglas Point prototype designs. Both systems have proven to be equally reliable and have achieved good operating records.

This document describes the CANDU fuel handling system of the present commercial units that have evolved from the prototype designs. The detailed description will focus on the CANDU 6 design for purposes of clarity.

Double-ended fueling requires the coordinated action of two fueling machines for fueling the present commercial units. Fuel handling design of CANDU 3, that is presently underway, was derived from CANDU 6, but unlike the present commercial units, incorporates single-ended fueling.

The description of the fuel handling system is supplemented by an introduction covering the basic features of the different CANDU fueling systems. Background information on the development history as well as fueling machine operating scenarios are also described.

The design of the CANDU fuel handling system is based on standards that are prepared by the Canadian Standards Association and approved as a National Standard of Canada by the Standards Council of Canada.

The design, manufacture, construction, commissioning, operation, and decommissioning of nuclear facilities in Canada are subject to the provisions of the Atomic Energy Control Act and Regulations. The standards are imposed by the Atomic Energy Control Board.

The pressure retaining components are registered under provincial jurisdictional authorities, such as: the Ministry of Consumer and Corporate Relations in the Province of Ontario, and equivalent jurisdiction in other provinces or countries.

This document also includes descriptions of fuel handling interactions with reactor physics and fuel design.

Accident analysis and probabilistic assessment are also discussed in this document.

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CANDU Operations

Énergie atomique du Canada limitée
Opérations CANDU

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CHAPTER 1

INTRODUCTIO N TO CANDU FUEL HANDLING SYSTEM

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1. INTRODUCTION

On-power fueling of CANDU reactors forms the basis for design and development of the commercial units that are now in service. They feature double-ended fueling on a horizontal pressure tube core.

In the evolution of the CANDU Pressured Heavy Water Reactor (PHWR) to the successful commercial stage, a prototype station using light water as coolant was also built at Gentilly, Quebec. This system is known as CANDU-BLW for Boiling Light Water. This system featured vertical pressure tube core with single-ended fueling from the bottom. This unit has since been placed in a partially decommissioned state.

In the latest concept in the family of the CANDU-PHWR's, the CANDU 3 reactor that is presently being developed at AECL CANDU, single-ended fueling is featured on a horizontal pressure tube core.

As prototype stations are permanently shut-down, used fuel has been removed from the wet fuel storage bay and placed in dry storage in concrete canisters that have been constructed at the site.

Wet fuel storage bays are normally sized for ten year capacity.

As the wet fuel storage bays in the operating commercial reactors become full, used fuel can be placed in dry storage as an alternative to construction of auxiliary storage bays.

2. FUEL HANDLING

2.1 GENERAL

The fuel handling system is provided for reception and storage of new fuel, for fuel changing with the reactor at full power and for temporary storage of irradiated fuel.

For a typical single-unit CANDU 6 station, a self-contained fuel changing system is provided (Figure 1-1). For multi-unit stations such as Pickering 'A' and Pickering 'B' which comprise four reactors each, dedicated fuel changing systems are provided for each unit. However, the fuel transfer systems for the units are integrated such that irradiated fuel is transferred routinely via a conveyor to a central irradiated fuel storage bay (Figure 1-2).

In other multi-unit stations such as Bruce 'A', Bruce 'B' and Darlington 'A', a "shared" fuel handling system is adopted, whereby the fuel changing equipment comprising two fueling machines (F/M) can service any of the reactors (Figure 1-3). The two F/Ms are mounted on a common trolley which can traverse a tunnel interconnecting the different reactor units. Irradiated fuel is therefore transported from each reactor, inside the F/M, to the fuel transfer port that is located at the common fuel storage bay.

There are two variations in the basic design of the fuel changing system. The Pickering/CANDU 6 design was derived from Douglas Point. Rajasthan Atomic Power Station (RAPS) and Madras Atomic Power Station (MAPS) in India are nearly identical to Douglas Point. They all incorporate fuel separators on the F/M head to sense the axial position of the fuel bundles as they pass between the F/M and the fuel channel, to act as a fuel string stop, and to push the fuel into the magazine rotor stations in the F/M. During fuel changing, a constant bore passage is provided by a guide sleeve between the F/M magazine rotor station and the fuel channel pressure tube. Fueling is carried out in the direction of fuel channel coolant flow.

Karachi Nuclear Power Project (KANUPP), Bruce and Darlington were derived from Nuclear Power Demonstration (NPD). With this concept, the fuel bundles are placed inside hollow cylindrical tubes called carriers that are placed in the F/M magazine rotor stations. During fuel changing, the fuel bundles remain in the carriers until they are discharged directly into the fuel channel pressure tube or the fuel transfer port. Fueling is carried out against the fuel channel coolant flow. A latch mechanism that is incorporated at the downstream end of each fuel channel, just outboard of the pressure tube rolled joint, maintains the fuel string axial position in the pressure tube. The aforementioned separator assemblies that are required on the Pickering/CANDU 6 F/M are not used.

All of the aforementioned fuel changing systems utilize two identical F/Ms at each end of the fuel channel.

2.2 FUEL BUNDLES

Fuel is fabricated from uranium oxide that is sintered into pellets that are sealed inside zircaloy tubes. Generally, 37 of these elements are grouped together to make up a fuel bundle that is 102 mm (4.02 in.) diameter and 495 mm (19.5 in.) long (Figure 1-4). These elements are held together by end plates. Small pads maintain correct inter-element spacings and bearing pads that support the fuel bundle assembly in the fuel channel are brazed to the elements.

The fuel handling system is designed to limit axial compressive loads on irradiated fuel bundles during normal operation to 18 kN (80 kip). Radial loads are limited to values equal to the normal weight of the fuel bundles.

New CANDU fuel bundles can be handled by personnel without protective shielding. Once the fuel bundles have been irradiated, handling must be carried out remotely with automated machines or with adequate shielding, if handled with manually operated tools. In addition to natural uranium (NU), slightly enriched uranium (SEU), recovered enriched uranium (REU) and mixed oxide (MOX) fuels have been considered. The criticality aspect of new fuel bundles other than NU must be considered. The fuel burn up increases for SEU fuel, compared to NU fuel. As a result, the SEU fueled reactor would consume fuel bundles at one third of the rate of the NU fueled reactor. Provided the bundle geometry is consistent, the F/M will be able to handle all of the different fuel bundles.

2.3 FUEL CHANNEL HARDWARE

The commercial CANDU-PHWRs use horizontal fuel channels arranged in a square lattice grid.

Each fuel channel comprises a zircaloy pressure tube that houses the fuel bundles in the reactor. The pressure tubes are provided with stainless steel end fitting extensions at each end (Figure 1-5). These tubes are mechanically connected using rolled joints. Within the end fittings at the inboard end, removable shield plugs (Figure 1-6) are provided. The ends of the fuel channels are provided with removable channel closures (Figures 1-7 and 1-8).

The fuel bundles in the fuel channel are not mechanically attached and are held together by the coolant flow hydraulic drag forces. In the Pickering/CANDU 6 design, there are twelve fuel bundles in each fuel channel and the fuel string rests against the downstream shield plug.

In the Bruce/Darlington design, there are 13 fuel bundles in each fuel channel and the fuel column is held by the fuel latch incorporated at the downstream end, located approximately one-half bundle length outboard of the calandria. Due to practical reasons, it is not possible to provide a mechanical fuel latch in the zircaloy pressure tube, precisely at the boundary of the calandria.

3. SYSTEM DESCRIPTION

3.1 PROCESS DESCRIPTION

The function of the fuel handling system is to provide on-power, bi-directional fueling capability at a rate sufficient to maintain continuous reactor operation at full power.

The fuel handling system is generally made up of one or more F/M heads, F/M head supports and associated supporting tracks, new fuel loading, irradiated fuel unloading and F/M calibration facilities, irradiated fuel transfer system, plus all associated auxiliaries, power supplies and control systems.

The fuel handling system can be divided into three interrelated systems: new fuel transfer, fuel changing, and irradiated fuel transfer. Figure 1-9 shows the typical movement of fuel, from the new fuel storage area through the reactor to the irradiated fuel storage bay.

The new fuel arrives at the site in pallets. Up to a nine-month supply is stored in the service building new fuel storage area. When required by station operation, the pallets are transferred to the new fuel loading area. There, the fuel bundles are uncrated, inspected and loaded into a F/M via the new fuel port and transfer mechanism. Once loaded with new fuel, the F/M traverses to the reactor face and connects to any one of the fuel channels. A second empty F/M connects to the same fuel channel at the other end of the reactor. Automatic fuel changing operations then commence, with new fuel bundles being loaded at one end while the equivalent number of irradiated fuel bundles is received by the other F/M. Bundle movement is controlled by the two F/Ms, but assisted by the coolant flow inside the channel. As the flow in each alternate channel is reversed for reasons of reactor symmetry, the F/M must be capable of operating bi-directionally, that is, the upstream F/M can perform the functions of the downstream machine and vice versa.

In a typical eight bundle fueling sequence for the Pickering/CANDU 6 design, as shown in Figure 1-10, the following fuel movements inside the fuel channel can be identified:

- Eight new bundles are inserted, two bundles at a time, from the upstream end.
- The whole 20 bundle fuel column (twelve old bundles plus eight new bundles) is moved towards the downstream end.
- Eight old bundles are discharged, two at a time, from the downstream end.
- The remaining twelve bundle fuel column is moved back against the coolant flow to the correct in-reactor position.

On completion of the fuel changing operation, the downstream F/M traverses to the irradiated fuel port and discharges the irradiated fuel bundles to the storage bay via the irradiated fuel port elevator and conveyor. Here, the irradiated fuel bundles are placed in storage trays.

Once the F/M has discharged the irradiated fuel, it goes to the new fuel port to pick up new fuel bundles, and traverses back to the reactor face to become the upstream F/M for the next channel to be fueled. The other F/M, having remained on the reactor face, will also home onto the next channel and now performs the functions required at the downstream side.

Articulated TV cameras, one in each F/M vault and one at the irradiated fuel discharge bay are provided to permit monitoring of critical equipment during breakdown conditions.

3.2 CONTROL SYSTEM

Automatic control by means of computer is normally employed on the F/M and its transport system. The sequences and logic of operation are designed to maintain fuel integrity, and personnel and equipment protection during all phases of the fuel handling operation.

The control system is designed to ensure that fuel integrity is maintained by ensuring that the applied forces on the fuel bundles do not exceed the limiting values.

Adequate cooling of the fuel bundles is maintained throughout the handling operation. When an irradiated fuel bundle is exposed to air during a part of the handling sequence, provision is made to ensure that this interval is within controlled limits. The cooling system is continuously monitored so that the necessary feedback is provided for the operation signal to the spray cooling system when required. In the event of an incident, back-up provision such as spray cooling or flooding can be initiated within 12 minutes or four minutes, respectively. Past experience has shown that the actual time that irradiated fuel can be exposed in air is significantly longer than the aforementioned times for CANDU 6. Where bundle power is less, as in CANDU 3, the permissible exposure time will be greater.

The control system and a mechanical snout lock directly connected to the channel hydraulic pressure ensures that when the F/M head is attached to the fuel channel end fitting, it maintains a leak tight joint and that accidental unclamping of the snout does not occur.

Throughout the fuel movement, a sequence of logic permissives is developed in conjunction with position monitoring and feedback. Interlocks are provided to prevent undesirable operations that may cause damage to fuel bundles or the equipment if done in the incorrect sequence.

Utilization of an automatic computer control with the inherent permissive logic ensures a safety feature that greatly reduces operator error.

Redundancy is built into the system for critical sensing and feedback devices. The control system components are also selected to ensure that they withstand radiation, temperature, humidity and other environmental conditions.

In the event that the automatic mode is impaired, more reliance is placed on the operator to interpret the information feedback and to decide upon the corrective action.

Some manual emergency drive provisions are provided on the F/M to back up the operator when an actuator prime mover fails, so that the corrective action can be taken with special tooling that can reach the drives, working through the reactor vault shielding.

Equipment for the fuel transfer system is enclosed in shielded rooms or immersed in water and the control actuators are generally placed in accessible areas that allow easy maintenance.

3.3 SAFETY AND RELIABILITY

When the F/M is coupled to the reactor fuel channel, it becomes an extension to the primary heat transport system. The pressure boundary of the F/M is therefore designed to the requirements of the American Society of Mechanical Engineers (ASME), Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NB for Class 1 components. The F/M head support system is designed to the requirements of ASME, Section III, Subsection NF.

An analytical model of the F/M head mounted on its support system, attached to the fuel channel and reactor structure is constructed to represent the masses, stiffness and degrees of freedom. This model is subjected to the design basis earthquake (DBE) Category A floor response spectrum, and worst-case dynamic loads are generated by analysis. ASME Code static analysis is used to perform stress analysis. Failure of the components could result in breach of the pressure boundary that would lead to a loss of coolant from the primary heat transport system.

Analyses are carried out to study performance of the fuel handling control system in the event of loss of coolant in the primary and secondary heat transport systems. This study includes potential flooding of the electrical equipment, common mode failures, mechanical and electrical failures, and oil and D_2O cooling system failures, to ensure safety of operation.

Fault-tree analysis of all major fuel handling assemblies and critical components in the control system is carried out during design to ensure reliability. Data for this analysis is drawn from prior experience with equipment in CANDU plants and from extensive development laboratory testing.

3.4 PRODUCTION TESTING

Prior to shipment, all newly built F/Ms are given a complete operational acceptance test. Checks on key operating devices and complete calibration and set-up of the control system components are carried out.

In order to qualify each F/M, it must complete ten uninterrupted fuel channel fueling sequences, performed under automatic computer control at full pressure, temperature and channel flow conditions.

3.5 MANUFACTURING AND QUALITY ASSURANCE

The CANDU F/M head and related equipment are designed so that they can be fabricated and tested prior to shipment to the site. Exceptions are the large structural components that are assembled at the site.

Although there are some specialized methods involved, most components can be fabricated using normal manufacturing methods. Extensive use is made of commercially available components. On occasion, some of these items may need to be upgraded to meet the required standard to ensure acceptable reliability and service life.

Since the early 1960's, AECL has developed the expertise in the design of corrosion resistant water lubricated mechanisms involving components such as anti-friction ball bearings, ball screws and shaft seals. Only qualified suppliers are chosen for these components to ensure reliable service.

On corrosion resistant water lubricated components, proper material and finish combinations are extremely important to preclude galling, seizure and wear.

In the manufacture of fuel handling components, contractors must comply with the Canadian Standards Association (CSA) quality assurance program standards. There are four levels of quality assurance in the CSA Z299 series program:

a. Z299.1 Quality assurance program requirements

b. Z299.2 Quality control program requirements

c. Z299.3 Quality verification program requirements

d. Z299.4 Inspection program requirements.

In descending order, each Standard in the series contains fewer, or less stringent, requirements than the one immediately above it. This does not mean that good quality practices used in meeting the requirements in Z299.1 can be abandoned when producing items to any of the lower Standards. The principal difference at the lower levels is that the items are produced with less recorded assurance, in the form of documentary evidence, of the implementation and effectiveness of these practices.

The F/Ms are produced to the highest level of the quality assurance program Standards, namely CSA Z299.1. Components built to meet pressure boundary jurisdictional requirements comply with CSA Z299.2. Most other fuel handling components are fabricated to CSA Z299.3, except for general purpose equipment and tools, which conform to CSA Z299.4.

3.6 MAINTAINABILITY

The ability to meet the on-power fueling requirements of the fuel handling system depends greatly on equipment maintainability during routine servicing and breakdown or repair operations.

In the design, considerable attention is paid to eliminate unnecessary tight tolerances on mechanical components and system controls.

Other factors that contribute to maintainability are remote monitoring, calibration and adjustments to the drive system. Modular construction of sub-assemblies that contribute to rapid exchange of components and packages are also important contributing factors to maintainability.

Maintenance areas for the F/Ms with dedicated systems, such as Pickering and CANDU 6, are generally located adjacent to the reactor vault and access is possible when the F/M is removed from the vault.

Pickering and CANDU 6 maintenance areas are depicted in Figures 1-11 and 1-12. For a multi-unit station such as Bruce/Darlington, with a shared fuel handling system, a central service area is provided (Figure 1-3).

4. NEW FUEL STORAGE AND HANDLING

New fuel is received in the central storage room that is located in the service building. This room accommodates the normal station inventory and temporarily stores the fuel for the initial reactor core load.

When required, new fuel pallets are transferred to the new fuel loading area. Here, the bundles are identified and are loaded manually into the magazines of new fuel loaders. Ports from the loaders penetrate into the reactor vault where they are terminated by end fittings, similar to those on the reactor fuel channels.

Interlocked valves are provided at each end of the ports to prevent tritium from the F/M entering into the new fuel loading area, and to maintain the required containment integrity and atmospheric separation within the reactor building.

5. FUEL CHANGING

5.1 GENERAL

The on-power fuel changing equipment consists of two identical F/Ms at each end of the reactor, suspended on a carriage from tracks on a bridge or a trolley that extends the full length of the shielded reactor vault. Vertical and horizontal traverse of the F/M is provided to allow access to all the fuel channel end fittings. Powered shielding doors separate the reactor vault from the maintenance lock and, when closed, allow access to the F/M in the maintenance lock while the reactor is operating.

While in the maintenance lock, the F/Ms also have access to the new fuel ports to receive new fuel, to the service ports for calibration or service, or to the rehearsal facility.

Fueling operations are performed with the equipment under remote automatic computer control. The shielding doors are opened and the two F/Ms travel along the tracks at each face of the reactor and are positioned on each end of the selected fuel channel.

Both F/Ms move forward to home and lock onto the fuel channel. After a leak test on the clamp seal, each F/M, which is filled with heavy water, is then pressurized to match the heat transport system pressure conditions. The temperature of the heavy water in the F/M is maintained at a lower temperature than that in the fuel channel and a steady inflow into the fuel channel is maintained to thermally isolate the F/M from the higher temperature of the heat transport system. The F/Ms remove the channel closures and store them in the F/M magazines. Guide sleeves are installed and the shield plugs are then removed from the fuel channel and new fuel is inserted at one end while irradiated fuel is discharged from the other end of the fuel channel.

Two fuel bundles can be inserted from each magazine position containing new fuel in the F/M head. Four to eight new fuel bundles are generally inserted on each visit, thus replacing four to eight of the fuel bundles in the fuel channel. Either F/M can load or accept fuel, depending on the direction of flow in the particular fuel channel being serviced.

When the required number of fuel bundles has been inserted, the shield plugs and channel closures are replaced and the closures are leak tested by the F/M. The two F/Ms then traverse to the irradiated fuel ports where irradiated fuel is discharged.

With four bundle shift fueling, the F/M can fuel one channel and then fuel a second one, before returning to the irradiated fuel ports. For a CANDU 6 reactor, fueling is required on about fourteen fuel channels per week, with eight fuel bundles being discharged at each visit to the reactor. The fueling frequency varies proportionately with the size of the reactor. Table 1-I gives typical fueling rates for different reactors.

There are two distinct fuel channel designs and fuel changing processes. The fuel bundles are separated by fuel separators built into the F/M in one design, and by integral fuel latches in the fuel channel by the other. Table 1-II shows the two different processes adopted by the different designs.

5.2 FUEL LATCH METHOD

The fuel latch method was originated with NPD and adopted in Bruce/Darlington. The characteristic features of this design are:

- The fuel channel contains 13 fuel bundles.
- Fuel latches that are located at the downstream end of each fuel channel restrain the fuel column against the hydraulic drag of the coolant flow.
- Channel closures and shield plugs incorporate a breech-type locking feature that requires rotary actuation. Correct radial orientation is mandatory.
- Movement of fuel bundles in pairs between the F/M and the fuel channel is carried out in fuel carriers.
- The fuel channel end fitting bore is larger than that of the fuel bundle to accommodate the fuel carrier.
- Fueling is carried out against the coolant flow. When the fuel bundle is discharged from the fuel carrier into the pressure tube, it passes through the spring-loaded fuel latch which is incorporated in the end fitting liner tube, to prevent reverse motion.

The fueling sequence for Bruce/Darlington is depicted in Figure 1-13.

5.3 FUEL SEPARATOR METHOD

The separator method that is adopted for the Pickering/CANDU 6 design originated with Douglas Point. The characteristic features of this design are:

- The fuel channel contains twelve fuel bundles, all located within the reactor core.
- Shield plugs and channel closures feature radially extending jaws that are actuated by axial motions. Radial orientation is not important.
- The fuel column is restrained by the downstream shield plug jaw mechanism.
- During fueling, a constant bore passage is provided between the pressure tube and F/M magazine station.
- The fuel bundle position is sensed by the separator assemblies on the F/M that also restrain the fuel column against hydraulic drag during fuel changing, separate fuel bundles and push pairs of fuel bundles into the F/M magazine station.
- Fueling is carried out in the direction of flow.

In the high flow channels, there is sufficient flow to allow the fuel column to move without assistance. Figure 1-9 depicts the fueling sequence. In the original Pickering design, the F/M ram was used to push the fuel column in the outer low flow channels, during fueling. However, this resulted in activation of the F/M ram components that made it difficult to service the F/M. Consequently, a free piston called the Flow Assist Ram Extension (FARE) tool was developed to create the impedance necessary to move the fuel column.

The on-power fuel changing equipment in the present CANDU reactors consists of two identical F/Ms. On CANDU 3, only one F/M is required on a single-ended fuel channel. The upstream end of the fuel channel is equipped with a resident fuel pusher that is basically similar to the FARE tool that is used in the Pickering/CANDU 6 design. During fueling, the fuel pusher creates the impedance that is necessary to move the fuel column towards the F/M head at the downstream end of the fuel channel. This fueling sequence is depicted in Figure 1-14.

5.4 FUELING MACHINE

The F/Ms comprise mechanisms for manipulating the fuel bundles, both at the reactor face and at the new fuel and irradiated fuel ports (Figures 1-15 and 1-16). The mechanisms for each F/M include a snout assembly that clamps and pressure-seals the F/M to the fuel channel end fitting; a magazine that accommodates the fuel bundles to be inserted or removed, together with shield plugs, channel closures and F/M hardware; rams that remove and replace channel closures, and F/M hardware; and in the case of the Pickering/CANDU 6 design, separators that separate and hold the fuel bundles during magazine storage.

5.4.1 Snout

The snout provides a pressure-tight joint between the F/M and the fuel channel or irradiated fuel port end fittings. In the Pickering/CANDU 6 design, the snout is driven by oil hydraulic pistons that convert rotary motion into an axial clamping motion using a screw and gear combination. Sealing between the F/M snout and the fuel channel end fitting is achieved by a self-energizing bellows type metallic seal.

The Bruce/Darlington snout features a design that is similar to a double-hinged Grayloc clamp, incorporating a Grayloc seal ring. Actuation is provided by the central gearbox through a gear drive.

5.4.2 Magazine Assembly

The magazine housing assembly is a pressure vessel consisting of two main forgings. The Pickering/CANDU 6 design uses a Grayloc clamp and seal ring to hold the housing together. A bolted flange joint with an 'O' ring seal is featured on the Bruce/Darlington design.

The magazine front opening and mounting faces are provided for the snout, while the rear opening is provided for attaching the ram assembly.

For the Pickering/CANDU 6 design, openings and mounting faces are provided for two separator assemblies, just behind the snout.

The magazine rotor assembly houses the fuel bundles, and the F/M/fuel channel hardware. The magazine rotor is supported by a shaft mounted on D_2O lubricated anti-friction ball bearings.

Indexing of the magazine rotor is achieved by an externally mounted commercial (Ferguson) mechanical indexing device. The drive is provided by an oil hydraulic motor and an electrically driven central gearbox for the Pickering/CANDU 6 and Bruce/Darlington designs respectively.

The bundle carrying capacities of the different F/M are shown in Table 1-III. With the double-ended concept, the minimum number of fuel bundles that the F/M should carry depends upon whether a four bundle or eight bundle shift is used. The increased capacity beyond the minimum value allows the F/M to visit more than one fuel channel during a fueling sequence. With CANDU 3 that features single-ended fueling, the minimum fuel bundle carrying capacity is 16 for a twelve bundle channel and a four bundle shift, if fueling is to be carried out in a single visit, since fuel shuffling is carried out in the F/M. A 20 bundle magazine was chosen for CANDU 3, therefore two fuel channels can be visited by the F/M head for each visit to the fuel transfer port with four bundle shift fueling.

5.4.3 Ram Assembly

In the Pickering/CANDU 6 design, the ram assembly is capable of three independently controlled axial motions; two of the motions are provided by mechanical actuation of ballscrews supported on anti-friction ball bearings in a water environment. The third motion is supplied by a telescopic heavy water actuated hydraulic ram. The ballscrews are driven by externally mounted oil hydraulic motors via shaft penetrations through the pressure boundary.

In the Bruce/Darlington design, the ram is also capable of three independent motions. Two of the motions are ballscrew driven axial motions, however, the third is a rotary motion provided by a gear drive, all operating in a water environment. The central gearbox that is equipped with two ac electric induction motors provides the actuation.

5.4.4 Separators

Each of the Pickering/CANDU 6 F/M incorporate two separator assemblies. The functions of this mechanism are:

a. to sense the position of the fuel being fed into or being discharged from the reactor and to provide a signal to the computer to stop the ram at the correct position

b. to insert a stop device between two adjacent fuel bundles or between the shield plug and the fuel column, and to restrain the motion of the fuel column extending from the stop device into the reactor

c. to push the bundles that have been separated from the fuel column into the magazine to allow clearance for magazine rotation

d. to verify the presence of shield plug and FARE tool as they pass under the separators at various steps during the fueling operation.

The two separator assemblies perform identical functions and operate in synchronism. They penetrate through the magazine end cover at a point just forward of the magazine tubes.

In the Bruce/Darlington design, fuel latches are incorporated at the downstream end of each fuel channel pressure tube to carry out a similar function. However, in order to sense the position of the fuel column as a pair of fuel bundles is inserted into the upstream fuel carrier, the upstream F/M ram ballscrew must backwind in reaction to the insertion motion of the downstream F/M ram ballscrew, indicating that the fuel bundles have fully entered the upstream fuel carrier to provide the removal permissive. At the downstream end, the fuel column will rest against the fuel latches to resist the hydraulic drag of the coolant flow. The empty downstream fuel carrier can then be retracted into the F/M magazine.

5.5 DEVELOPMENT PROGRAMS

The F/M head is the key component of the fuel handling system and its reliability has direct impact on performance.

Development programs are carried out on a continuing basis to improve equipment life and reliability.

The development of water lubricated components such as ballscrews, anti-friction ball bearings and shaft seals have now advanced to a stage whereby reliable operation is assured. Work is still continuing to increase life expectancy. This involves studies on the wear and frictional characteristics of mating surfaces in a water environment.

6. FUELING MACHINE HEAD TRANSPORT

A number of different methods have been used for F/M transport. The F/M must be able to traverse the whole reactor face so that access to all fuel channels is possible. The F/M must also be capable of visiting the new fuel port, irradiated fuel port and service port.

On NPD, the F/Ms were suspended from the top, outside the reactor vault by vertical hydraulic telescopic booms.

The Douglas Point and Kanupp designs incorporated a floor mounted trolley that ran on rails that were mounted in front of the reactor face for horizontal motion. Vertical motion was achieved by a ballscrew driven suspension that was supported between columns on the trolley.

For the larger commercial units, the F/M carriage is mounted on a bridge th moves vertically and is supported on columns that are equipped with ballscrew drives. Horizontal traverse is achieved by the motion of the carriage along rails that are provide bridge (Figures 1-11, 1-12 and 11-7).

The CANDU 3 design, being smaller than the existing commercial units, has reverted to the use of a trolley that runs on floor mounted rails and is provided with a restraint at the top to resist seismic loads.

Generally, a floor mounted trolley is used for small reactors, and a bridge and column arrangement for larger units.

Heavy water, electric power and control signals are supplied to the F/M thro h a flexible catenary of hoses and cables which connects the mobile F/M to the station auxiliary systems.

The F/M is secured to the carriage through a suspension. The suspension is a gimbal assembly that allows the F/M to align properly with a fuel channel end fitting to reduce the forces exerted on the end fitting by the F/M when clamped onto the channel. The gimbal assembly is restrained by spring stabilizers when the F/M is detached from the reactor. The catenary hoses and cables supplying the F/M are connected by quick-disconnect type couplings which, in conjunction with a mechanical disconnect, enable the F/M to be removed from the carriage remotely in the unlikely event that irradiated fuel should become stuck in the F/M and cannot be discharged by normal, operational means.

7. FUEL TRANSFER

Two distinct methods are used to discharge irradiated fuel from the heavy water environment in the F/M to a light water storage bay that is located outside reactor containment.

Method 1

Wet discharge is featured at Pickering. Irradiated fuel is discharged from the F/M through the discharge port into a heavy water filled transfer mechanism. The heavy water level is lowered in the transfer mechanism and the irradiated fuel is discharged dry onto an elevator laddle that interconnects with a light water immersed conveyor system that transfers the irradiated fuel to the storage bay. The light water column in the elevator shaft forms a part of the reactor building containment boundary (Figure 1-2).

Method 2

In CANDU 6, the F/M clamps onto the fuel transfer port and forms a leak tight joint and the level of heavy water in the F/M is lowered to below the snout level. As the valve on the fuel transfer port is open to the discharge bay atmosphere that is outside the reactor containment boundary, the F/M pressure boundary becomes a part of the reactor containment boundary. Irradiated fuel is discharged dry through the fuel transfer port onto the laddle on the elevator and lowered into the discharge bay that is interconnected to the storage bay through the reception bay (Figure 1-1).

Method 2 (alternative)

In the Bruce/Darlington design, the fuel transfer port is connected to an air hood that is submerged in the storage bay. When the F/M clamps onto the fuel transfer port, the level of heavy water is already below that of the snout and irradiated fuel is discharged dry onto a laddle in the air hood. After the irradiated fuel is placed on the laddle, it swings out from the air hood into the light water environment of the storage bay. The water surface in the air hood therefore forms a part of the reactor building containment boundary.

8. WET STORAGE

Storage of used CANDU fuel in water filled, reinforced concrete bays is provided at each site. Epoxy has been used extensively as a liner material in the bays. Stainless steel liners have also been used. The bay is considered as interim storage. Initial bay storage capacity is mostly based on ten years output at 80 percent minimum reactor operating capacity, plus one core load. An area is set aside in the storage bay for underwater filling of transportation casks.

Any defected fuel is sealed in cans with provision to vent noble gases and are stored in a separate area in the bay. The present achieved defected fuel rate is less than 0.06%. Defected bundles are later decanned and loaded under water into holding cans for long-term storage. An underwater fuel examination station is also possible to establish within the bay.

At Pickering, used fuel is stored in rectangular modules containing 96 used fuel bundles. The same modules are also used at Darlington. The modules are stacked in frames equipped with expanded metal mesh along the sides for seismic restraint and International Atomic Energy Agency (IAEA) safeguarding purposes.

At the CANDU 6 stations, used fuel is stored in trays containing 24 fuel bundles arranged in two rows, in a single layer. Trays are stacked, approximately 19 high and arranged in groups of two or four. Each group of stacks is provided with a cover that is held in place by vertical rods that integrate and tie the stacks together to resist possible seismic loads and for IAEA safeguarding.

At Bruce, used fuel is also stored in single layer trays that are stacked one on top of the other, but these trays are different from those used on CANDU 6, and are placed in stacking frames similar to Pickering for seismic restraint and safeguarding purposes.

9. DRY STORAGE

Subsequent dry storage of used CANDU fuel five years after discharge from a reactor is an AECB approved system of used fuel storage. The future size of the storage bays on CANDU stations now can be reduced to as little as six years capacity, including capacity for a full core load.

AECL has decommissioned Gentilly 1, Douglas Point and NPD reactors and uses concrete canisters (Figure 1-18) located outdoors at the sites, for interim dry storage.

Used fuel is transferred from the trays into cylindrical containers in the bay. The filled container is then raised into a dry shielded work station that is installed at the edge of the pool and a lid is seal welded, using remote handling equipment (Figure 1-19).

The sealed container is transported in a flask to the outdoor concrete canister for interim storage until it will be disposed permanently off-site at a future date. The minimum life expectancy of these canisters is 50 years.

10. TRANSPORTATION CASKS

Some of the CANDU reactor sites are provided with separate auxiliary used fuel storage bay facilities. At Pickering, a transportation cask is used to transfer used fuel from the primary bay to the auxiliary bay. The cask is made from stainless steel and is filled underwater. When full, whilst the cask is suspended above the water, it is decontaminated by hosing down with hot demineralized water spray. The cask is allowed to drip dry before it is transported. Decontamination is carried out routinely and is completed in about two hours.

At decommissioned CANDU reactor sites, casks transport the used fuel container from the dry shielded work station to the dry storage concrete canisters, located at the site. The casks are constructed from carbon steel plates filled with lead shielding and designed to fit onto the opening on the top of the dry shielded work station. The container that is filled with used fuel is lifted into the cask through a hinged opening at the bottom. The filled cask is checked for contamination at vulnerable locations with a smear swipe over a 100 mm (3.9 in) square area. If loose contamination is detected, the contaminated area is simply cleaned with water using a mop. If loose contamination is still present, appropriate cleaning fluids are used to mop the contaminated areas.

The cask containing the used fuel container is transported to the dry storage concrete canister and placed on top of it for unloading through the bottom hinged opening. The top of the cask is equipped with a penetration for a grapple, suspended by a hoisting arrangement, to lift or lower the filled container.

11. SAFEGUARDS

The IAEA safeguards nuclear facilities by nuclear material accountancy, complemented by a combination of containment and surveillance measures. This approach allows the IAEA safeguards objectives to be achieved with minimum intrusion upon routine plant operations.

Television and film cameras are deployed along the fuel transfer path, including the reactor vault area, F/M maintenance vaults, fuel unloading area, and irradiated fuel receiving and storage bays. Bundle counters are located close to the fuel transfer ports, to monitor the fuel flow and keep an independent, irradiated fuel inventory.

The station's civil, electrical and mechanical design includes provisions such as penetrations through the containment boundary, embedments, signal and power cables, brackets and supports for the above equipment and for devices supplied by the IAEA.

Containment measures in the fuel storage bay include tamper-indicating frames or covers that prevent any fuel bundle from being removed from the storage tray or module without breaking the seal or damaging the frame or covers (Figure 1-22). Surveillance measures also include optical devices such as closed circuit television and film cameras, and monitors such as fuel bundle counters and thermal-photo luminescent dosimeters.

Safeguards measures are extended to include used fuel bundles in dry storage in concrete canisters that incorporate tamper-indicating seals.

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TABLE 1-1: CANDU FUELING RATES

CANDU Station	Net Output per Reactor MW(e)	* Normal Steady State Fueling Rates (Fuel Bundles/Week/Reactor/Unit)
Pickering 'A' and 'B'	508	80
CANDU 6 for: Gentilly 2 Point Lepreau Cordoba Wolsung	600	112
Bruce 'A' and 'B'	750	161
Darlington 'A'	850	161
CANDU 3	320	89

* New CANDU reactors can operate for about 150 full power days before excess reactivity reduces to zero. Fueling operations will begin shortly before this time.

TABLE 1-II: CANDU FUELING SYSTEM CLASSIFICATIONS

FUEL HANDLING SYSTEM FEATURES					
STATION	NET OUTPUT MWe	COUNTRY	FUEL CHANGING PROCESS	FUELING MACHINE HEAD TRANSPORT	MULTI-UNIT FEATURES
NPD (1)	22	Canada	Fuel Latch	Vertical Telescopic Boom	
Douglas Point (1)	206	Canada	Fuel Separator	Trolley	
Kanupp	125	Pakistan	Fuel Latch	Trolley	
RAPS 1,2	2x220	India	Fuel Separator	Trolley	Dedicated fueling
MAPS 1,2	2x235	India	Fuel Separator	Trolley	Dedicated fueling
Gentilly 1 (1)	250	Canada	Fuel String	Trolley	
Pickering 'A'	4x508	Canada	Fuel Separator	Bridge	Dedicated fueling
Pickering 'B'	4x508	Canada	Fuel Separator	Bridge	Dedicated fueling
Bruce 'A'	4x750	Canada	Fuel Latch	Bridge	Shared fueling
Bruce 'B'	4x750	Canada	Fuel Latch	Bridge	Shared fueling
Darlington 'A'	4x850	Canada	Fuel Latch	Bridge	Shared fueling
Pt. Lepreau (2)	600	Canada	Fuel Separator	Bridge	
Gentilly 2 (2)	600	Canada	Fuel Separator	Bridge	
Embalse (2)	600	Argentina	Fuel Separator	Bridge	
Wolsong 1 (2)	600	South Korea	Fuel Separator	Bridge	
Cernavoda (2)	4x600	Romania	Fuel Separator	Bridge	Dedicated fueling
CANDU 3 (3)	320		Fuel Separator	Trolley	

NOTES:
(1) Prototype Power Plants
(2) CANDU 6 Power Plants
(3) Single-ended fueling

TABLE 1-III: FUELING MACHINE MAGAZINE BUNDLE CARRYING CAPACITY

FUELING MACHINE	MAGAZINE BUNDLE CARRYING CAPACITY
DOUGLAS POINT	12
PICKERING	10
CANDU 6	10
BRUCE	16
DARLINGTON	16
CANDU 3	20

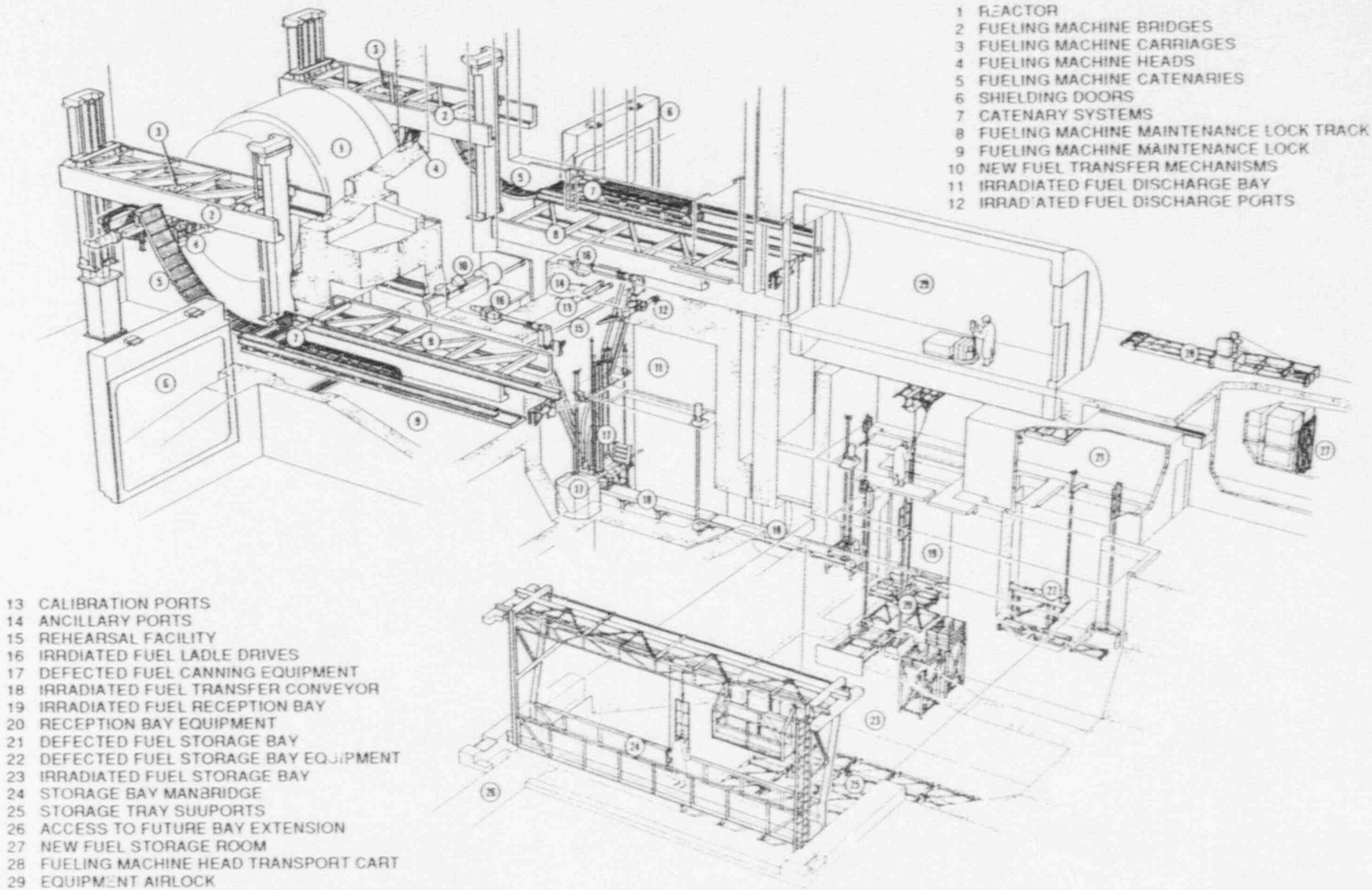


FIGURE 1-1 CANDU 6 FUEL HANDLING SYSTEM

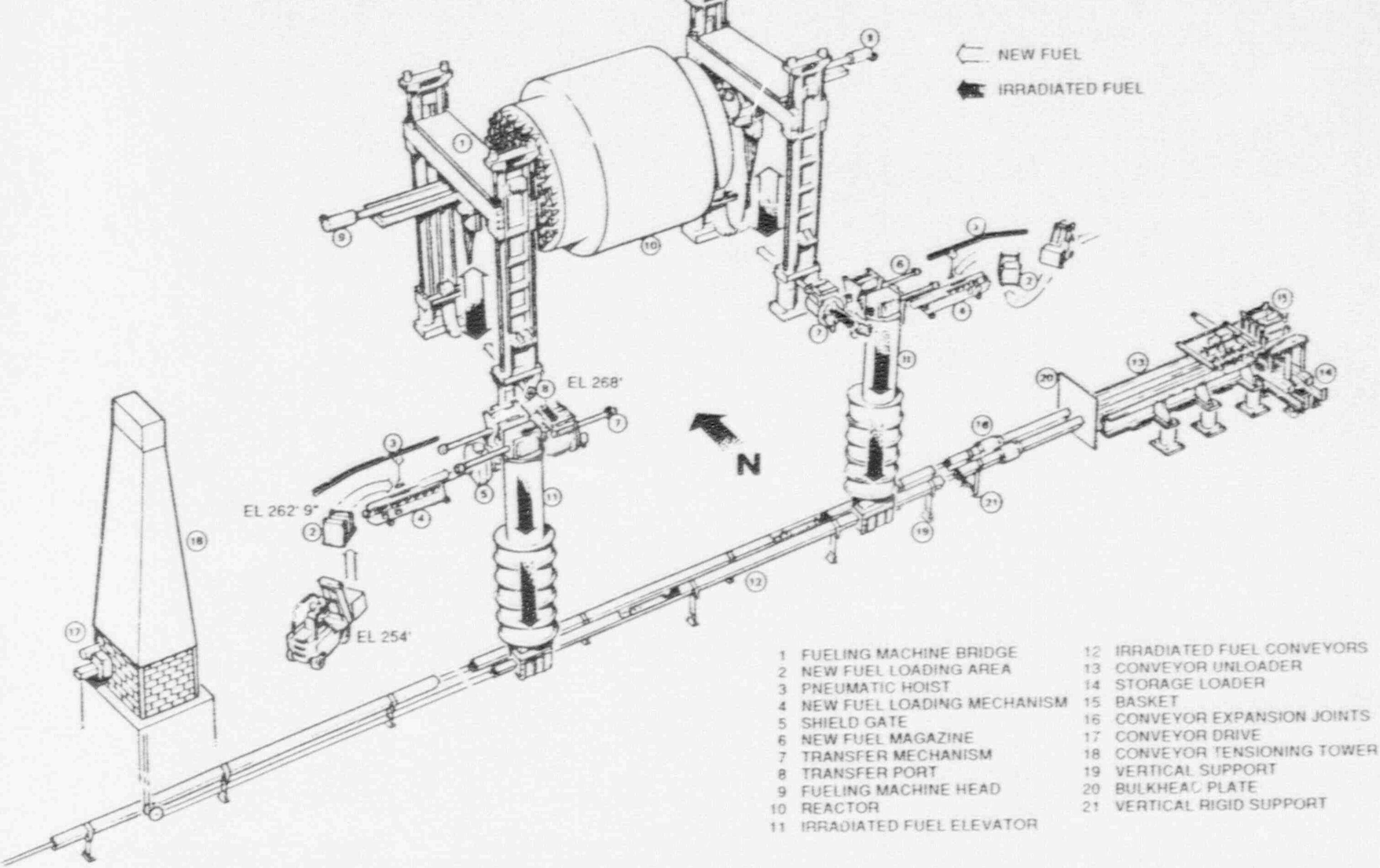


FIGURE 1-2 PICKERING FUEL HANDLING SYSTEM

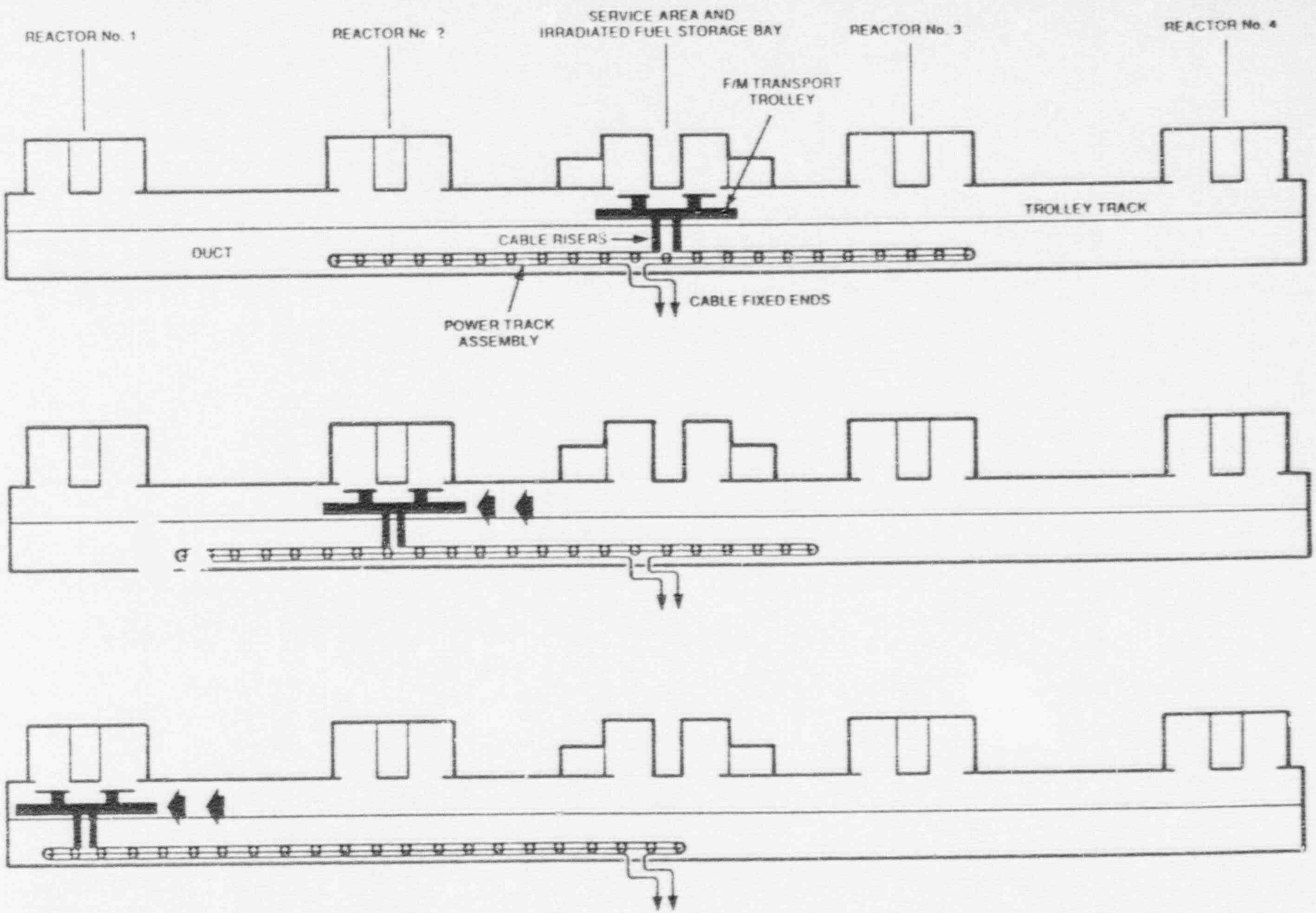


FIGURE 1-3 BRUCE MULTI-UNIT CONCEPT

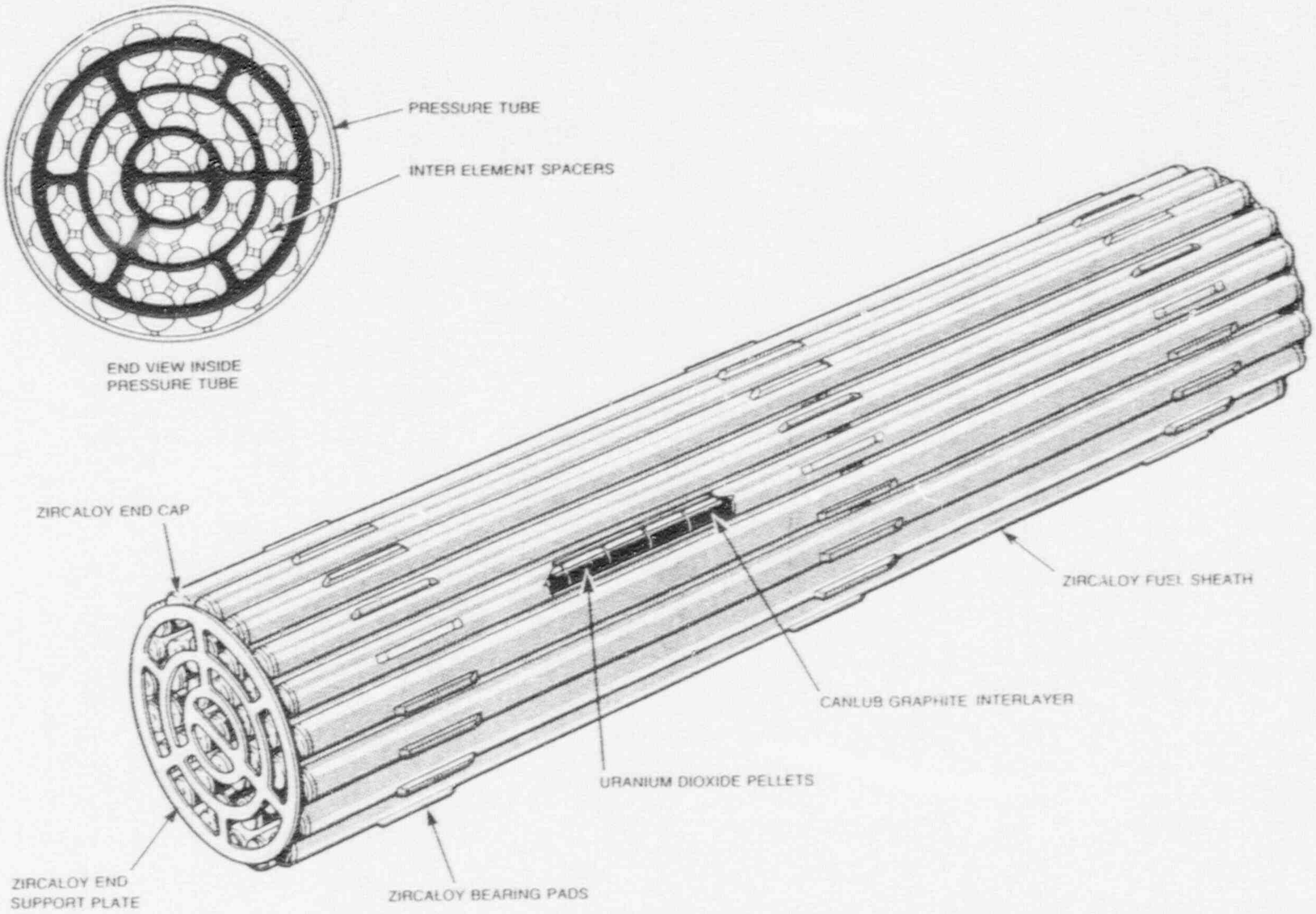


FIGURE 1-4 FUEL BUNDLE

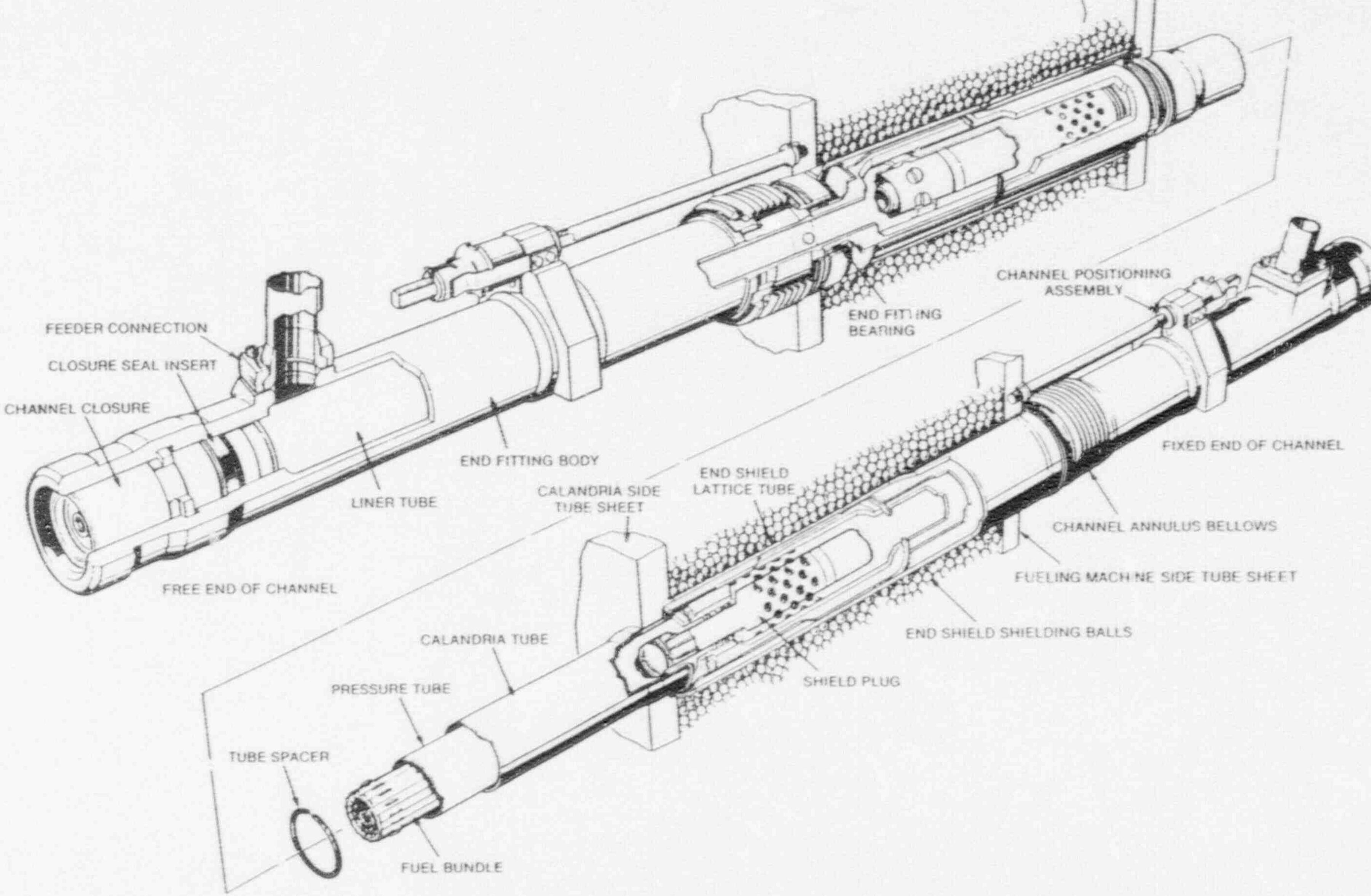
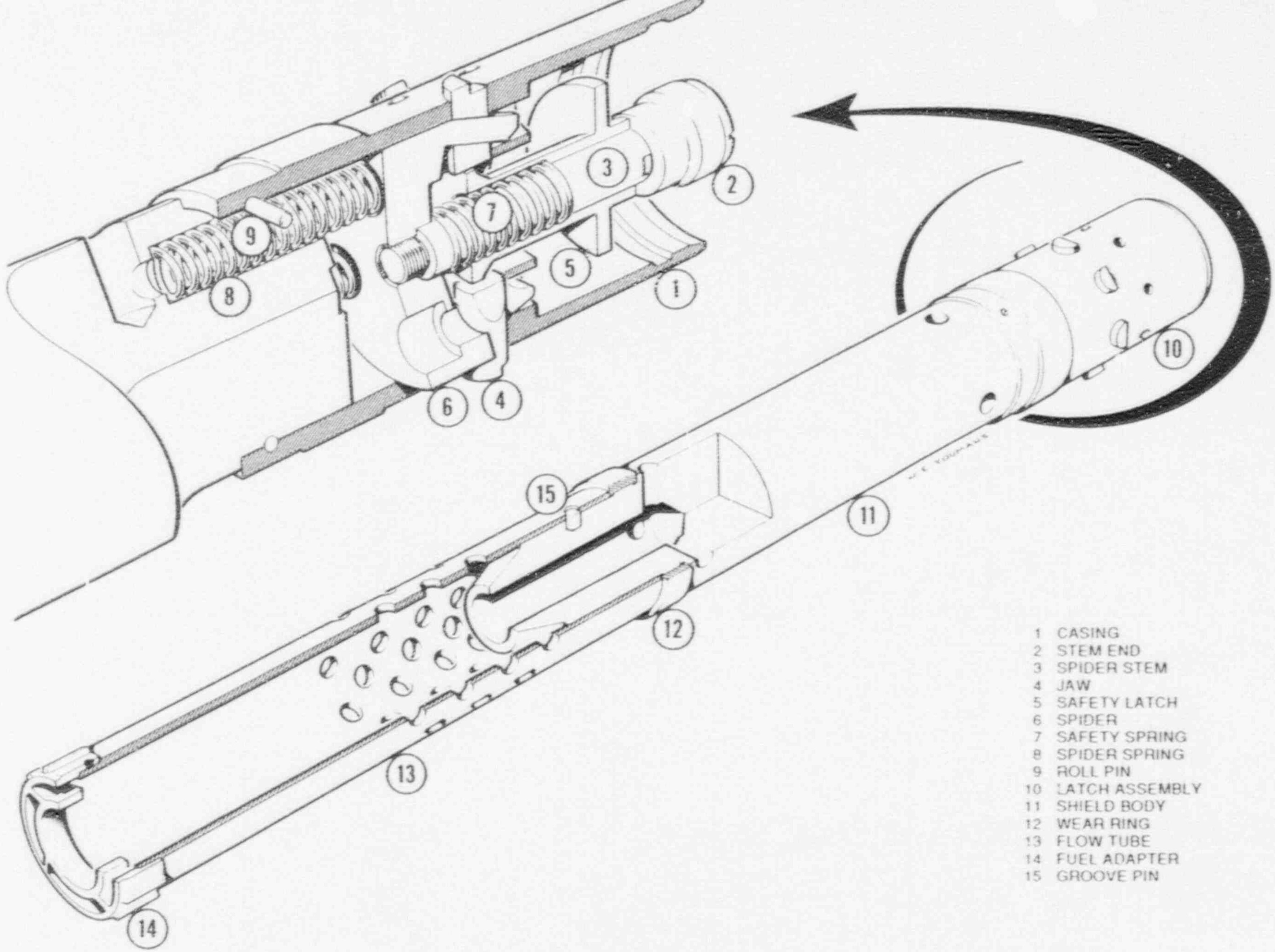
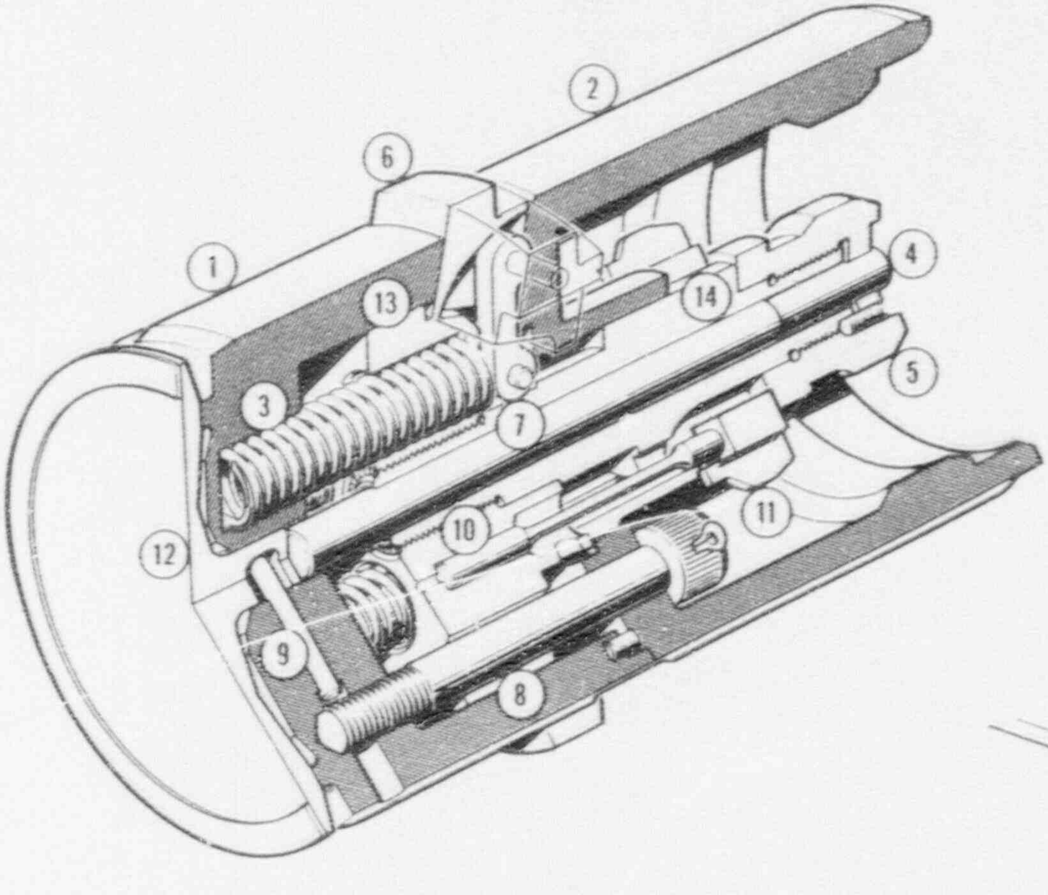


FIGURE 1-5 PICKERING/CANDU 6 FUEL CHANNEL

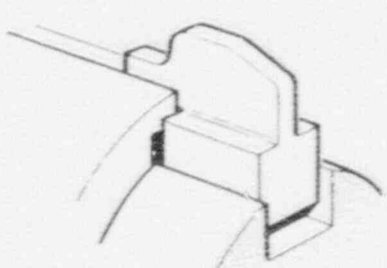


1 CASING
2 STEM END
3 SPIDER STEM
4 JAW
5 SAFETY LATCH
6 SPIDER
7 SAFETY SPRING
8 SPIDER SPRING
9 ROLL PIN
10 LATCH ASSEMBLY
11 SHIELD BODY
12 WEAR RING
13 FLOW TUBE
14 FUEL ADAPTER
15 GROOVE PIN

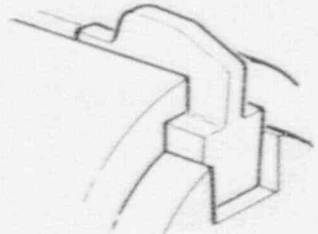
FIGURE 1-6 PICKERING/CANDU 6 SHIELD PLUG



1 FRONT HOUSING
2 REAR HOUSING
3 SPRING
4 PLUNGER
5 STEM END
6 JAW
7 TOGGLE
8 CAP SCREW
9 SEAL DISC PIN
10 SAFETY LATCH SPRING
11 SAFETY LATCH
12 SEAL DISC
13 SPIDER
14 STEM



SAFETY LATCH LOCKED
VIEW 2



SAFETY LATCH UNLOCKED
VIEW 3

FIGURE 1-7 PICKERING/CANDU 6 CHANNEL CLOSURE

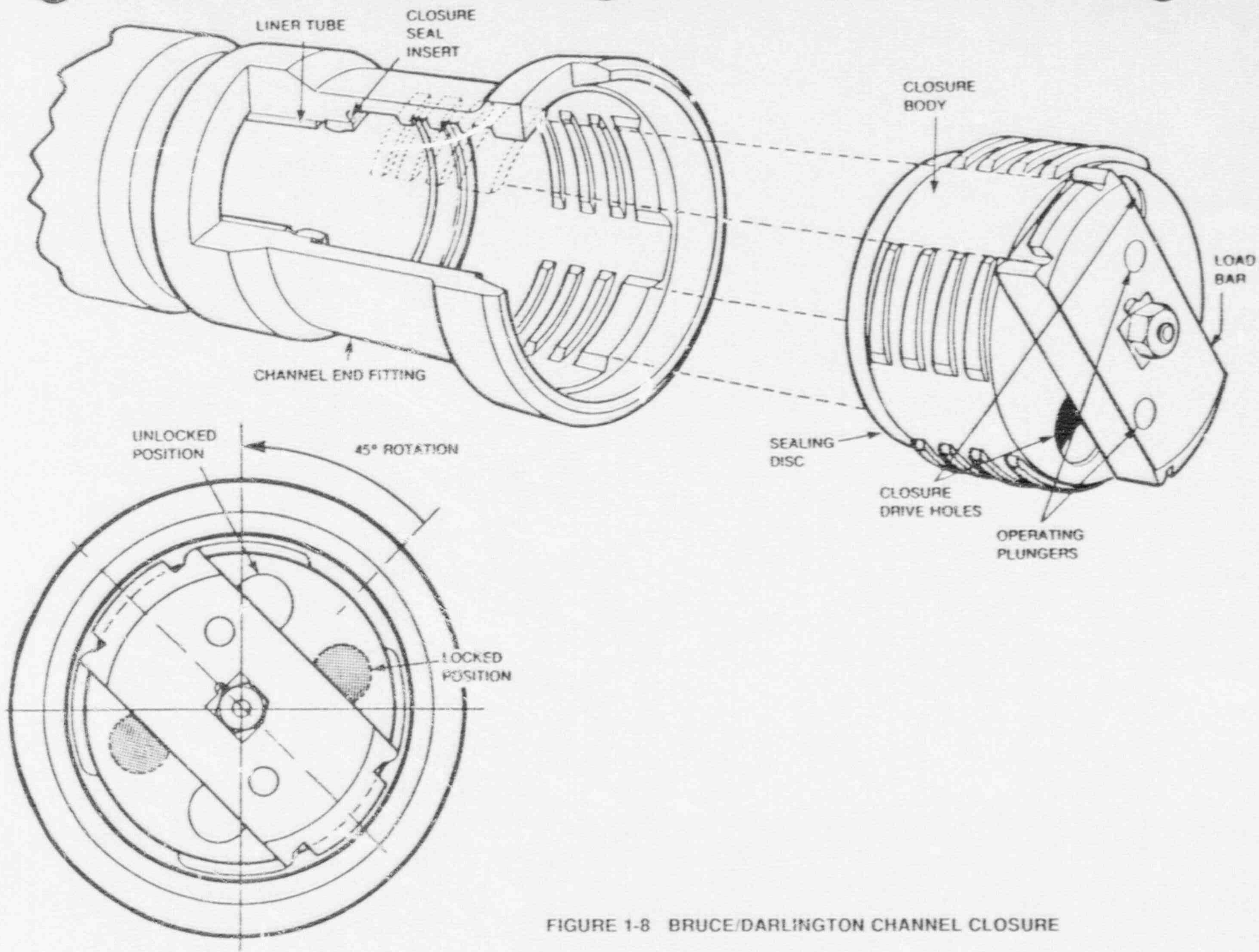


FIGURE 1-8 BRUCE/DARLINGTON CHANNEL CLOSURE

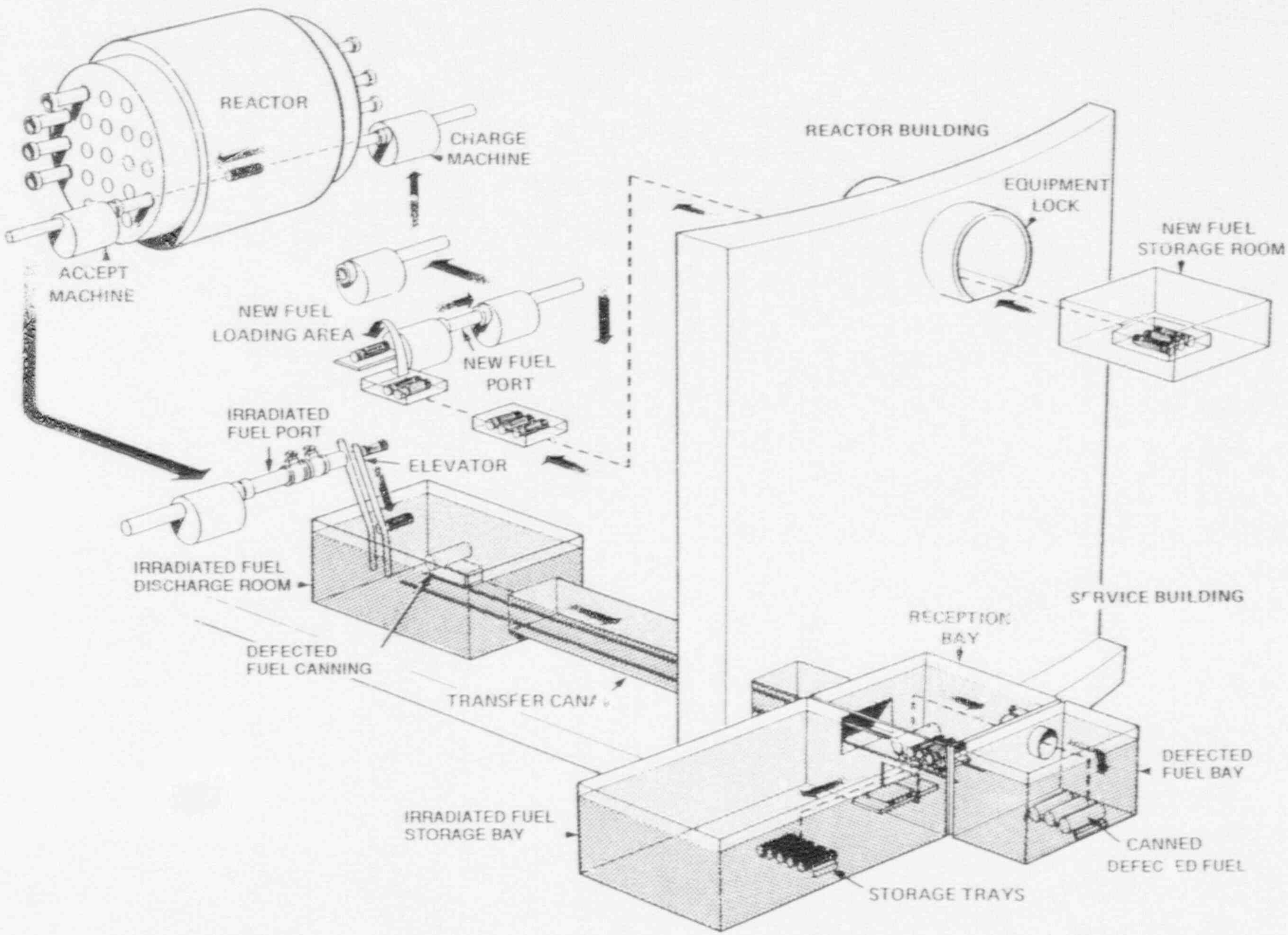


FIGURE 1-9 CANDU 6 FUEL HANDLING SEQUENCE

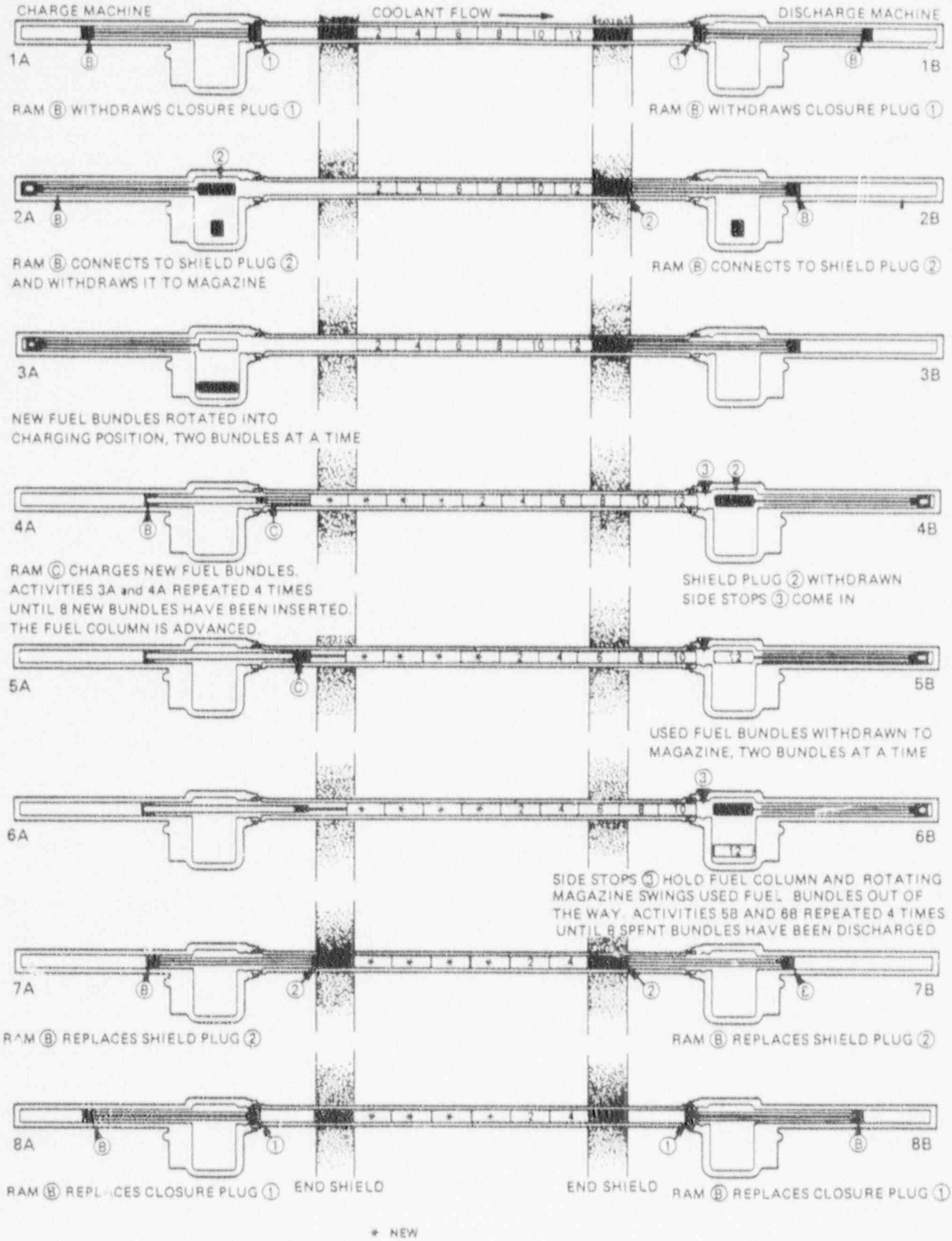


FIGURE 1-10 PICKERING/CANDU 6 8-BUNDLE FUELING SEQUENCE

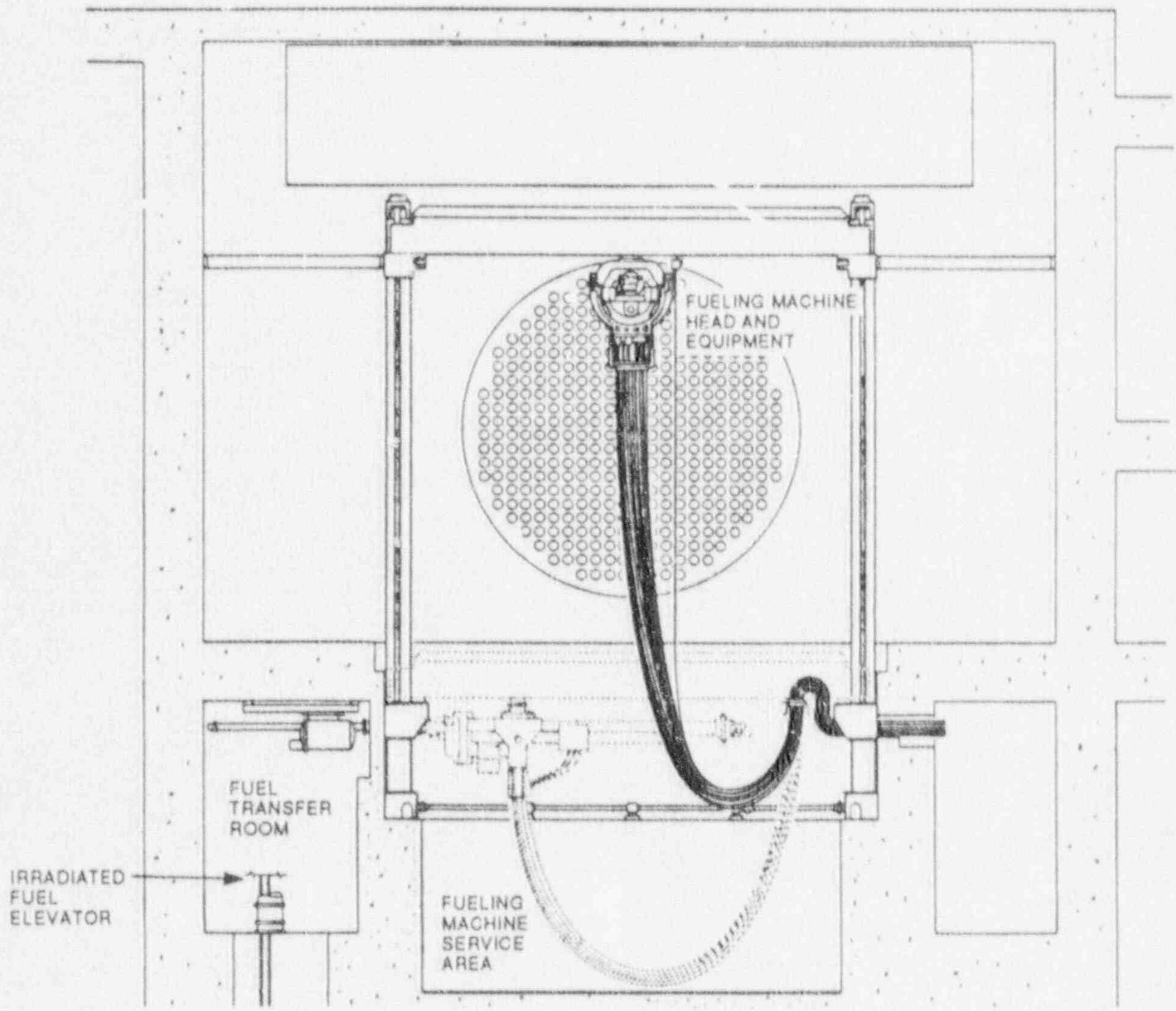


FIGURE 1-11 PICKERING FUELING MACHINE MAINTENANCE FACILITIES

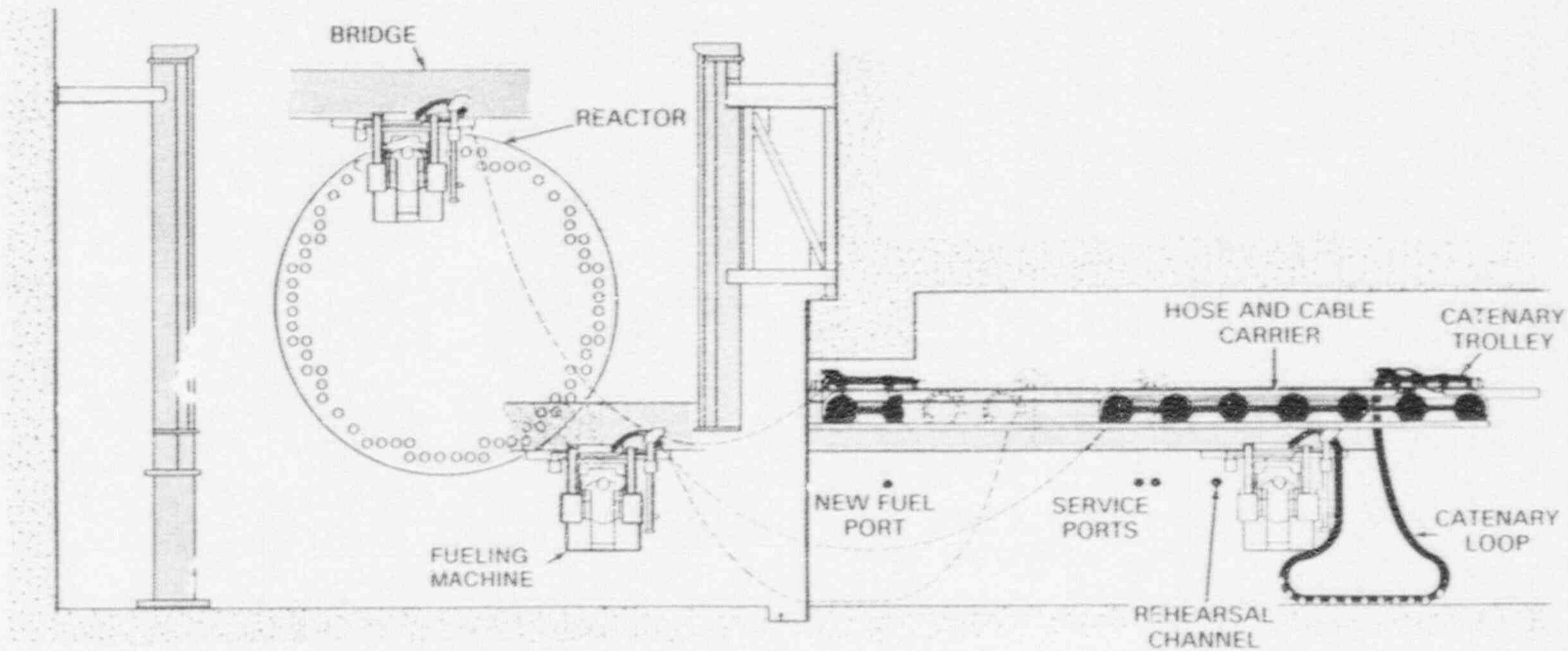


FIGURE 1-12 CANDU 6 FUELING MACHINE MAINTENANCE FACILITIES

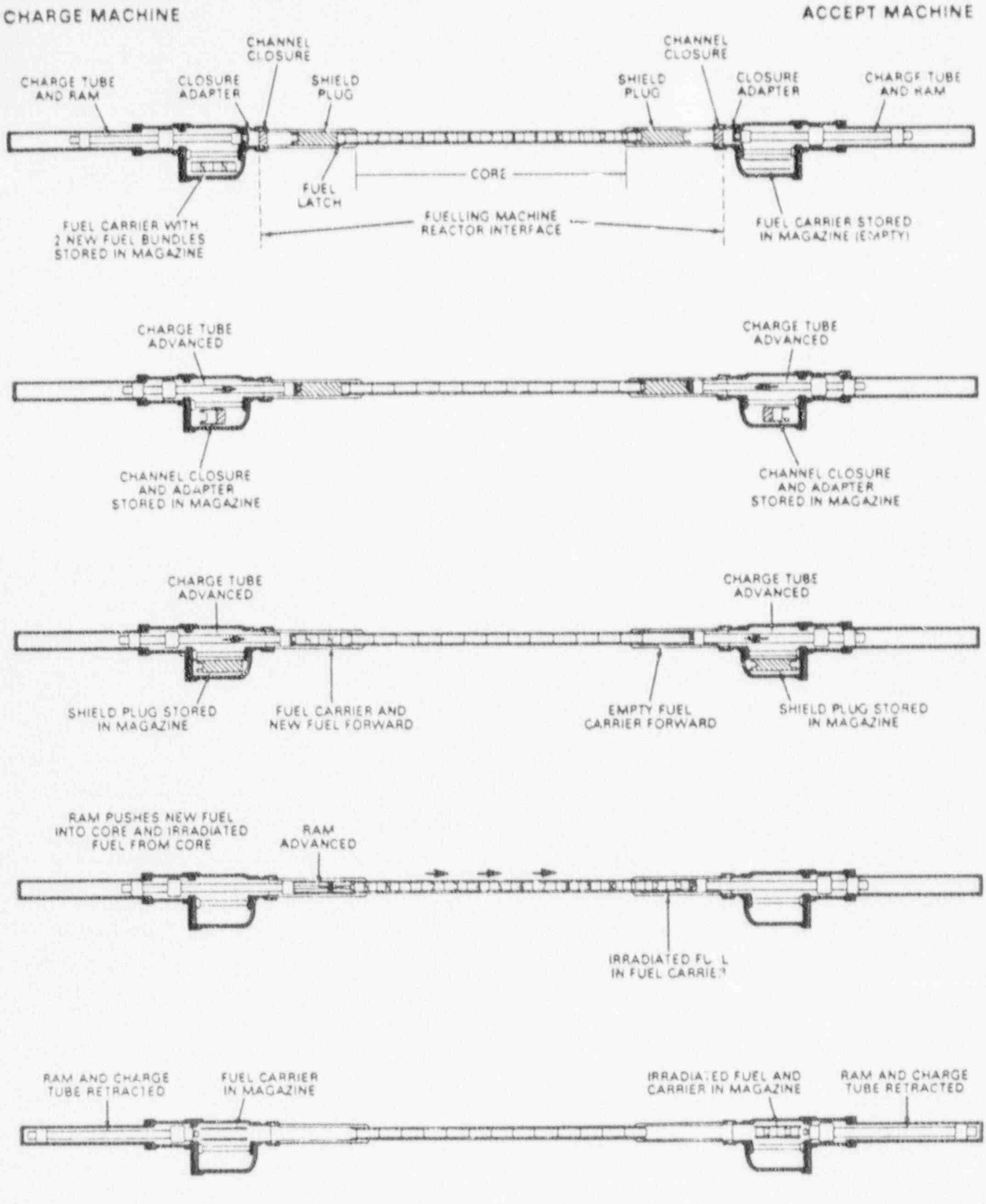


FIGURE 1-13 BRUCE/DARLINGTON NGS 8-BUNDLE FUELING SEQUENCE

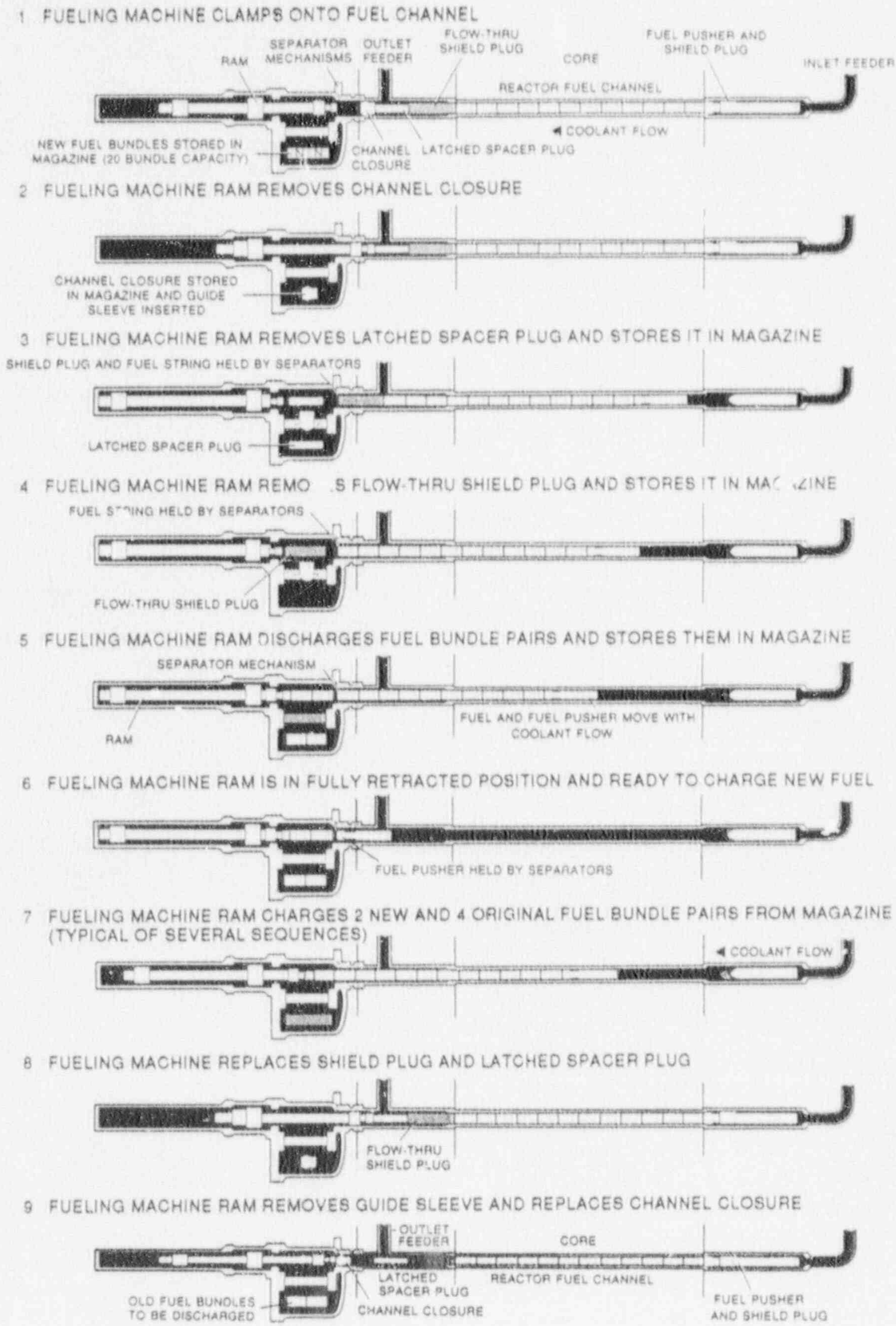


FIGURE 1-14 FUEL MOVEMENT SEQUENCE FOR SINGLE-ENDED FUELING

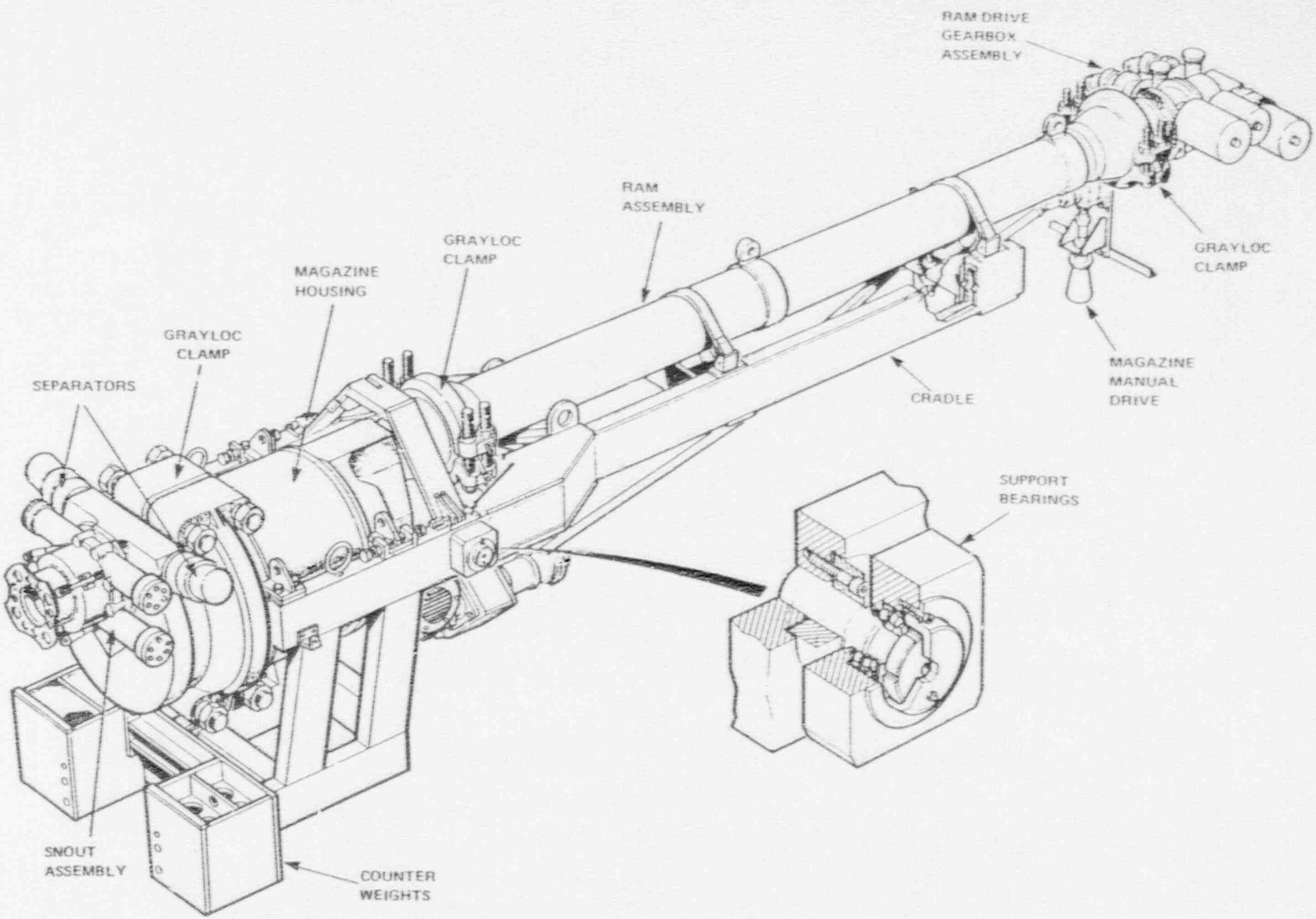
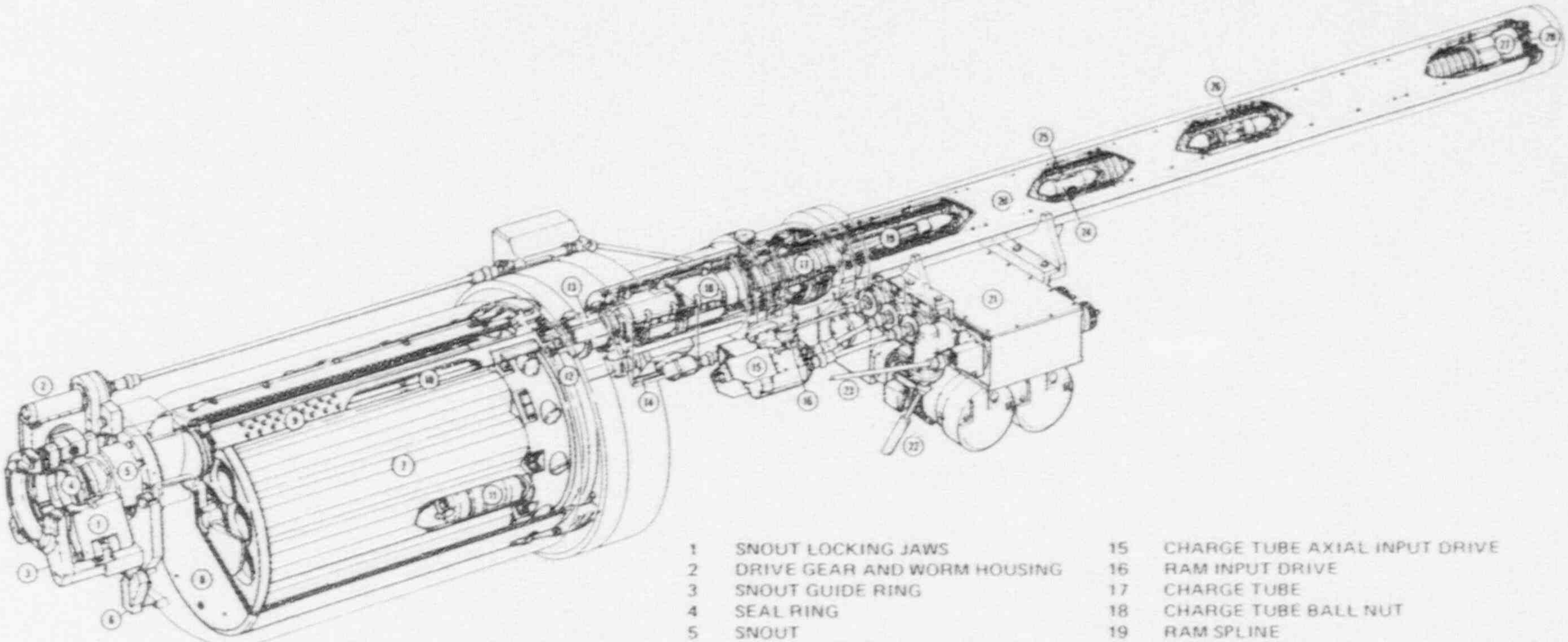


FIGURE 1-15 PICKERING/CANDU 6 FUELING MACHINE HEAD



1	SNOUT LOCKING JAWS	15	CHARGE TUBE AXIAL INPUT DRIVE
2	DRIVE GEAR AND WORM HOUSING	16	RAM INPUT DRIVE
3	SNOUT GUIDE RING	17	CHARGE TUBE
4	SEAL RING	18	CHARGE TUBE BALL NUT
5	SNOUT	19	RAM SPLINE
6	HEAVY WATER LEAK DETECTOR	20	RAM DRIVE SLEEVE
7	MAGAZINE	21	GEARBOX
8	THERMAL BARRIER	22	FINE Y DRIVE
9	FUEL CARRIER	23	FINE X DRIVE
10	FUEL BUNDLE	24	RAM EXTENSION TUBE
11	CHANNEL CLOSURE ADAPTER	25	GUIDE WHEEL
12	RAM HEAD	26	RAM BALL NUT
13	CHARGE TUBE HEAD	27	RAM DRIVE GUIDE
14	MAGAZINE INDEXING UNIT	28	RAM SCREW ROLLER

FIGURE 1-16 BRUCE/DARLINGTON FUELING MACHINE HEAD

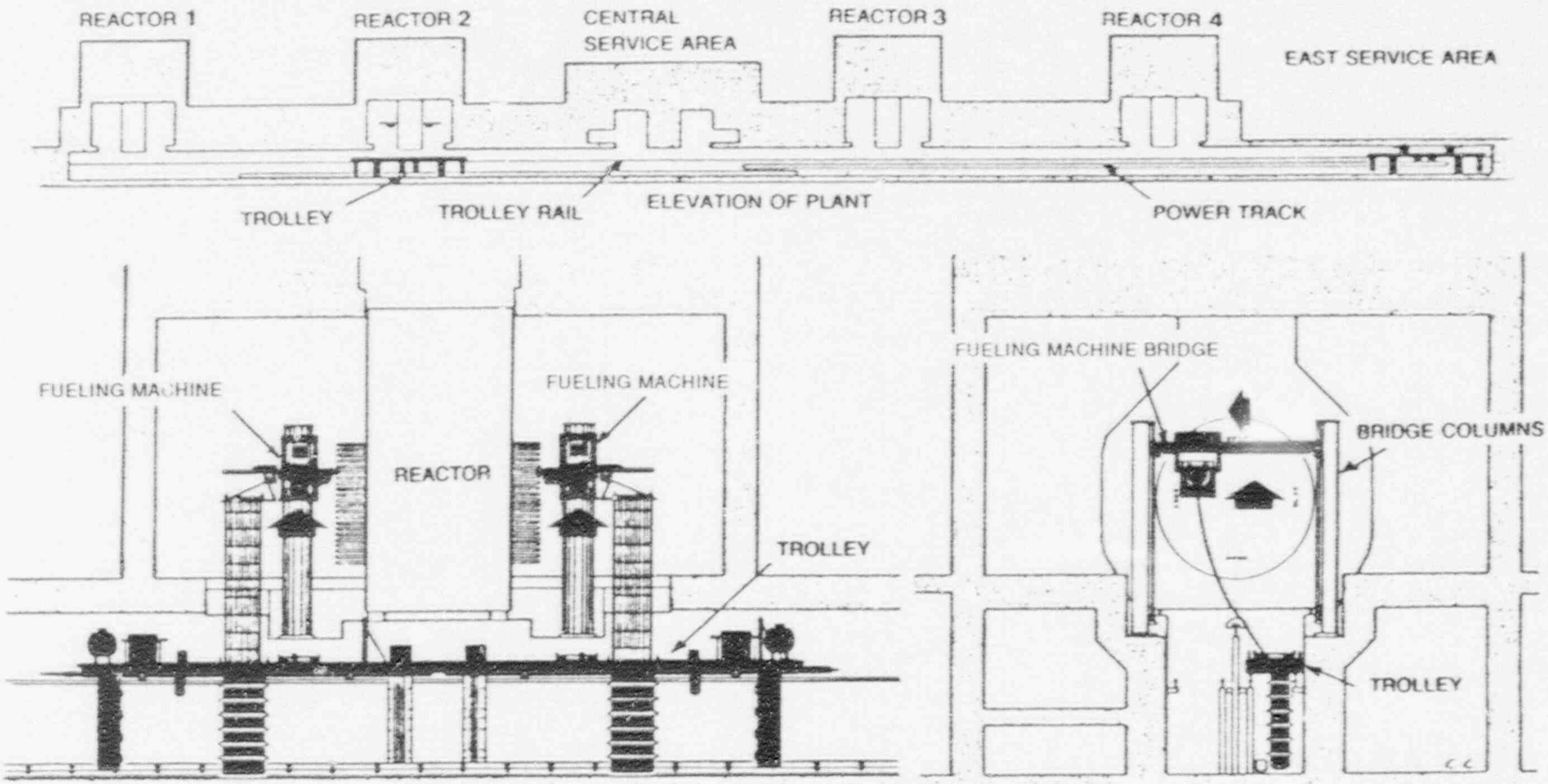


FIGURE 1-17 BRUCE FUEL HANDLING SYSTEM

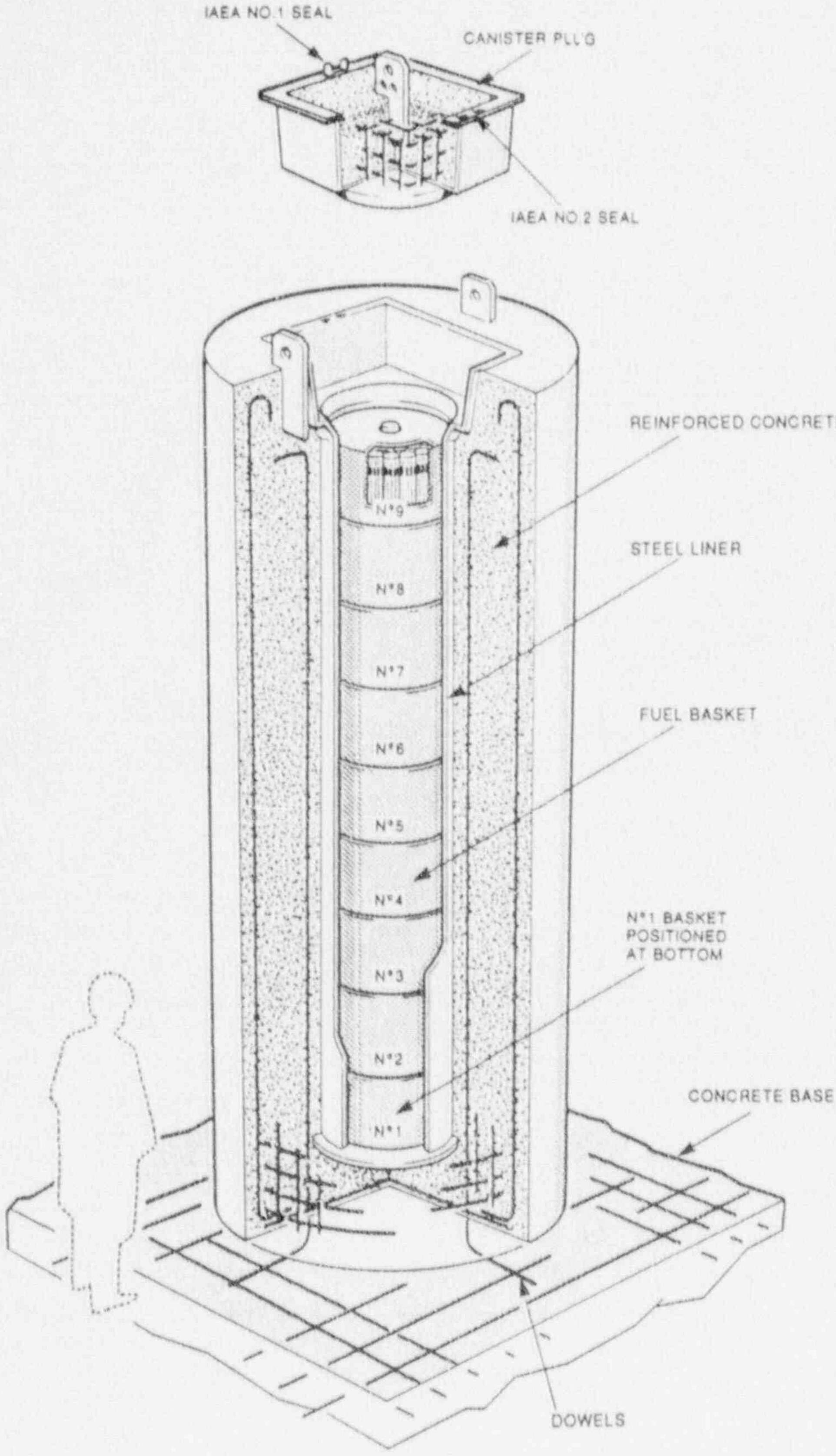


FIGURE 1-18 INTERIM DRY STORAGE CONCRETE CANISTER

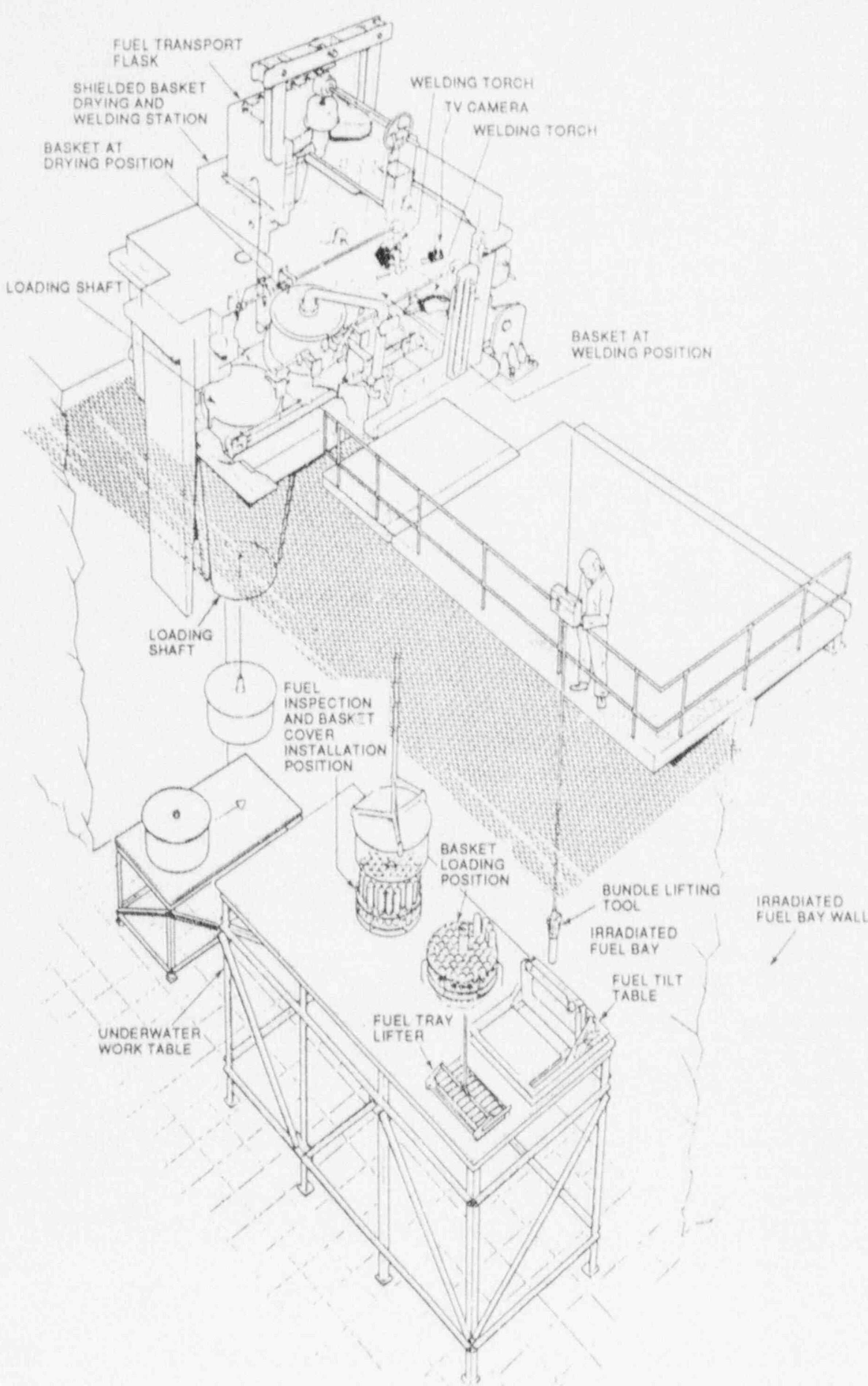


FIGURE 1-19 DRY STORAGE BASKET LOADING EQUIPMENT

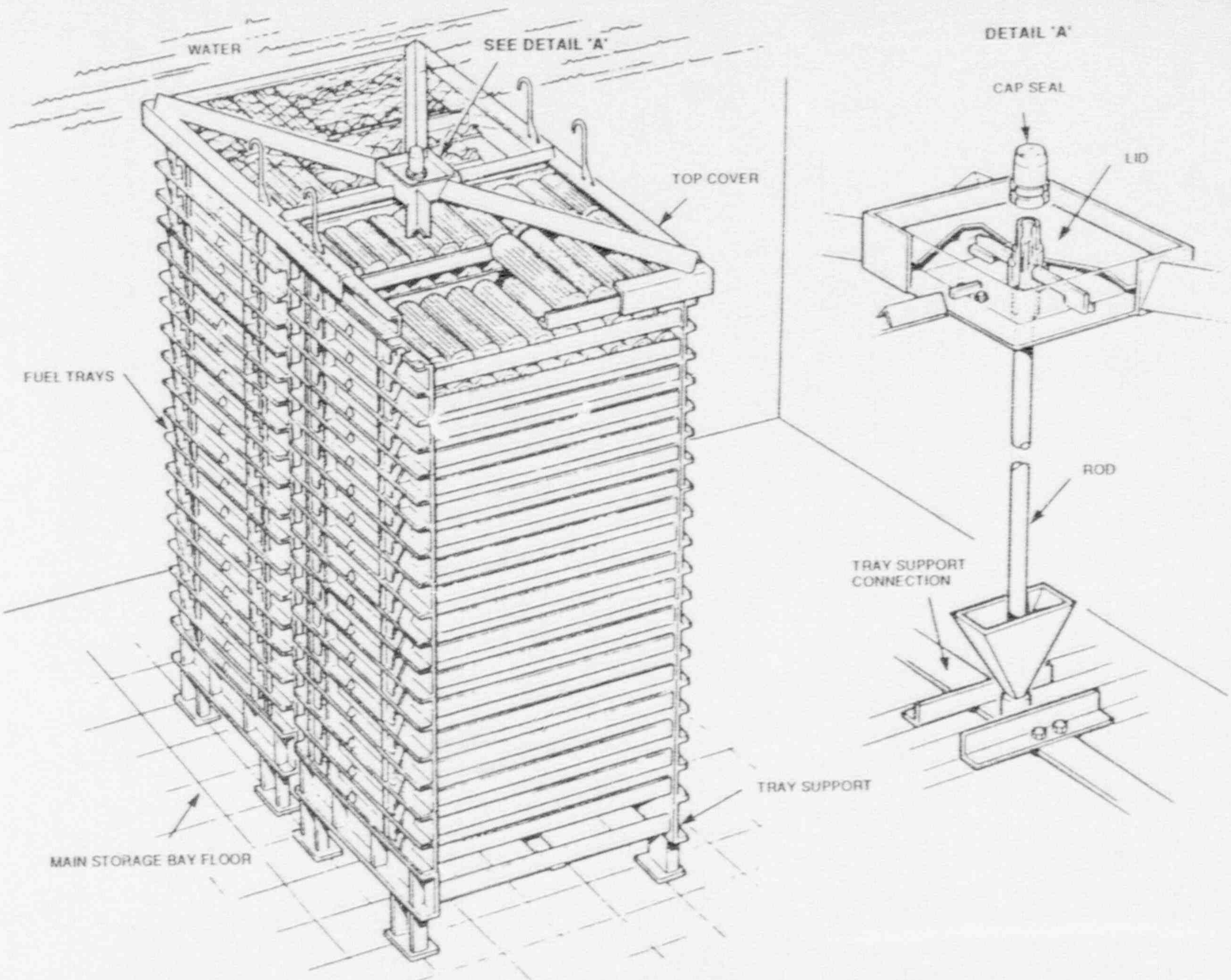


FIGURE 1-20 CANDU 6 FUEL STORAGE STACK WITH IAEA SAFEGUARDS CONTAINMENT

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CHAPTER 2

CANDU SPECIFIC ON-POWER FUELING REQUIREMENTS

1991 January

AECL CANDU
Sheridan Park Research Community
Mississauga, Ontario, Canada
L5K 1B2

CHAPTER 2

CANDU SPECIFIC ON-POWER FUELING REQUIREMENTS

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1. INTRODUCTION

During on-power fueling, the fueling machine (F/M) becomes an extension of the reactor fuel channel end fitting and is subjected to the pressure in the primary heat transport system. The F/M is designed as a reliable high integrity device. Portions of it are equivalent to static pressure vessels and are designed to the CSA Standard CAN3–N285.0 standard which provides general requirements for all pressurized systems on the plant including administrative, regulatory and quality requirements. CSA Standard CAN3–N285.1 is also used to provide direction into the ASME Code for Class 1, 2 and 3 systems and components for all technical rules of design and construction. Other portions, such as elastomeric hoses, the failure of which results in release of fluid, are designed to CSA Standard CAN/CSA-N285.2 which provides technical rules for those components which are unique to the CANDU design and are not adequately dealt with by the ASME Code. Additionally, the on-power fueling concept requires the F/M pressure boundary and its support structure to be seismically qualified to the requirements of CSA Standard CAN3-N289.3.

Furthermore, the F/M must visit different reactor fuel channels, the fuel transfer port and auxiliary ports. Therefore its support system must provide transport mobility, whereas the requirements for ASME pressure vessel supports generally address static structural components.

2. CSA STANDARDS

2.1 PURPOSE

The CSA N285 series of standards has been produced to provide uniform rules for the design, fabrication, and installation of pressure-retaining systems and components in CANDU nuclear power plants. CSA Standard CAN3–N285.1 provides direction into the ASME Code requirements to properly relate the design and construction of specific CANDU components. In other cases, CSA Standard CAN/CSA N285.2 rules are provided where the ASME Code does not address CANDU design needs. The design fabrication, installation, commissioning and operation of nuclear facilities in Canada are also subject to the Atomic Energy Control Act and Regulations. Therefore, additional requirements may be imposed by the Atomic Energy Control Board of Canada.

The specific objectives of the series are:

a. To establish rules relating to authorization, approval, and acceptance, where such rules differ from those specified in the ASME Code;

b. To specify requirements for materials and rules for the design, fabrication, installation, examination, inspection, testing, and repair of pressure-retaining systems and components, where such systems and components are not covered by the ASME Code;

c. To establish rules for classification of systems and components based on the rationale and criteria consistent with the Canadian safety philosophy, as set forth by the Atomic Energy Control Board;

d. To set up rules for the periodic inspection of CANDU nuclear power plants;

e. To provide interpretation of the rules contained in the standards for nuclear power plants systems and components.

2.2 DESCRIPTION

The CSA Standards that are pertinent to fuel handling design are as follows.

2.2.1 General Requirements for Plants and Pressure-Retaining Systems and Components in CANDU Nuclear Power Plants. (CAN3-N285.0)

This standard specifies the general requirements for the design, fabrication, and installation of pressure-retaining systems and components in CANDU nuclear power plants. Most of these requirements govern the Canadian administrative system of classification, registration, and quality assurance, where they differ from the ASME Boiler and Pressure Vessel Code.

2.2.2 Requirements for Class 1, 2 and 3 Pressure-Retaining Systems and Components in CANDU Nuclear Power Plants. (CAN3-N285.1)

This standard specifies the requirements for design, fabrication, and installation of Class 1, 2, and 3 pressure-retaining systems and components in CANDU nuclear power plants, as defined by CSA Standard CAN3-N285.0. Classes 1, 2 and 3 basically include nuclear systems and components excluding containment systems. To a large extent these classes are adequately covered by the ASME Code, however some additional technical rules complement the ASME Code.

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

This standard applies to pressure-retaining components of CANDU nuclear power plants that have a Code Classification of Class 1C, 2C, or 3C as defined by CSA Standard CAN3-N285.0. These classes include components that would be classified as Class 1, 2 or 3 components according to CAN3-N285.0, but do not have their requirements given in CAN3-N285.1. Essentially, these are Class 1, 2 or 3 components for which ASME Boiler and Pressure code rules do not exist, are inapplicable or are insufficient. Use of a non-ASME code material does not mean the component will be classified as 1C, 2C or 3C.

These rules complement those in CSA Standards CAN3-N285.0 and CAN3-N285.1 for the design, fabrication, installation, examination, and inspection of CANDU nuclear power plant components and supports.

2.2.3.1 Supports

Fueling machine supports in CANDU reactors are composed of structural supporting elements and mechanisms. Portions of them have mobile functions not usually found in supports for pressure-retaining components. For example, an elevating bridge and carriage is commonly used to move the F/Ms from one reactor channel to another during on-power fueling. A ballscrew and nut assembly is often used to produce bridge and carriage motion as well to provide support.

Mechanisms that produce or control motions and carry support loads, whose failure would result in a loss of support, must satisfy a stress analysis, experimental stress analysis, or load rating, similar to that required in the applicable ASME Boiler and Pressure Vessel Code section.

These mechanisms must be equipped with controls and interlocks to prevent motion of the support that could result in overstressing a pressure-retaining component or its support. It must also be possible to verify the operation of controls and interlocks.

2.2.3.2 Threaded Connections and Tube Joints

Where threaded fasteners are permitted by the ASME Boiler and Pressure Vessel Code, use of helical coil or other metallic inserts are allowed with appropriate destructive testing on representative samples. Non-welded tube joints may be used subject to several testing and design requirements.

2.2.3.3 Reinforced Elastomeric Hose Assemblies

This section applies to elastomeric components, such as hoses, where their failure results in a significant release of fluid. Seal components such as O' rings and gaskets whose failure results in a leak rather than rupture, are not covered.

Elastomeric hose may be used in Class 2 and 3 systems. Elastomeric hose may be used only if a failure will not cause the operating personnel to exceed their dose limit. Hose materials must be reinforced and compatible with the contained fluid. Hose design must be qualified by proper testing and documentation, and the fabrication of hose assemblies is subject to several test requirements.

2.2.3.4 Reactor Channel Closure Safety Lock

A safety lock is needed on each channel closure to prevent it from being unintentionally released from a fuel channel. The safety lock must be a positive mechanical locking device. Frictional type locking devices are not acceptable.

2.2.3.5 F/M Safety Lock

A positive mechanical lock is required to prevent the F/M accidentally unclamping from the reactor fuel channel, when the channel closure has been removed by the F/M. Frictional type locking devices or electrical interlocking devices are not acceptable. A control or manual release to override the safety lock is not acceptable.

The safety lock must be engaged prior to removal of the channel closure by the F/M and remain engaged until the channel closure has been inserted and secured.

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

This standard specifies the requirements and establishes the rules for design, fabrication, and installation of pressure-retaining containment system components. This standard does not cover the requirements for systems.

2.2.4.1 Vessels

Design of vessels and their attachments that form part of the containment boundary must comply with the requirements for Class 2 components of CSA Standard CAN3-N285.1 which gives direction into the ASME Boiler and Pressure Vessel Code.

2.2.4.2 Airlocks and Transfer Chambers

Airlocks and transfer chambers providing access through the containment boundary must meet the following requirements:

a. Doors must continuously maintain the containment boundary.

b. Airlocks or transfer chambers must have pressure-relief systems and minimize the spread of radioactive substances.

c. The shell of a metal airlock or transfer chamber is considered a vessel. If the shell is made of concrete, it is considered part of the containment structure to be designed in accordance with CSA Standard CAN3-N287.3.

2.2.4.3 Seal Plates

Seal plates may be used between the containment structure embedment and process system components that penetrate the containment structure, to form a portion of the containment boundary. Seal plates may also provide an anchor or support function for the penetrating system.

2.2.4.4 Electrical and Mechanical Penetration Assemblies

Electrical and mechanical penetration assemblies shall be designed to comply with the requirements of the applicable class within CSA Standard CAN3–N285.1.

2.2.4.5 Flexible Bellows and Seals

Flexible bellows and seals must accommodate movements between the containment structure and penetrating systems. When non-metallic flexible bellows or seals are used to perform the containment seal function for the penetrating systems, dual seals shall be installed with provision for in-service testing by pressurizing the space between the seals.

2.2.5 Design Procedures f Seismic Qualification of CANDU Nuclear Power Plants. (CAN3-N289 3)

This standard applies to those structures and components in CANDU nuclear power plants that require seismic qualification by analytical methods.

Seismic design requirements for commercial structures and industrial plants have existed in Canada for many years through the National Building Code of Canada (NBCC), which is mandatory throughout Canada. The seismic design of nuclear power plants requires special consideration for the safety of the public. The seismic design philosophy for CANDU nuclear power plants is based on principles established by the Atomic Energy Control Board of Canada.

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3. CAN/CSA-N285.2, Requirements for Class 1C, 2C and 3C Pressure-Retaining Components and Supports in CANDU Nuclear Power Plants.
4. CAN/CSA-N285.3, Requirements for Containment System Components in CANDU Nuclear Power Plants.
5. CAN3-N285.4, Periodic Inspection of CANDU Nuclear Power Plant Components.
6. N285.5, Periodic Inspection of CANDU Nuclear Power Plant Containment Components.
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CHAPTER 3

DESCRIPTION OF CANDU ON-POWER FUELING SYSTEM

1991 January

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91/01/17

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DESCRIPTION OF CANDU ON-POWER FUELING SYSTEM

1. INTRODUCTION

This chapter covers the fuel handling system, its principles of operation, a broad description of the equipment involved, its duty cycle and associated reactivity considerations. It will generally focus on the CANDU 6 design.

The system is designed for operations availability on the reactor for 75% of the year, with a service incapability factor of 0.6% at station maturity, that is, five years after the in-service date.

The following design values of maximum radiation fields are applicable:

a. General access (fuel handling areas) 154.8×10^{-9} C/kg/h (0.6 mR/h)

b. Infrequent access (maintenance of equipment) 322.5×10^{-9} C/kg/h (1.25 mR/h)

c. Emergency access (using temporary shielding when necessary) 516×10^{-9} C/kg/h (2.00 mR/h)

The total absorbed radiation dose of a fueling machine (F/M) maintainer is to be limited to 25 mGy (2.5 rad) per year.

All equipment is designed to withstand response spectra based on design basis earthquake (DBE) conditions appropriate to the station site to ensure integrity of the pressure retaining components.

The mechanical portion of this chapter includes descriptions of the following subjects:

Fuel Handling and Storage System
New Fuel Transfer and Storage
Fueling Machine (F/M) Head
Channel Closure, Shield Plug, Snout Plug and FARE Tool
F/M Bridge and Maintenance Lock Tracks
F/M Carriage and Suspension
Irradiated Fuel Discharge Equipment
Defected Fuel Canning
Irradiated Fuel Transfer Equipment
Semi-Automated Irradiated Fuel Transfer
Storage Bay
Irradiated Fuel Dry Storage

The controls portion of this chapter includes descriptions of the oil hydraulics auxiliary system, the F/M head D_2O system, and the control and instrumentation for the above subjects.

1.1 PURPOSE OF THE FUEL HANDLING SYSTEM

The purpose of the fuel handling system is to provide on-power, bi-directional fueling capability at a rate sufficient to maintain continuous reactor operation at full power.

1.2 SYSTEM DESCRIPTION

1.2.1 Introduction

The fuel handling system is made up of two F/Ms, two F/M support carriages and associated supporting tracks, two reactor vault bridge/column assemblies, two each of new fuel loading, irradiated fuel unloading and F/M calibration facilities, one irradiated fuel transfer system, plus all associated auxiliaries, power supplies and control systems.

The fuel handling system can be divided into three interrelated systems: new fuel transfer, fuel changing, and irradiated fuel transfer. Figure 3-1 shows the movement of fuel from the new fuel storage area through the reactor to the irradiated fuel storage bay.

1.2.2 New Fuel Transfer

The fuel arrives at site in pallets. Up to a nine month supply is stored in the service building new fuel storage room (Figure 3-2, Item 27). As required by station operation, the pallets are transferred to the new fuel loading area located inside the reactor building. There, the fuel bundles are uncrated, inspected and transferred to the new fuel transfer room.

There are two new fuel transfer mechanisms (Item 10), one for each F/M, serving each face of the reactor. Up to 12 fuel bundles can be stored in the new fuel magazine of each new fuel transfer mechanism, from where they are transferred, two bundles at a time, into the F/M located in the maintenance locks (Item 9).

Each fuel bundle is inspected during the loading process to check for defects.

Loading of new fuel into the new fuel mechanisms is done under local manual control, while the transfer of new fuel from the new fuel transfer mechanism magazines to the F/M magazines is normally done under computer control.

1.2.3 Fuel Changing System

The fuel changing system comprises two F/Ms (Figure 3-2, Item 4), one on each reactor face, two F/M head support carriages with associated catenary trolleys (Item 7) and two bridge-column assemblies (Item 2). The F/Ms are designed to interface with the fuel channel assemblies in order to transfer fuel on power while retaining heat transport system integrity. At the reactor site there is a total of three F/Ms (two operating F/Ms and one spare). Any one of the reactor F/Ms can operate at either reactor face.

The fuel channel assemblies (Figures 3-3, 3-4) locate and support the fuel bundles inside the reactor and form part of the primary heat transport system. There are 380 fuel channels in CANDU 6, with heavy water flowing through each channel and over the fuel bundles, removing up to 6.5 MW of heat per channel.

A fuel channel assembly consists of a pressure tube, two end fittings and associated hardware.

The pressure tube is connected by an expanded joint to an end fitting at each end. The pressure tubes are located inside the reactor calandria tubes which isolate the pressure tubes from the heavy water moderator in the calandria. The annular gap between the pressure and calandria tubes is filled with an insulating and protective gaseous atmosphere. Tube spacers in the annulus support and centralize the pressure tubes in the calandria tubes. The annulus is sealed at both ends by a bellows assembly rolled into and welded to the fueling tubesheet and also welded to the bellows attachment ring (shrunk onto the end fitting).

The end fittings are supported on two bearings at each end of the fuel channel. A positioning assembly at each end of the channel provides 'fixed' or 'free' end conditions to allow for thermal expansion and pressure tube creep.

The primary heavy water coolant flows into and out of the end fitting side-ports which are connected to the feeders by couplings. Inside the end fitting, coolant flows around a liner tube. Flow connection to the pressure tube is through holes at the inboard end of the liner tube.

The outboard face of each end fitting makes a sealed connection with the F/M for fuel insertion and removal. When the F/M is not engaged to the channel, the end fitting is sealed by a channel closure. The closure can be removed, stored, and reinstalled by the F/M, during refueling.

Each end fitting liner tube houses a shield plug which is removed and stored in the F/M during fueling operations. The shield plugs are located in the end fitting liner tube and provide the required shielding and axial location of the fuel bundles.

Once loaded with new fuel, the F/M traverses to the reactor face and connects to a fuel channel. A second empty F/M connects to the same fuel channel at the other side of the reactor. Automatic fuel changing operations then commence, with new fuel bundles being loaded at the upstream end while an equivalent number of irradiated fuel bundles are received by the downstream F/M. Bundle movement is controlled by the two F/Ms, but assisted by the coolant flow inside the channel. Because the flow in each alternate channel is reversed for reasons of reactor symmetry, the F/Ms must be capable of operating bi-directionally, that is, the upstream machine can perform the functions of the downstream machine and vice versa.

In a typical eight bundle fueling sequence (Figure 3-5), the following fuel movements inside the fuel channel can be identified:

- eight new bundles are inserted, two bundles at a time, from the upstream end.
- The whole 20 bundle fuel column (12 old bundles plus eight new bundles) are moved towards the downstream end.
- eight irradiated bundles are discharged, two at a time, from the downstream end.
- The remaining 12 bundle fuel column is moved back to the correct in-reactor position.

On completion of the fuel changing operation, the downstream machine traverses to the irradiated fuel port located in the maintenance lock.

1.2.4 Irradiated Fuel Transfer

Irradiated fuel is discharged from the F/M through the irradiated fuel ports (Figure 3-2, Item 12), located in the walls between the F/M maintenance locks and the irradiated fuel discharge room.

Two ball valves are mounted in series in each discharge port to seal the port and complete the containment boundary. The discharge room is considered outside the containment boundary, and when fuel is being transferred the F/M becomes part of the containment boundary.

The irradiated fuel discharge operation is performed in air from the point where the fuel bundles leave the D_2O environment in the F/M magazine until they are lowered into the water in the discharge room by either one of two elevators (Item 17), depending from which F/M the fuel is delivered.

The discharge bay (Item 11) is connected by an underground canal to a reception bay (Item 19) which in turn connects to the irradiated fuel storage bay (Item 23).

The elevators in the discharge room lower the irradiated fuel bundles, two at a time, onto a rack on a conveyor (Item 18) which transfers the bundles through the canal into the reception bay (Item 19). In the reception bay, the bundles are transferred onto trays for interim storage in the bay. The fuel trays are moved from the reception bay to the storage bay by the irradiated fuel transfer conveyor. In the storage bay, the trays are stacked one on top of the other, by an operator from a manbridge. The trays are normally stacked no more than 19 high as a minimum free water depth of 4.1 m (162 in) must remain between the top bundles and the water surface to ensure negligible radiation levels in the accessible area ssurrounding the irradiated fuel bay. The storage bay capacity for CANDU 6 allows for 10 years of reactor full power operation.

After the fuel leaves the reception bay, all operations are performed manually using tools suspended from the bay crane. Defected fuel is segregated from normal irradiated fuel in the discharge bay, and then is stored in a carousel type container for an initial decay and degassing period. Finally, it is canned and transferred to the defected fuel storage bay (Item 21) for long term storage.

Defected fuel is identified through two systems: the gross activity monitoring system and the defected fuel location system. The gross activity monitoring system continually monitors the two loops of the heat transport system for fission products indicative of a fuel defect. The defected fuel location system identifies the fuel channel containing the defected fuel and further indicates when the defected bundle or bundles have left the channel flow during the refueling operation. The location of the defected fuel bundles in the machine magazine is then known, so that, on arrival in the irradiated fuel discharge bay, the bundle pair can be manually segregated.

1.2.5 Fuel Handling Control

A fuel handling control console is provided in the station main control room. From here the fuel handling operations are controlled, except for the loading of new fuel into the new fuel transfer magazine and the semi-automated and manual operations of irradiated fuel storage. Two main digital control computers are available for reactor control: one in operation and the other on standby. The major portion of fuel handling operations are handled automatically by the standby digital control computer. This includes initiation of the semi-automatic irradiated fuel handling operations in the reception bay.

Two identical and complete separate control systems are provided, one for each F/M. The only communication between the two systems occurs during the fuel column movement in a channel, and initially on channel closure plug removal to check that both machines are at the same fuel channel.

The mode of control is selected at the control room fuel handling control console. Four modes of control are available: automatic run, automatic step, semi-automatic and manual operation.

Automatic run is the preferred mode of operation. In this mode of control the station digital computer takes command once a fuel channel and "job" are selected, and continues until refueling is completed. Communication between the computer and the instrumentation and control devices permits the computer to maintain control and perform the fuel changing operation. Only if a malfunction occurs should it be necessary for operator intervention.

In the automatic single step mode of control the computer controls the fueling operation, however, after each step of a sequence is completed, the computer must be commanded by the operator to proceed to the next step.

Semi-automatic operation consists of keyboard statements supplied by the operator independent of any 'job' or 'sequence', which are then executed automatically under computer control.

Manual operation requires the operator to perform each step by operating the functional controls on the control console. The operator checks for completion of each step using the console indicators, and then initiates the next step.

A 'protective system', which is a set of logic relays, has all the output control commands (both computer controlled and manual) routed through it. Its function is to prevent, through the use of interlocks, major damage to equipment or creation of a hazardous environment for personnel. The logic of this system is separate and in addition to that provided in the computer. The interlocks can be by-passed by handswitches located at the control console only with proper authorization, which must be obtained beforehand.

The control room fuel handling console consists of two identical sections, one for each F/M and a control panel for common systems. Apart from the control panels, each F/M section contains a cathode ray tube for data display, an 'operate panel' to communicate commands and select desired displays, and an alpha-numeric keyboard for operator communications with the computer.

1.3 OPERATING PRINCIPLES

1.3.1 Duty Cycle

The normal fueling duty cycle is made up of the incremental movements of the F/Ms as they traverse between the maintenance locks and the reactor vaults, inserting new fuel into the reactor and removing irradiated fuel.

Assuming continuous reactor full power operation, the rate of fueling in the equilibrium state is 112 bundles per week. Note that for approach to the equilibrium condition this rate is different, as described in Section 1.3.2.

The normal fueling duty cycle is based on fueling seven days per week, and considers the addition and removal of 16 bundles per day, with bundles handled at a rate of eight bundles per channel fueled.

The minimum time required to fuel a channel can be divided into four separate duty cycles:

a. At New Fuel Port	26.4 min
b. Traversing to and from reactor face	12.5 min
c. On-reactor duty cycle	60.3 min
d. At Irradiated Fuel Port	28.7 min
Total:	127.9 minutes or 2.13 hours

For two channels per day, the minimum fueling time would be 4.26 hours. Adding in a performance factor of 1.5 to provide for operator efficiency, routine calibration and check-out, the daily fuel handling system availability must not be less than 6.4 hours. Fuel handling system availability therefore must be about 28% per day to maintain full power operation in the equilibrium burn-up state, assuming a seven day per week fueling operation.

If a five day per week operation is introduced, a system availability of not less than 9.6 hours or 40% per day would be required for those days when three channels per day are refueled. For two channel refueling days, the system availability would be as in the preceding paragraph. The normal average rate of refueling of 112 bundles per week would require three three-channel refueling days for each two-day channel refueling day.

1.3.2 Approach to Equilibrium Burn-up

As mentioned before, the normal rate of fueling in the equilibrium state is 112 bundles per week, assuming sustained reactor full power operation. To obtain the equilibrium state, the new core load and its effect on reactivity must be considered. Because of built-in excess reactivity in the fresh core, there is a time period of approximately 120 days of full power operation during which refueling operations are not required. However, after that, fueling must proceed at about twice the normal rate (i.e., up to 50 bundles per day) for a three to six week period to compensate for an increased rate of reactivity decrease with burn-up.

2. NEW FUEL TRANSFER AND STORAGE SYSTEM

2.1 INTRODUCTION

The new fuel transfer and storage system covers the new fuel transfer process, from the delivery of new fuel pallets to the stations to the reception of new fuel bundles into the F/M. It can be divided into two parts:

a. New fuel storage and handling, which extends from delivery of new fuel to the movement of this fuel into the new fuel transfer mechanism. These operations are performed manually.

b. The new fuel transfer mechanism, which loads new fuel bundles into the F/M. This operation is performed under computer control.

2.2 PURPOSE

The purpose of the new fuel transfer system is to provide a safe and reliable way of supplying the two F/Ms with sufficient quantities of new fuel in order to maintain full-power operation. Since refueling is normally carried out with the reactor at power, the system also provides the facility to load fuel in an accessible area for transfer into the F/Ms, to which access is limited.

2.3 SYSTEM DESCRIPTION

2.3.1 Storage and Handling up to the New Fuel Transfer Room

The new fuel for the 600 MWe CANDU reactor consists of 37 fuel sheaths per bundle (Figure 3-6).

The bundles are individually packed in styrofoam containers, 36 bundles to a pallet, each pallet weighing about 900 kg (2000 lb_f). The pallets arrive at the station via truck. Once the truck is parked at the unloading dock, the shipping personnel will use the service building hall crane with a pallet fork attachment to lift the pallets, two at a time, from the truck to the service building temporary loading area. The pallets are visually inspected to ensure that there was no damage during transit. A fork lift truck will then move the pallets, one at a time, to the new fuel storage area in the service building, and place them on specially designed racks for storage. Up to nine months supply of pallets can be stored in this room.

Each week enough fuel for one week's operation, normally 112 bundles or about three pallets, will be removed from the new fuel storage room via fork lift truck and placed in the service building crane hall. Using the service building hall crane, the fuel, two pallets at a time, are raised using a crane attachment and transported to the equipment airlock laydown area.

The pallets are next moved, two at a time, through the equipment air-lock using a pallet truck.

From the reactor side of the air-lock, the pallets, two at a time, are transported and lowered, using the 13600 kg (15 ton) reactor building crane with another crane attachment, to the new fuel transfer room (Figure 3-7). The fuel is placed, two pallets high, in the storage area of the new fuel transfer room. Normally, there are six pallets in the new fuel transfer room.

2.3.2 New Fuel Transfer Room

Once a fuel pallet has been moved into the new fuel transfer room, an operator will open it and unwrap the individual fuel bundles. He will pick up one bundle at a time and move it onto the bundle inspection table via the bundle lifting tool attached to the air-balanced hoist. He carefully inspects the bundle size with the fuel spacer interlocking gage. He also ensures that each bundle is free of damage and foreign matter prior to loading.

The loading operation is preceded by a status check of the transfer mechanism to ensure that the system is ready.

Status of Transfer Mechanism Prior to Loading:

- All electrical and air systems are on.
- Magazine active vent is open (i.e., the vapor recovery system is on).
- Shield plug is locked in new fuel port.
- Transfer ram and loading ram are fully retracted.
- Air lock valve is closed.
- Magazine is empty of new fuel.

The actual loading operation is divided into a series of steps. Each step is a permissive for the one following. Confirmation of the successful completion of each step is indicated by either a limit switch or a shaft encoder.

All steps, except the first which is a manual operation, are controlled from the control panel mounted on the transfer mechanism.

- Manually open trough lid, load two fuel bundles into the loading trough and close trough lid.
- Index transfer mechanism magazine until an empty magazine position is in line with the loading trough.
- Open air lock valve to fully open.
- Advance loading ram to fully advanced position.
- Retract loading ram to fully retracted position.
- Close air lock to fully closed.
  - Repeat above steps until the required number of bundles are loaded.

2.3.3 Transfer to F/M

The transfer of fuel bundles from the transfer mechanism magazine to the F/M magazine is normally performed under complete computer control. It is possible to operate the transfer mechanisms manually, using the switches on the main control room console, but the benefit of computer software checks will be lacking when manual mode is in use.

There is no provision on the local control panel to initiate this transfer. Prior to beginning the transfer sequence, the F/M D_2O level is lowered below the snout level and the F/M is clamped onto the new fuel port.

To ensure that the F/M is ready to begin the sequence the computer memory is checked to see that the F/M snout plug is in its magazine station and the guide sleeve has been installed in the snout. The feedback must indicate that all rams are at home positions without the ram adapter. The F/M rams are not used in this sequence and must be clear of the magazine.

The feedbacks of new fuel system also check to ensure that the airlock valve is closed, that there is fuel in the new fuel magazine stations and that the new fuel magazine is not in use.

All conditions being satisfactory, the new fuel magazine is rotated to the shield plug station, the new fuel 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 F/M 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 fuel bundles into the F/M magazine station.

The feedback of the new fuel transfer ram being fully advanced means that the two new fuel bundles have been transferred from the new fuel magazine to the F/M magazine. The new fuel transfer ram is moved back to the home position. The F/M and new fuel magazine are rotated to the next stations and two more fuel bundles are transferred. This process is repeated until the F/M magazine contains the required number of bundles.

After completion of the bundle transfer, the shield plug is reinstalled into the new fuel port and locked in place.

The F/M then removes the guide sleeve from the new fuel port, installs its snout plug, raises the D_2O level and unclamps from the new fuel port in order to transfer to the reactor face.

2.4 EQUIPMENT DESCRIPTION

2.4.1 Jib Cranes

Before loading new fuel bundles, a pallet must be moved from the storage area to the loading area in the new fuel transfer room. Two 1800 kg (2 ton) jib cranes are mounted in the corners of the new fuel transfer room above the fuel transfer mechanisms, to move pallets of new fuel and pieces of equipment within the room. They are provided with electrically powered hoists (Figure 3-7, Item 8).

2.4.2 Air Balance Hoist

After uncrating, the individual fuel bundles are lifted and transferred between the pallet inspection table and the loading trough by the fuel lifting tool suspended from the air-balance hoist.

The air-balance hoist is mounted on a jib crane of 140 kg (300 lb_f) capacity Figure 3-7, Item 7). This crane is pivoted from the building wall above the two new fuel transfer mechanisms, at approximately the building center line, and covers the area of the new fuel transfer room through which new fuel bundles have to be moved. The air balancing hoist is free to travel along the jib. It is air powered at a gauge pressure of 827 kPa (150 psi) and can be adjusted to balance the load from a control on the operator's handgrip on the bundle lifting tool.

2.4.3 Bundle Lifting Tool

The bundle lifting tool is a manually operated device which clamps around the end plates of the fuel bundles, through lifting adaptors. When the weight of the bundle is on the tool, the tool is clamped securely to the bundle end plates 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 with a minimum of effort and without damage.

Once the bundle is on the air balance hoist, it is moved onto the inspection table (Figure 3-7, Item 5), centrally located between the two new fuel transfer mechanisms (Item 1).

Before placing a bundle in the loading trough of the transfer mechanism, it must be thoroughly inspected and its serial number recorded with respect to its final location in the reactor. Under no circumstances may fuel be put into the reactor if there is any doubt about its physical condition. While the bundle is held in the lifting tool over the inspection table, a check of the bundle diameter and a visual check for cleanliness will be carried out to make sure no foreign material such as the polyethylene wrapping or styrofoam packing is stuck to the bundle.

2.4.4 Fuel Spacer Interlocking Gage

The fuel spacer interlocking gage (Figure 3-8), is used to check the overall diameter of each fuel bundle before it is placed in the loading trough. Separation among the elements at the fuel bundle mid-length is maintained by three spacers which are brazed to the elements. The spacers are positioned on each individual element such that contact between any two mating elements is spacer-to-spacer. Furthermore, adjacent spacers are skewed in the opposite directions to increase the effective width of contact among the spacers and to decrease the possibility of their interlocking. The diameter of the bundle indicates whether or not the spacers of the bundle elements are interlocked. The gage is used on the bundle while the bundle remains supported in the lifting tool. It consists of two pivoted segments and a dial gauge, the dial gage having a shaded area which indicates a 'GO/NO GO' range.

2.4.5 Loading Trough and Loading Ram

After the bundles are thoroughly inspected, they are placed in the fuel loading trough of one of the transfer mechanisms (Figure 3-9). They are identical in construction but mounted in opposite directions, in order to supply new fuel to the F/M on both faces of the reactor.

The loading trough and a ram are provided for loading the new fuel into the new fuel transfer mechanism magazine. Two fuel bundles are normally loaded into the trough (Item 10), and after the bundles are loaded, the lid is closed and the bundles are pushed into the magazine (Item 5) by the loading ram. The magazine is indexed to the next channel position and two more bundles are inserted, until the magazine contains the required number of fuel bundles.

The trough is provided with a hinged lid (Item 11) 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 connects to the transfer mechanism rear cover at the top position, in line with the top magazine station. The ram is an oil/air operated, double-acting cylinder, supplied from the new fuel auxiliaries system. The oil/air system of ram operation is used since it enables better speed control and smoother ram operation. Proximity switches are installed at each end of the cylinder to indicate when the limits of ram travel have been reached.

2.4.6 Air Lock Gate Valve

The air lock gate valve (Figure 3-9, Item 8 and Figure 3-10) 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 any contamination from the F/M head, the maintenance lock or the reactor vault, into the new fuel room. Limit switches indicate when the valve is at the open and closed positions.

2.4.7 New Fuel Transfer Mechanism Magazine

The transfer mechanism magazine assembly (Figure 3-9, Items 4-7) 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 vapor recovery system to remove any contamination through purging.

The magazine rotor contains seven tubular channels, six for accommodating the new fuel bundle pairs and one for the new fuel transfer mechanism shield plug. The shield plug, which is normally located in the new fuel port, reduces radiation streaming into the new fuel transfer room from the F/M head when passing by the new fuel port of the F/M maintenance lock.

The drive unit is shown in Figure 3-11. A bevel ring gear is mounted to the rotor assembly, connecting with the bevel drive pinion for a 7:1 gear reduction. A coupling connects the bevel drive pinion to a 'Ferguson' indexing unit located outside the magazine housing. This 'Ferguson' unit has a 4:1 reducing ratio. It features a special cam mounted on the input shaft meshing with eight roller followers mounted on the output shaft.

The lead on the cam is shaped such that through 90° of input shaft rotation, there is no movement on the output shaft. The spaces between the eight roller followers correspond to the seven magazine stations, thus allowing for accurate magazine positioning without close positioning requirement on the input shaft. A spring-set electrically released brake on the motor minimizes coasting and provides positive positioning.

2.4.8 Transfer Ram and Drive

The function of the transfer ram is to push the new fuel bundles from the new fuel transfer mechanism magazine into the F/M, and to move the shield plug between the new fuel port and the transfer mechanism magazine. The openings for the transfer ram on the magazine front and rear covers is 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 (Figures 3-12, 3-13).

The ram is driven through a continuous duplex chain by a variable speed dc motor through a speed reducer and a torque limiter. The ram tube is supported at the rear on two pillow blocks, fitted with split ball bushings, which run on two roundways. The ram is sealed to the back of the new fuel magazine housing by a floating seal assembly. This contains a wiper and a seal, both mounted in a housing which is free to move radially within the main housing. The ram head is chrome plated and contoured to permit free movement in the magazine channels and in the port.

The ram is normally driven under program control from the digital computer, although manual control from the control console in the main control room is possible. When pushing fuel or a shield plug, the ram is operated at slow speed at the beginning and end of each stroke, and at high speed for the balance of the stroke. During ram retract, the slow speed is only used at the end of the stroke. Controlled acceleration and deceleration and dynamic braking are also provided by the motor controller.

Ram force is limited by a torque limiter mounted between the speed reducer and the chain drive sprocket.

Ram position, for control of ram stopping and speed changing operations, is detected by a shaft encoder driven through a speed reducer connected to the end of the chain drive sprocket shaft.

2.4.9 Magazine/Port Adaptor

An adaptor assembly is bolted to the new fuel transfer mechanism front cover, at a bottom position in line with the respective magazine station and the new fuel transfer ram. The adaptor connects the new fuel magazine to the new fuel port and consists of a spool piece with two double acting pneumatic cylinders (Figure 3-9, Item 7, and Figure 3-12). The function of the two cylinders is to lock the new fuel shield plug in position in the new fuel port, and to release the transfer ram from the shield plug after locking, allowing the transfer ram to retract while the shield plug remains in the new fuel port. Whenever the shield plug or new fuel bundles require passage through this area, both pneumatic cylinders must be retracted.

The mechanism to unlatch the shield plug in the transfer mechanism magazine is illustrated in Figure 3-13. A ramp bracket built into the magazine tube actuates the latching mechanism and disconnects the shield plug from the ram head.

2.4.10 New Fuel Port

Embedded in the walls of the F/M maintenance lock are the new fuel ports (Figure 3-14). Their centerlines are located 2.4 m (8 ft) above the floor in the maintenance locks and 460 mm (18 in) above the floor in the new fuel transfer room. Again there are two ports for the two F/Ms servicing the reactor. The port is a tubular connection with an end fitting extending into the maintenance lock and the other end engaging with the new fuel transfer mechanism port adaptor. On loading new fuel into a F/M, the new fuel port becomes the passageway for bundle movement from the new fuel transfer mechanism to the F/M.

The two ports are offset by 270 mm (10.5 in) relative to each other to join the two new fuel transfer mechanisms, which are offset. Where the new fuel port extends into the F/M maintenance lock, a drain connection is located to collect any run-off from the F/M magazine during new fuel transfer.

2.4.11 Local Control Panel

A local control panel is mounted beside each transfer mechanism. The control panel contains the controls and indicators required for loading the fuel bundles into the magazine and for indicating the magazine load status. A key operated switch permits the selection of 'AUTO', 'MAN' or 'REMOTE' for the loading function. When selected to 'AUTO', the normal method of operation, both transferring of the fuel into the magazine and indexing of the magazine are performed automatically through a single manual pushbutton actuation. In the 'MAN' mode of operation, the loading ram, air lock valve and the magazine operations are under full manual control through actuation of three-position switches on the panel. The 'REMOTE' selection permits operation under abnormal conditions of the ram and air lock valve from the fuel handling control console in the main control room.

3. FUELING MACHINE HEAD - GENERAL

3.1 INTRODUCTION

The F/M (Figures 3-1 to 3-16) is basically a pressure vessel designed to form an extension of the heat transport system to enable refueling operations with the reactor at full power.

3.2 PURPOSE

The purpose of the F/Ms is to transfer new fuel to the reactor, receive and transfer irradiated fuel from the reactor and to perform the operations necessary for on-power refueling at the reactor face.

3.3 SYSTEM DESCRIPTION

The fuel changing operation is carried out by the F/Ms. This process requires the F/M to interface with the new fuel port, fuel channels, irradiated fuel ports, and the associated plugs and adaptors. The fuel changing operation is shown in Figures 3-17 to 3-21.

The fuel changing operation begins as one F/M traverses to the maintenance lock to receive new fuel. The operation is described by the duty cycle, 'at the new fuel port', as follows:

Step	Operation
1	Home and Lock F/M
2	Drain down
3	Remove snout plug and insert guide sleeve
4	Remove port shield plug
5	Insert two bundles into F/M and retract new fuel port ram
6	Repeat steps 4 and 5 three times
7	Index new fuel magazine, insert and lock port shield plug and retract ram
8	Remove F/M guide sleeve and insert snout plug
9	Unlock F/M 'Z' motion out

The F/M then traverses to the reactor face and locks onto a fuel channel. The F/M at the other side of the reactor also locks onto this channel. The F/M then performs various functions to move the new fuel into the channel while the opposite F/M receives the irradiated fuel. At both ends of the channel the channel closures and snout plugs must be removed.

The operation of the changing F/M is described by the 'on reactor' duty cycle:

Step	Operation
1	Home and Lock F/M
2	Pressurize
3	Remove snout plug and store
4	Remove closure plug and store
5	Insert guide sleeve in snout
6	Remove shield plug and store
7	Fuel eight bundles
8	Replace shield plug
9	Remove guide sleeve and store
10	Replace closure plug
11	Replace snout plug
12	Depressurize
13	Unlock F/M 'Z' motion out

The F/M accepting the irradiated fuel will then traverse to the irradiated fuel port to discharge the irradiated fuel bundles. This operation is described by the duty cycle, 'at irradiated fuel port', as follows:

Step	Operation
1	Home and Lock F/M
2	Flood port, remove snout plug and insert guide sleeves
3	Drain down and open port valves
4	Index F/M magazine
5	Advance F/M ram to load two bundles onto ladle
6	Retract F/M ram to clear and retract fuel stop
7	Lower ladle
8	Index rack
9	Raise ladle
10	Repeat steps 4 to 9 three times (includes complete ram retraction after last bundle pair)
11	Close port valves, remove guide sleeve, insert snout plug
12	Unlock F/M 'Z' motion out

The process will then continue with the 'accept' F/M traversing to the new fuel port in the maintenance lock. The 'accept' F/M and 'charging' F/M, therefore, perform both fueling functions. Fueling will always be done with the flow in the fuel channel. Alternate fuel channels have opposite coolant flows.

The traverse time of the F/Ms is lumped into one duty cycle, 'traversing to and from the reactor face':

Step	Operation
1	Traverse from start position to new fuel port
2	Traverse from new fuel port to bridge (average)
3	Raise bridge and position F/M at fuel channel (average)
4	Align reactor area bridge with maintenance lock tracks (average)
5	Traverse to irradiated fuel port
6	Traverse from irradiated fuel port to finish position

3.4 EQUIPMENT DESCRIPTION

The F/M is made up of several main assemblies, and also requires additional associated components, supporting structures, and supply and control systems.

The F/M is comprised of four major assemblies: the snout assembly, the magazine assembly, the separators and the ram assembly.

The ram adaptor, guide sleeve assembly, snout plug, coolant channel closure, coolant channel shield plug, and the FARE tool are operated and handled by the F/M major assemblies. These components are required to maintain system integrity while not refueling or to allow proper handling of the fuel bundles.

The cradle (Figure 3-15) supports the F/M, and carries much of the D_2O, electrical and oil hydraulic equipment. The cradle also supports the magazine manual drive equipment and the F/M counterbalance weights. The F/M is secured to the cradle through fittings on the magazine housing, while the ram housing is supported in the cradle on two pairs of rollers which permit differential expansion. To overcome the effects of ram housing whip under seismic loading, restraint straps are located over the ram housing at each support location. These straps also allow for differential expansion.

The equipment required for F/M mobility, support, control and power supply include the F/M bridge, F/M carriage assembly, catenary system, F/M D_2O control and F/M oil hydraulics. The F/M assemblies and associated equipment are described individually, in Sections 4 to 18.

4. F/M SNOUT

4.1 PURPOSE

i. To achieve on-power fueling, the snout assembly enables the F/M to clamp onto any reactor fuel channel end fitting and to seal the connection at high D_2O pressure and high temperature.

ii. To achieve loading of new fuel bundles and the discharging of irradiated fuel bundles from a F/M, as well as testing and maintenance, the snout assembly enables the F/M to clamp onto the new fuel port, irradiated fuel port, ancillary port, or rehearsal-facility port.

4.2 EQUIPMENT DESCRIPTION

The snout assembly (Figure 3-22) comprises the center support, the clamping mechanisms, the emergency lock assembly, the head antenna and the snout probes. It is designed to prevent D_2O leakage under a high operating pressure and increased temperature during on-power fueling operations.

The pressure tight connection is accomplished by advancing the F/M in the 'Z' direction until the clamping barrel (Figure 3-22, Item 9) is over the end fitting and two of the snout probes (Item 27) are depressed. There are four snout probes that detect the proximity of the seal face to the end fitting, so that proper contact for clamping can be determined. Once the probes are depressed, clamping is initiated by driving wedge segments (Item 6) down behind the end fitting flange. This also serves to press the end fitting face up against metallic seal on the end of the center support (Item 14). A pressure tight connection is achieved when the required clamping force has been reached.

Another important feature of the snout assembly is the antenna which is mounted on the front of the snout and is used to detect any gross position error of the F/M when it is advancing in the 'Z' direction towards a channel end fitting. If the F/M is misaligned with the end fitting, the antenna plate (Item 1) will be depressed. This actuates the antenna switch (Item 3) and the motion of the F/M towards the reactor is stopped as a consequence. Also, disengagement of the clamping mechanism while the magazine is at reactor pressure is prevented by an emergency lock assembly which is activated when the magazine pressure is over 3.79 MPa (550 psi).

The snout plug, which is used to seal the F/M, is held in place by jaws engaging the locking groove of the center support. The seal is made by expanding a radial bore seal in the smooth bore of the center support. The center support also acts as a connecting channel between the magazine and the end fitting, and accommodates the guide sleeve during fueling operations.

4.2.1 Snout Center Support and Seal

The snout center support (Figure 3-23), is a concentric stainless steel forging extending the pressure boundary from the reactor end fitting into the F/M magazine. It keys to the magazine front cover and has a smooth inside bore with a locking groove for the snout plug and a keyway for the guide sleeve.

Located on the front face of the snout center support is the static seal that interfaces between the F/M snout and the fuel channel end fitting. The static seal is a one-convolution metallic ring. It is held in front of the center support by a seal holder and seal holder ring and is replaced on average every three to six months.

4.2.2 Snout Clamping Mechanism

The snout clamping mechanism is actuated oil-hydraulically by four pistons (Figure 3-22, Item 23) mounted on either end of the upper and lower racks (Items 21, 22). Two pistons are used for clamping and two for unclamping. Linear rack movement causes a rotary motion in the screw and gear component (Item 16) which in turn moves the clamping barrel (Item 9) in an axial direction. The clamping force generated reacts against the snout center support through a thrust bearing (Item 17) and the lock ring (Item 15), placing the center support section forward of the lock ring under compression during clamping. A second thrust bearing locates the screw and gear components while a spacer and 'Belleville' spring washer (Items 18 and 19) accommodate any additional movement due to thermal expansion in the center support after the clamping action is complete.

The correct rack and gear meshing is ensured by a guide plug (Item 26) for the upper rack and the emergency lock piston housing (Item 28) for the low rack.

Four identical linkage mechanisms are provided to drive four wedge segments (Item 6) into position during clamping.

Each linkage mechanism (Figures 3-22 and 3-23), is comprised of a wedge segment (Figure 3-22, Item 6), a post and screwed link (Item 8), a lever arm with two attached roller bearings (Item 7), a cam block (Item 5), and a lever bearing. The lever bearing is rigidly mounted to the clamping barrel with an appropriate cut-out provided in the outer support to allow for movement in the axial direction, as shown in Figure 3-23. The cam block is rigidly mounted to the outer support and engages the two roller bearings connected to either side of the lever arm. The slots in the cam block are shaped such that the lever arm is forced down when the clamping barrel (and hence the lever arm) retracts during the clamping operation. With the four wedge segments thus inserted, the clamping force is transmitted axially from the clamping barrel via the wedge segments to the end fitting shoulder, pressing the end fitting against the snout center support.

When the snout is unclamped the wedge segments are retracted. This is necessary as the end fitting shoulder must pass the wedge segments prior to clamping.

An O' ring seal (Figure 3-22, Item 13 and Figure 3-23 Detail 'A') is provided to prevent corrosion in the annular space containing the threaded section as well as the main thrust bearing. The O' ring seals against any D_2O which otherwise may enter this area in the event of snout seal leakage. An inter-cavity leak-off is provided from the annular space to give an indication of either oil leakage past the rack pistons or D_2O leakage past the emergency lock piston. Another leak-off is provided from the inter-cavity between two O' rings (Figure 3-22, Item 25), to detect any in-leakage from the magazine side.

4.2.3 Snout Emergency Lock Assembly

The snout emergency lock assembly safeguards against inadvertent snout unclamping while the snout cavity is pressurized above 3.93 MPa (570 psi). The snout cavity is defined as the area forward of the F/M snout plug when installed in the snout. During refueling, both the coolant channel closure and the F/M snout plug are removed and the F/M becomes an extension of the heat transport system. Inadvertent snout unclamping (resulting in a loss-of-coolant accident) is therefore prevented by mechanically engaging a solid piston (Figure 3-22, Item 29) into a recess on the lower rack, thus positively arresting the unclamping motion. The lock piston is engaged by D_2O hydraulic pressure through a direct line connecting the snout cavity pressure to the underside of the lock piston. A spring (Item 30) fully returns the lock piston if the snout cavity pressure falls below 3.93 MPa (570 psi). Conversely, if the snout cavity pressure rises above 5.86 kPa (850 psi), the piston is fully engaged. The heat transport system pressure is approximately 10.76 MPa (1500 psi).

4.2.4 F/M Antenna Assembly

The F/M antenna consists of a stainless steel plate (Figure 3-22, Item 1) shaped to interfere with the fuel channel end fittings if the position error between the end fitting and F/M snout center lines is more than 12 mm (0.475 in) during homing operation. The plate is held in position by four spring assemblies mounted to a support ring (Item 2) which in turn attaches the whole antenna assembly to the snout clamping barrel. Depending on the direction of the position error, one or more of the four antenna switches (Item 3) mounted 90° apart on the support ring will be actuated if the antenna plate is depressed, that is, if misalignment exists beyond the capability of the 'X' and 'Y' correction-systems. The control system then stops further F/M head advance and corrective action by the operator becomes necessary.

4.2.5 Snout Probes

Four probes (Figure 3-22, Item 27) are located 90° apart on the seal face of the snout center support. The probes are actuated by the reactor end fitting during the homing operation to indicate close proximity of the end fitting seal face and hence correct position for snout clamping. Each probe is mounted through a lever bearing to the snout and connects to a linear potentiometer mounted to the outer support. A spring connected in parallel to the potentiometer holds the linkage assembly under tension.

5. F/M MAGAZINE ASSEMBLY

5.1 PURPOSE

The magazine assembly provides a storage facility within the F/M head for fuel bundles, channel closures, shield plugs, snout plug, ram adaptor, and guide sleeve and insertion tool.

5.2 EQUIPMENT DESCRIPTION

The magazine assembly can be divided into three main parts, the magazine housing, the magazine rotor and the rotor drive unit.

5.2.1 Magazine Housing Assembly

The magazine housing assembly (Figure 3-24) is a pressure vessel designed to operate at a rated pressure of 13.1 MPa (1900 psi) and a temperature of 149°C (300°F). It consists of two forgings; the magazine front cover and the magazine rear housing (Figure 3-24, Items 18 and 23) held together by a large Grayloc clamp and seal ring (Items 21 and 22).

The Grayloc clamp consists of two halves made of cast steel and a seal ring made of stainless steel. Each clamp half is designed with an integral lifting lug for convenience in handling. The threaded steel studs holding the clamp halves together are equipped with indicator rods fitted axially through their centers and secured at one end. Proper clamping force is indicated by the extension of the studs in tension relative to the untensioned rods. The steel nuts have spherical ends which seat in spherical seats of the clamp halves. The nuts have extended hexagon outer ends for access of the wrench socket without fouling the hoop or the clamp.

The seal ring provides concentricity between magazine front cover and rear housing while a dowel pin connecting into both contact faces assures correct alignment of the magazine housing and the front cover, so that the ram assembly and top center position of the magazine rotor will be lined up with the snout assembly.

The magazine front cover provides openings and mounting faces for the snout assembly, the separators and the weir, while the magazine rear housing has a smaller clamping hub for attachment of the ram assembly via another Grayloc clamp (Item 33) and an extension to house the indexing drive unit. Components inside the magazine housing comprise the magazine rotor with its shaft seal, the D_2O lowering weir which maintains a minimum level of D_2O in the magazine, four D_2O mixing eductors, temperature sensing devices and a flow shield.

The funnel shaped flow shield (Item 28) is fitted into the back end of the magazine housing and is trapped in place between a shoulder in the housing and the spherical bearing housing of the ram assembly. Its function is to minimize thermal shock to the back end of the magazine housing by shielding it from the flow of cooler water entering the magazine housing from the ram housing.

The four mixing eductors (Item 35) are fed from the magazine D_2O supply line. Two eductors are fitted around the center hub near the back and two are fitted inside the rear housing about 400 mm (16 in) further forward.

The inner eductors direct flow clockwise and the outer eductors direct flow counterclockwise. Their purpose is to provide good mixing of the entering water with the water already in the magazine coming from the ram assembly.

The D_2O level control weir (Figure 3-24, Item 20 and Figure 3-16) is mounted on the inside of the front cover and allows the water level inside the magazine to be lowered below the snout if the drain valve is opened.

There are three temperature sensing resistance temperature detectors (RTDs), one on the top of the magazine front cover, one on the top of the magazine housing, and another on the back of the magazine housing on the right hand side below the lowered water level.

5.2.2 Magazine Rotor Assembly

The magazine rotor consists of a solid rotor shaft and a cylindrical weldment holding 12 magazine tubes. All components are made of stainless steel. The end plates of the weldment are machined to a scalloped shape to form the 12 equally spaced saddles for positioning the magazine tubes. Two lugs on each tube provide for screws and dowels to form the attachment to the scalloped end plates of the weldment. Individual tubes can thus be replaced if they become worn or damaged.

There are five stations for fuel bundles (two bundles per magazine station), two stations for channel closures (one spare), two stations for shield plugs (one spare), one station for the ram adaptor, one station for the guide sleeve and insertion tool and one station for the snout plug. The guide sleeve station is the only one split along its length to provide a guiding key-way for the guide sleeve. The ram adaptor station has a bar welded across its front opening to ensure against entry of fuel bundles.

5.2.3 Rotor Shaft and Drive Unit

5.2.3.1 Rotor Shaft Support

The rotor shaft support is a stainless steel long neck flanged structure. It holds the rotor shaft in place with one set of single row deep groove radial ball bearings in the front and a triple stack of angular contact ball bearings at the rear. The rotor shaft support is bolted to the magazine rear housing. The bearings are designed to support the mechanical loads and to withstand the hydraulic load. The mechanical loads include the weight of the loaded magazine channel stations and the ram forces. The hydraulic load is generated by the magazine internal pressure.

5.2.3.2 Balanced Shaft Seal

The magazine housing has two separate compartments; the magazine enclosure and the Ferguson Drive enclosure. The rotor shaft passes through the wall between the two compartments and the pressure boundary is provided by a balanced shaft seal (Figure 3-25). This seal assembly comprises a spring loaded rotor assembly mounted to the magazine rotor shaft and running against a stator which connects to the magazine housing through a gland plate.

5.2.3.3 Drive Unit

The rotor shaft section extending into the Ferguson Drive enclosure attaches to a plate of 12 equally spaced roller followers and also connects to a rotary potentiometer (Figure 3-25). The roller followers engage an indexing cam. The cam shaft which mounts the indexing cam is installed perpendicular to the rotor shaft and supported by two sets of tapered roller bearings. Both ends of the cam shaft extend from the Ferguson Drive enclosure and are sealed by a pair of oil seals. One side of the cam shaft is attached to a drive gear which engages the worm gear of the oil hydraulic motor in the gearbox. The other side (not shown in Figure 3-25) is attached to a rotary potentiometer. The oil hydraulic motor, the gearbox and the rotary potentiometer are mounted outside of the Ferguson Drive enclosure.

Whenever the oil hydraulic motor is energized, it rotates the magazine via the indexing cam and roller followers. For change of one channel station, the roller follower turns 30° while the indexing cam rotates 360° with 90° dwell. Throughout the 90° dwell the magazine station remains aligned.

5.2.3.4 Magazine Emergency Drive

The emergency drive gearbox assembly is mounted between the hydraulic drive motor and the worm drive reduction gear assembly, and enables the hydraulic drive motor to be disengaged and a manual drive shaft to be engaged with the worm drive input shaft for manual operation. The manual drive shaft of the emergency drive gearbox is connected through rotary drive shafts and a miter gearbox to a manual drive shaft at the rear of the ram assembly (Figure 3-15). The manual drive is locked by a dowel pin engaging a hole in the manual input drive shaft flange. To rotate the manual drive, an upward force on the input drive must be maintained in order to release the flange from the pin.

In normal operation, a sliding coupling sleeve in the emergency drive gearbox (Figure 3-26) is held in engagement with the hydraulic drive motor by an eccentric stop on the manual input shaft. When the manual input shaft is rotated 180°, the eccentric stop releases the sliding coupling sleeve, which through springs, slides along the guide pins to disengage the hydraulic drive motor and engage the manual input shaft with the worm drive reduction gear input shaft. Continued rotation of the manual input shaft from the connection point at the rear end of the ram assembly will then rotate the magazine.

To return the emergency drive gearbox to hydraulic motor operation, the manual input drive shaft is positioned so that the eccentric stop is clear of the sliding coupling sleeve. The sliding coupling sleeve is then repositioned by a squared shaft on the emergency drive gearbox and the manual input drive shaft is rotated 180° to engage the eccentric stop with the sliding coupling sleeve to hold the coupling sleeve engaged with the hydraulic drive motor.

5.2.4 Magazine D_2O Level Drain Assembly

The magazine housing is a pressure vessel filled with D_2O. Whenever new fuel bundles are loaded into the magazine, or discharge of irradiated fuel bundles from the magazine is required, the magazine must be depressurized and its D_2O level lowered below the snout opening. For this purpose, the magazine has a weir built in the magazine front cover (Figure 3-16). In operating a drain valve, the weir retains the magazine D_2O level such that all channel stations remain submerged except the one indexed to the snout. A drain valve is mounted under the bottom of the magazine front cover and is powered by an oil hydraulic actuator. The actuator stem of the drain valve has a heavy spring, such that when the oil pressure acting on the actuator is equal to (or greater than) the spring force, the valve is closed. The spring will force the valve to open if the oil pressure becomes lower. A linear potentiometer attached to the drain valve stem provides electrical signal feedback to the control system. Whenever the fueling operation requires lowering of the magazine D_2O level, a mechanism termed the D_2O discharge port comes into play.

The D_2O discharge ports, located on the floor of both F/M maintenance locks under the new fuel, irradiated fuel, and ancillary calibration ports, provide for:

i. D_2O discharge from the F/M magazine to be funnelled back to the D_2O recovery system

ii. drainage of D_2O collection tank mounted on the F/M cradle.

The D_2O collection tank contains clean D_2O collected during snout cavity venting, and possible transfer of D_2O from the magazine during partial level lowering while the F/M traverses with irradiated fuel from the reactor face.

5.2.4.1 D_2O Discharge Port

The D_2O discharge port consists of a mounting block assembly which engages with the drain flange on the F/M magazine front cover. The mounting block contains a butterfly valve, flanged to a flexible braided stainless steel 7.62 cm (3 in) diameter hose. This assembly is connected through a four bar linkage to an air actuator.

Energizing the air actuator causes the entire mounting block assembly to be raised, making contact with the F/M drain flange, and at the same time opening the butterfly valve on the discharge port through the linkage mechanism. By the same means this valve closes when the air actuator is de-energized.

Air actuators are mounted on each discharge port assembly. At the irradiated fuel and ancillary ports there are two air actuators which operate a butterfly valve on the F/M to drain the magazine to weir level after the drain valve is opened, or to drain the collection tank. The run-off is gravity fed into the storage tank and then pumped back to the main D_2O storage facility.

At the new fuel port location, there is a third air actuator, which operates a ball valve which drains the oil and D_2O mix tank. The run-off is discharged into a separate container and then disposed of manually.

All air actuators located at the discharge port assembly are coupled with potentiometers, for positional feed back purposes, and the air actuators are controlled by solenoid-operated directional valves having a separate control panel.

6. SEPARATOR ASSEMBLY

6.1 PURPOSE

The functions of the separator assemblies are:

a. To sense the position of the fuel being fed into or being discharged from the reactor and to provide a signal to the computer to stop the ram at the correct position.

b. To insert a stop device between two adjacent fuel bundles or between the shield plug and the fuel column, and to restrain the motion of the fuel column extending from the stop device into the reactor.

c. To push the bundles that have been separated from the fuel column into the magazine to allow clearance for magazine rotation.

d. To verify the presence of the shield plug and FARE (Flow Assisted Ram Extension) tool as they pass under the separators at various steps during the refueling operation.

6.2 COMPONENT DESCRIPTION

The separators are components of the F/M. The separators can be removed and replaced relatively easily.

For each F/M there are two separator assemblies which perform identical functions and operate in synchronism. They penetrate through the magazine end cover at a point just forward of the magazine tubes and each assembly is oriented at 57.5° from the vertical. In order to distinguish between the two assemblies they are referred to as either the 'left hand' or 'right hand', as seen from the rear of the F/M. The following descriptions refer to one separator only.

6.2.1 Feeler

The feeler, or sensor (Figure 3-27, Item 13) acts as a mechanical finger, powered by D_2O pressure, in order to sense the presence of a fuel bundle or shield plug that is under the separator assembly. This mechanism is controlled by a piston ('C' piston, Item 19) through a mechanical linkage and it slides up and down inside the pusher (Item 14). The piston in turn has a connection to a rectilinear potentiometer (Item 7) for position monitoring of the feeler, which has three control positions. The feeler can move from the fully retracted, or 'OUT', position to the fully advanced, or 'INSERTED', position (Figure 3-28). There is also an intermediate position known as 'FLOATING', in which there is equal D_2O pressure on both sides of the piston. In this state, a light spring in the potentiometer assembly exerts a small force down on the feeler to float it on a fuel bundle or shield plug. If there is no such obstacle, then the spring will force the feeler into the 'INSERTED' position. The piston has no seal since this would create enough friction that the feeler might not drop under the force of the spring and gravity. The absence of this seal is not of vital importance since the actuating fluid is D_2O and leakage past the piston will only enter the snout assembly which has a D_2O environment. Grooves are provided on the piston and rod to reduce leakage.

6.2.2 Pusher

The main purpose of the pusher is to stop at the correct position for separating fuel, and to assist directly in the fuel separation. The pusher (Item 14) incorporates and acts as a guide for the feeler. When piston 'A' (Item 18), which is connected to the pusher, is activated by D_2O pressure, there is a pivotal movement of the pusher about the forward pin. This tends to move the feeler outwards (PUSH COMPLETE position) a distance which is necessary to move a fuel bundle fully into the magazine so that the magazine can be rotated freely. The forward pin is also attached to the side stops (Item 15) so that movement of the side stops will move this part of the pusher. The rear pin, however, is linked to piston 'A' which requires D_2O pressure to be actuated. It is this linkage that causes the pusher to push the feeler outward. There are two spring and pin arrangements (Detail A) in the side stops that are linked to the pusher by a lug (Item 12). This assists the pusher to return to its neutral position in the event that piston 'A' may be sticking. Piston 'A' utilizes a commercial seal and also a series of grooves on the piston head to provide a water-tight seal. From piston 'A' there is a connection to a potentiometer assembly identical to that of the feeler for position monitoring of the pusher.

6.2.3 Side Stops and Safety Latch

The side stops are used to prevent the passage of the fuel string beyond the end of the guide sleeve. They are able to resist the combined load of the hydraulic drag of the fuel bundles in the fuel channel as well as the force of the rams of the upstream F/M. The stops are inserted between adjacent bundles by actuation of two hydraulic pistons. These pistons are mechanically linked to the side stops and pinned to provide some pivoting of the stops. This motion is limited by a guide pin (Figure 3-28), which extends downward from the side stops and is inserted in a guide bushing, which is a component of the snout center support. This bushing has a large enough bore to allow the pin to move from one side of the bushing to the other and provide limited motion of the stops.

The position of the stops is indicated by signals from magnetic reed switches which are actuated by a magnet and piston rod assembly (Figure 3-27, Item 10) connected to the side stop piston 'B' (Item 17).

It is essential that the side stops remain in the position called for, either inserted or retracted. The inserted position must be assured to prevent the fuel string from entering the F/M under uncontrolled conditions. The retrracted position must be assured to avoid bundle damage since the side stops have sufficient force to cut into a fuel bundle if inserted out of step. The safety latch gives this assurance. This is effected by a latching rod (Item 24), the end of which engages with one of two notches cut in an extension spindle on the other side stop operating piston (Piston 'D', Item 20). The latching rod is held forward to engage either notch by spring pressure and is disengaged by energizing a solenoid. A magnet attached to the latching rod actuates magnetic reed switches (Item 27) so positioned as to indicate the 'LATCHED' or 'UNLATCHED' condition. In case there is a loss of power or the solenoid is defective, then the manual override (Item 5) can be used to unlatch the side stops. This mechanism consists of a T-handle, bellows and shaft. The handle is turned manually to depress a lever and engage a pin that is attached to the latch shaft. This pulls the shaft out from the notch on the side stop piston. The bellows on the override acts as a seal to prevent D_2O from escaping to the atmosphere.

7. F/M RAM ASSEMBLY

7.1 PURPOSE

The ram assembly provides the necessary movements and forces required for transfer and discharge of fuel bundles, or installation and withdrawal of the guide sleeve, the plug, the shield plug and the snout plug.

7.2 EQUIPMENT DESCRIPTION

The F/M ram assembly consists of a 'B' ram, 'latch' ram and 'C' ram. These rams are essentially concentric tube assemblies supported by the ram housing. Each ram has a different ram head assembly to perform the necessary plug or fueling operations. Both the 'B' ram and latch ram are driven by oil hydraulic motors through a gear system and ball screws. The 'C' ram is powered by D_2O from the D_2O supply system. All three rams have rotary potentiometers to provide continuous information of the ram positions to the control system.

The 'B' ram has three speeds and five force levels to perform its operational functions. The latch ram has one speed and one force level while the 'C' ram has five force levels and its speed varies with the force selected.

The ram sub-assemblies are discussed in detail in the following sections.

7.2.1 Ram Housing

The ram housing is a pressure vessel consisting of two parts: ram housing and ram rear forging. The housing (Figure 3-29) has a 254 mm (10 in) inside diameter and an overall length of about 4 m (158 in). The front end of the ram housing (Figure 3-30, Item 19) joins the smaller clamping hub of the magazine housing while the rear end of the ram housing (Figure 3-31, Item 9) connects to the ram rear forging via small Grayloc clamps and seal rings. The gearbox enclosure is bolted to the ram rear forging and is outside of the pressure boundary.

7.2.2 Ram Head Assemblies

The ram head assembly is shown in Figure 3-32. The stainless steel 'B' ram head (Item 1) screws on to the front end of the 'B' ram tube. Four axial flutes in the outside diameter provide water passages. The chrome plated front end is reduced in diameter to provide a shoulder for pushing, and tapered for entry into the plugs and guide sleeve tool. Twelve balls are staked into the front end for gripping the plugs and guide sleeve tool.

Two cross pins (Item 6) are located between the push ring (Item 4) and the 'B' ram head through clearance openings in the latch tube. This enables 'B' ram force to be applied via the push ring to the deflecting rod.

The stainless steel latch sleeve (Item 2) screws into the front end of the latch tube. Eight latch balls are staked in place about halfway along the sleeves length (Item 10).

The stainless steel 'C' ram head (Item 3) is screwed into the front end of the 'C' ram tube. Six balls are staked into the front end for gripping plug, tool or adaptor stems. The back end of the 'C' ram head is slotted and, when screwed into the 'C' ram tube, a forward projection on the tape anchor plug (Figure 3-29) enters its back end to prevent any tendency for the forked thread sections to collapse.

7.2.3 Ball Screws

There are four ball screws (Figures 3-30 and 3-31), and two bearing plates with radial ball bearings. A fixed bearing plate at the front of the ram housing (Figure 3-30, Item 16) supports the four ball screw front ends (Items 22, 23). A stack of bearings in the ram rear forging supports the four ball screw rear ends.

The 'B' ram has two ball screws on a vertical plane, and the latch ram has the other two ball screws on a horizontal plane. A trunnion connection (Figure 3-31, Item 13), which transmits an equal load, joins the two ball screws with the 'B' ram. The latch ram has a similar trunnion connection (Item 15). Each ball screw has a hydrostatic seal assembly (Item 22) with low friction and relatively small differences between starting and running torques. A stack of preloaded Belleville Spring Washers on both ends of the 'B' ram ball screws provide the 'B' ram with cushioned over-travel stops. The latch ram has independently adjustable over-travel stops. Forward of the front bearing plate, a spherical bearing (Figure 3-30, Item 14) mounted inside a bearing housing supports the 'B' ram tube assembly and also provides an optimum alignment to the ram assembly and magazine housing. An oil lubrication system supplies the bearing oil gallery of each ball screw seal package housing and flows through the bearing into the gearbox. It also supplies the bearings of the 'B' ram and the latch ram worm gear shafts.

The facilities for oil seals and drain connection in the lubricating path prevent oil leak, or overflow.

7.3 'B' RAM

7.3.1 'B' Ram Drive Unit

The drive unit of the 'B' ram includes an oil hydraulic motor, a gear system and two ball screws. The motor is mounted outside the gearbox and is powered by the F/M oil hydraulic system. Figure 3-33 shows the 'B' ram gear system in the gearbox enclosure and is constantly bathed.

7.3.2 'B' Ram Manual Drive

The 'B' ram manual drive has two steps to move the 'B' ram manually as described below and in Figure 3-34.

i. Disconnecting the worm gear shaft with the motor coupling.

   In front of the 'B' ram oil hydraulic motor, there is a 'B' ram coupling which connects the motor shaft to the worm gear shaft. A coupling - disconnecting unit is contained in a shaft housing and mounted perpendicular to the worm gear shaft. An eccentric cam follower connects to the sleeve coupling of the 'B' ram worm shaft. Should the 'B' ram oil hydraulic motor become disabled, a special tool would be used to engage and turn the manual coupling positioner which would disengage the worm gear shaft from the motor and allow for manual driving.

ii. Manual Drive Assembly

   The 'B' ram manual drive, which is housed in a guide funnel, is installed parallel to the coupling - disconnecting unit. It has an input drive shaft and a helical gear. The drive shaft with one end exposed in air is held by a threaded shaft, thrust bearings and ball bearings. Normally, the helical gear is pushed into a position by a compression spring such that it would not be able to engage the helical gear on the 'B' ram worm shaft. Once the coupling sleeve is disengaged from the worm shaft, a special tool is used to engage the 'B' ram manual drive shaft that forces the helical gear on the manual drive shaft to mesh with a helical gear on the 'B' ram worm shaft by compressing the compression spring. The torque produced by the special tool is transmitted to the 'B' ram tube via the manual drive shaft, helical gears, 'B' ram worm shaft, sleeve gear pinions and 'B' ram ball screws.

The special tool can be turned in either the clockwise, or counterclockwise directions. This will drive the 'B' ram to advance, or retract.

7.3.3 'B' Ram Potentiometer Assembly

The 'B' ram potentiometer assembly is fixed in a cylindrical potentiometer cover, which is closed and bolted to the gearbox front cover with a mounting plate. In the potentiometer cover, there are four wire-wound potentiometers mounted in the upper space, and a counter mounted in the lower portion. The four potentiometers are divided into two sets. One is the main set; the other is the standby. Each set can provide a course and fine reading. They are driven by the 'B' ram worm gear shaft through speed reducers, gears, and a bellows coupling. On the bottom surface of the potentiometer cover, there is a magnifying lens that the operator can look through to read the counter. The counter is driven by the 'B' ram worm shaft via speed reducers, a series of gearing, and a bellows coupling. This facility is used primarily for calibration when the F/M head is accessible.

7.4 LATCH RAM

Latch ram is second to the outer tube in the three ram assemblies. It normally moves while the 'B' ram is moving, but can move independently, and extends 38.2 mm (1.5 in) more than the 'B' ram tube for plug latching. It consists of a latch head and tube, two ball screw assemblies, hydrostatic seals, a drive unit, and a potentiometer assembly for position feedback.

7.4.1 Latch Ram Drive

The latch ram drive motor is mounted outside the gearbox and is powered by the F/M oil hydraulic system. The gear system is contained in the gearbox enclosure and is constantly bathed in oil (Figure 3-33).

The latch ram manual drive has a similar construction to that on the 'B' ram manual drive. It is used only in an emergency for positioning of the latch ram.

7.4.2 Latch Ram Potentiometer Assembly

The construction and arrangement of the latch ram potentiometer assembly is similar to that on the 'B' ram potentiometer assembly.

The latch ram potentiometer continuously feeds electrical signals to both the digital computer and the control console, to control the motion of the latch ram, and monitors the position of the latch ram for the operating personnel.

7.5 MOTIVATION OF 'B' RAM AND LATCH RAM

7.5.1 Combined 'B' Ram and Latch Ram Motion

The arrangement of the gear box planetary gearing system gives the latch ram drive a superimposition and synchronization on the 'B' ram drive.

Whenever the 'B' ram oil hydraulic motor is energized, it rotates the sleeve gear (Figure 3-33, Item 30) around the gear box main shaft. Since the main shaft is fixed to the gear box, the power from the 'B' ram worm gear will transmit to both 'B' ram pinions and latch center gear (Item 37) through the sleeve gear. The torque to the 'B' ram pinions then turns the two 'B' ram ball screws to move the 'B' ram to advance or retract.

If the latch ram oil hydraulic motor is not energized, the torque transmitted to the latch center gear from the 'B' ram oil hydraulic motor via the sleeve gear will turn the two latch ram ball screws through the three sets of side-by-side pinions (Item 38), the double center gear (Item 42), and the two latch pinions (not shown).

7.5.2 Latch Ram Motion with 'B' Ram Stationary

Whenever the latch ram oil hydraulic motor is energized, it rotates the internal gear around the gear box main shaft. Since the main shaft is fixed in the gear box, the power from the latch ram worm gear will transmit only to the two latch ram ball screws through the internal gear, the three sets of side-by-side pinions, the double center gear and the two latch pinions. Because the oil hydraulic control system locks the 'B' ram motor, the sleeve gear and the latch center gear thus have no relative movement with respect to the gear box main shaft. So the three rear side-by-side pinions only spin on the latch center gear. The latch ram then moves alone with 'B' ram at a stationary position. The two pairs of the 'B' ram potentiometers will indicate to the control console where the 'B' ram is locked. Because the latch ram can move forward another 33 mm (1.3 in) to 38.2 cm (1.5 in) more than the locked 'B' ram position, the latch ram potentiometers will provide the control console with additional information about the latch ram moved position.

7.6 'C' RAM

The 'C' ram arrangement (Figure 3-35) is powered by the F/M D_2O system. It is formed by one 'C' ram tube and three telescopic tubes (tubes No. 1, No. 2, and No. 3). These tubes are concentrically fitted in the latch ram tube. The 'C' ram tube and tube No. 3 are moveable and are the longest tubes. Tube No. 1 and No. 2 are stationary and are the shortest tubes. The front ends of tube No. 1 and No. 2 are attached to the tube No. 2 piston. The piston, with piston rings, seals against the tube No. 3 bore and supports the front ends of tube No. 1 and No. 2. The rear ends of tube No.1 and No. 2 are fixed to the ram rear forging and sealed.

The front of 'C' ram tube and tube No. 3 are attached and sealed by a tape anchor assembly. The rear end of tube No. 3 is screwed to the latch ram trunnion and the annulus between tube No. 3 and the latch ram tube becomes the 'C' ram hydraulic cylinder. The latch ram trunnion mounting forms the rear head for the 'C' ram hydraulic cylinder. When the latch ram moves forward, the 'C' ram hydraulic cylinder moves with it.

The rear end of the 'C' ram tube is screwed to a 'C' ram piston assembly. The piston moves in the annulus between latch ram and tube No. 3 so that when the 'B' ram reaches its extreme forward position, it will provide the F/M an additional ram length.

The 'C' ram has a 127 mm (5 in) overtravel before its piston hits the latch ram trunnion stop. The Belleveille washers of the 'C' ram piston acts as a cushion. This arrangement balances the dimensional changes due to temperature change in the different tubes when they lock onto a plug and move it from the hot D_2O environment of an end fitting to the relatively cooler environment of the F/M magazine.

7.6.1 'C' Ram Drive

Since the 'C' ram is powered by the F/M D_2O system, it will not stop at any preset position and stops only when it hits an object. The travelling position of the 'C' ram is indicated by a tape drive assembly. The 'C' ram, with a ram adaptor, is used to push the fuel bundles to their final position in the reactor.

When 'C' ram advances, D_2O enters the annular space between tubes No.1 and No. 2 through a drilled passage in the ram rear forging. It flows forward in this annulus to the back of No. 2 tube piston where it passes through holes to the annular space between tubes No. 2 and No. 3. It then flows backward in this annulus to holes near the back end of No. 3 tube where it enters the back space of 'C' ram piston. The D_2O pressure, therefore, exerts on the 'C' ram piston and pushes the 'C' ram forward.

When 'C' ram retracts, D_2O enters tube No. 1 inside space through a drilled passage in the ram rear forging. It flows forward to the front end of tube No. 1 through the opening of No. 2 tube piston and enters the front part of tube No. 3. Passing holes in the front part of tube No. 3, D_2O then flows into the annulus between No. 3 tube and 'C' ram tube. It then flows backwards in this annulus to holes near the back end of 'C' tube where it enters the front space of 'C' ram piston. The D_2O pressure, therefore, exerts on the 'C' ram piston and pushes the 'C' ram backwards.

7.6.2 Tape Anchor Assembly

A tape anchor pin joins the tape, the tape anchor and the tape anchor weight together. The tape which passes through tube No. 3 support is kept in a horizontal position. The tape anchor is sealed in a tape anchor plug. The plug is held by a retaining ring in the rear of 'C' ram head. The function of the tape anchor assembly is to prevent twisting of the tape if the 'C' ram turns when it moves.

7.6.3 Tape Drive Assembly

The tape drive assembly (Figure 3-36) is housed in a blank cylindrical pressure vessel which is mounted at the rear end of the ram rear forging. The pressure rating of the vessel is 16.13 MPa (2340 psi) at 148.8°C (300°F) but the normal temperature will not be higher than 79°C (175°F). The assembly consists of tape, pulley, spring motor gears, drive shaft and four wire-wound potentiometers. The tape drive housing has a drive housing cover and a potentiometer cover. The tape drive housing is pressurized by F/M D_2O supply system. The potentiometer cover is bolted to the drive housing and contains air at atmospheric pressure. The drive shaft passes through the drive housing cover where it is supported and sealed.

The tape front end attaches to the tape anchor assembly which seals the 'C' ram front end and its rear end winds around the tape driven pulley. When the 'C' ram advances, it pulls the tape forward. This not only gives a torque to the pulley to rotate the drive shaft, but also winds the spring motor to provide a tension in the tape itself. Once the drive shaft is turning, it turns the potentiometers through a set of gears. These potentiometers will give a continuous indication of the 'C' ram position providing electrical feedback signals to the digital computer and the control console.

7.7 RAM POSITIONING

To achieve the sequences of various operations, such as pick-up of shield plug, installation of guide sleeve, etc., the computer controls the 'B' ram positioning by a positioning loop program. This enables the 'B' ram and latch ram to go to the preset position to accomplish the assigned job.

The 'C' ram cannot be positioned like the 'B' ram or latch ram, but its feedbacks are checked against a set point for positioning accuracy. Unlike the 'B' ram operation, the 'C' ram can only be advancing, or retracting, to stall against an obstruction. Using a ram adaptor, the 'C' ram pushes the fuel bundles into the fuel channel upstream, or maintains a pressure against the fuel bundle column from the fuel channel downstream. The 'C' ram is also used to discharge the irradiated fuel bundles from the F/M magazine onto the irradiated fuel elevator ladle via the irradiated fuel port.

8. F/M RAM ADAPTOR

8.1 PURPOSE

The ram adaptor provides:

i. a suitable face for contacting the end plate of a fuel bundle.

ii. It centralizes the 'C' ram, minimizing sagging of the ram during operation in a fuel channel.

iii. provides a buffer zone, absorbing neutrons emitted by irradiated fuel bundles, consequently preventing both fuel bundles and ram head from overheating.

8.2 COMPONENT DESCRIPTION

The ram adaptor consists of five parts. The ram adaptor body (Figure 3-37, Item 1) provides the contact face with the fuel. The face is machined to simulate a fuel bundle, so that the gap between the ram adaptor and a fuel bundle is identical to the gap between two fuel bundles. Holes in the adaptor body provide for a through flow of D_2O through the ram adaptor. Contained within the adaptor body is the adaptor sleeve (Item 2) which is preloaded towards the F/M end by an inner and outer spring (Items 4, 5). The stem (Item 3) which is machined from a solid piece and is centrally connected to the adaptor body, provides a shoulder for the adaptor sleeve and engages the F/M 'C' ram.

8.3 OPERATING PRINCIPLES

8.3.1 Pick-up From Magazine Station

The steps involved are illustrated in Figure 3-37. After the correct magazine station has been selected, the F/M 'B' ram head is advanced such that the ram deflector rod contacts the stem of the adaptor located in the magazine station (View 1). The 'C' ram is then advanced which causes the balls in the 'C' ram head to ride up the incline of the stem. The protruding balls come in contact with the adaptor sleeve, causing the sleeve to move forward against the springs (View 2). Further 'C' ram advance motion causes the 'C' ram balls to drop behind the stem major diameter. The adaptor sleeve is now free to move back under the force of the springs and in so doing entraps the 'C' ram balls. Thus the 'C' ram is locked with the ram adaptor (View 3). Retraction of the 'C' ram will overcome the spring force of a small plunger (built into the magazine station to hold the ram adaptor in its storage position) and will cause the ram adaptor to stall out against the front face of the 'B' ram head. With continued ram 'C' retract motion, the ram adaptor thus becomes an extension of the ram head, suitable to contact and push the fuel string.

8.3.2 Deposition in Magazine Station

With the correct magazine station selected and the adaptor on the ram head locked to the 'C' ram, which is selected for retract, the 'B' ram is advanced until it stalls out against the locating bar in the magazine station (View 4). The latch ram then is advanced which pushes the adaptor sleeve back against the spring (View 5). Once the larger sleeve inside diameter reaches the plane of the 'C' ram balls, the 'C' ram balls become unlocked and ram 'C' is free to retract to its home position (View 6). The ram adaptor is now disconnected from the ram head and secured in its magazine storage position.

9. F/M GUIDE SLEEVE ASSEMBLY

9.1 PURPOSE

The channel closure seal face in each channel end fitting forms a step in the 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 the shield plugs through this region. A guide sleeve is stored in the magazine and is moved partially into the end fitting, when the channel closure is removed to provide a smooth bore for the passage of fuel bundles and shield plugs between the magazine and the fuel channel.

The guide sleeve is moved between the magazine and the F/M snout by the F/M rams 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 magazine and are held there by means of a locating tube and a spacer located in the magazine tube. The guide sleeve and tool can only be installed in or removed from the head by disconnecting and removing the ram assembly from the magazine housing.

9.2 COMPONENT DESCRIPTION

The guide sleeve assembly is purely mechanical and there is no process system or instrumentation associated with it. Figure 3-38, upper view, shows the guide sleeve assembly in its F/M magazine storage condition while the lower view shows a cross-section of the guide sleeve tool insertion only.

9.2.1 Guide Sleeve

The sleeve is about 660 mm (26 in) long, with an inner diameter equal to the fuel channel diameter of 104.0 mm (4.094 in), and an outer diameter equal to the channel closure diameter.

The rear section of the sleeve (Figure 3-39) has three outer keys, two of which are mounted rigidly to the sleeve body. the third key is part of a rotatable ring segment, called the 'latch ring', and is located between the two fixed keys. It is this latch ring that provides the locking function of guide sleeve to F/M snout and guide sleeve to the insertion tool respectively.

Internally, the rear section of the sleeve has three similar keyways, two fixed, in line with the latch tang, and the third on the inside diameter of the latch ring between the two keyways. A second set of three keyways is located 120° from the main set to mate with the corresponding key arrangement on the insertion tool.

When the outer keys are 30° out of line, the guide sleeve is located in the F/M snout. When the outside keys are out of line by 30°, the inside keyways are in line. At this condition, and only at this condition, the insertion tool can can be withdrawn from the guide sleeve as it features a similar key arrangement, that is, two fixed outer keys and a rotable center key. The spring-loaded latch tang adjacent to the latch ring locks the ring in place when the keys are out of line by 30°, that is, when the guide sleeve is located in the F/M snout. The entry of the guide sleeve tool into the sleeve depresses the latch tang and thus allows rotation of the latch ring. The front stationary key on the insertion tool releases the latch tang.

The keyway configuration in the F/M snout center support eng ges the guide sleeve keys. The guide sleeve cannot rotate because its two fixed keys are lo ted in the keyway, and the key on the latch ring is locked out of line which prohibits any axial movement.

The two cut-outs in the rear end of the guide sleeve provide for access of the F/M separator mechanisms to fuel bundles, and other components passing through the sleeve.

Summarizing the important guide sleeve features:

a. Keys on the outside out-of-line by 30° implies keyways on the inside are in-line. In this condition, the guide sleeve is locked in the F/M snout and the insertion tool can be withdrawn from the guide sleeve.

b. Keys on the outside in-line implies keyways on the inside are out-of-line. In this condition, the insertion tool is locked into the guide sleeve and the guide sleeve can be withdrawn from the F/M snout.

c. There is also an arrangement where the latch ring has rotated only 15° instead of 30° (Figures 3-39 and 3-40). In this condition, neither keys nor keyways are aligned and the guide sleeve and insertion tool remain locked together. This partial stroke is required when transferring the guide sleeve to and from the F/M magazine and is possible in one specific location in the F/M magazine only.

9.2.2 Guide Sleeve Insertion Tool

The guide sleeve insertion tool is shown cross-sectioned in Figure 3-38, lower view. The front half of the tool up to the shoulder engages into the rear of the guide sleeve, while the larger diameter rear section fits into the magazine locating tube and also engages with the F/M ram 'B' head.

The tool's function is to translate the linear motion of the F/M latch ram into a rotary motion required to manipulate the guide sleeve latch ring while also serving as an adaptor between ram head and guide sleeve. The translation of motion is effected by the ball spline assembly, which consists of two outer races and and inner race. When assembled, one of the outer races is fixed to the tool body and the other is mounted on two bearings so that it can rotate.

The ball spline inner race (Figure 3-38) has two sections a straight spline section, and a helical spline (or screw) section. This translates to axial motion on the inner race in order to obtain the 30° rotation required on the helical spline outer race for guide sleeve operation.

The ball spline straight outer race is keyed to the tool body and is positioned on the straight spline section of the common inner race. This outer race allows for axial motion of the comm on inner race, but does not allow it to rotate.

The ball spline helical outer race is mounted on bearings and positioned on the helical spline section of the common inner race. Therefore, when the common inner race is pushed in, the helical outer race will rotate.

The helical outer race incorporates locking ears which extend through cutouts in the tool body to form part of the key arrangement on the outside of the guide sleeve tool. Rotational positioning of the helical outer race with its locking ears is a function of the F/M latch ram movement. The locking ears on the insertion tool, in turn, position the guide sleeve latch ring, thereby controlling the alignment of the guide sleeve outer keys.

There are three keys on the insertion tool: two are mounted rigidly to the tool body while the third one is the locking ear which is part of the helical outer race. This key arrangement is duplicated on the guide sleeve tool to obtain a better torque transmission from the tool to the sleeve. The lower view shows the two locking ears while for clarity only one set of the fixed keys is shown.

A circumferential groove is provided in the end of the tool body for latching of the F/M 'B' ram balls. The F/M latch ram head contacts a spring-loaded push ring which is rigidly connected to the inner race. The inner race is pushed in when the latch ram advances, and is spring-returned on retracting the latch ram. In addition to the springs behind the push-ring, there is another spring in the front of the tool which is relied on to assist in pushing back the inner race. The inner race has a hole through its center through which a rod passes. One end of the rod is the 'C' ram shaft end while the other end reacts against the spring arrangement. The rod and stem end have no direct involvement in the operation of the tool. They merely safeguard against inadvertent tool actuation by the F/M 'C' ram. If the 'C' ram were to advance accidentally, it would contact the 'C' ram shaft end and depress the front spring until the slide bottomed out against the front cover. No actuation of the inner race would occur as the clearance in the front spring arrangement is less than the clearance between the shaft end and the ball spline inner race.

The insertion tool is kept aligned angularly in the F/M magazine guide sleeve station by a key mounted on the tool's outside diameter. Longitudinal cut-outs on either side of the key allow for clearance with two small lugs that protrude into the inside diameter of the locating tube. These lugs engage the tool's moveable keys and locate it axially in its magazine storage position.

9.2.3 Locating Tube and Spacer

The locating tube and spacer tube are located against a shoulder in the F/M magazine guide sleeve station. They are held in place axially by a retaining ring while a key on each tube ensures correct radial position.

On removing the retaining ring, the whole assembly can be pulled from the F/M magazine, once access has been provided by removing the F/M ram assembly.

The latch ring key prevents any axial motion of the guide sleeve so that it cannot be advanced from the magazine storage position until the latch ring key has been rotated through 15° to navigate around the lug in the locating tube. The 15° rotation, however, is not enough to release the guide sleeve from the insertion tool. This allows the insertion tool to lock the guide sleeve securely in the magazine locating tube, while itself remaining locked to the guide sleeve.

10. F/M SNOUT PLUG

10.1 PURPOSE

The snout plug is used to seal the snout of the F/M head when the F/M is off the reactor. The interior of the F/M head can then be maintained full of water at controlled temperature and pressure, as required, to maintain cooling of the spent fuel while in transit from the reactor fuel channel to the irradiated fuel port.

The snout plug also serves as an isolation device for leak testing the channel closure seal prior to unclamping the F/M from the reactor end fitting after refueling, and for leak testing the F/M snout seal prior to opening the channel.

As a side benefit during maintenance, the snout plug prevents the spread of contamination, such as tritium and air-borne particulates, and provides shielding against direct radiation from the F/M magazine. Contamination will usually be present in the magazine since it has contact with irradiated fuel.

10.2 COMPONENT DESCRIPTION

The F/M snout plug (Figure 3-41) is composed basically of two parts, the latching mechanism and the seal assembly. Operation is shown in Figure 3-42.

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 F/M snout center support.

The spider movement is achieved by the F/M latch ram head pushing the spider down by means of four latch pins. This is necessary as the F/M snout plug operation requires two independent actuations, latching and sealing.

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.

Expansion of the O' ring, to make a radial seal, is achieved by mounting the O' ring on a fixed diameter and applying an axial squeeze. This causes the O' ring to bulge out and make a seal on the F/M center support bore. The axial squeeze is applied by a spring, which activates the links that move the squeeze ring onto the O' ring. Retraction of the O' ring is obtained by pushing the plunger to compress the spring and actuate the links to move back the squeeze ring, unloading the O' ring. The O' ring retracts by freely returning to its natural shape in the retracted condition.

The F/M magazine has a tube position suitable for storing the snout plug during channel fueling and fuel transfer operations. When the snout plug is deposited in the magazine, the O' ring is in the compressed and extended condition. A relief diameter in the F/M magazine bore is provided to prevent permanent setting of the O' ring and subsequent reduction in seal effectiveness.

11. COOLANT CHANNEL CLOSURE

11.1 PURPOSE

The purpose of the channel closures is to reliably seal the ends of the coolant assemblies in order to prevent the escape of heavy water from the end fittings, under all modes of reactor operation. There are 380 coolant channel assemblies in a CANDU 6 reactor, with a closure at each end, for a total of 760 channel closures. Thus, even small leaks would result in high demands on the D_2O collection and upgrading systems.

The normal operating conditions of the primary heat transport system against which the channel closures seal are 11.24 MPa (1630 psig) and 266°C (511°F) at the flow inlet end fittings, and 10.34 MPa (1500 psig) and 310°C (590°F) at the flow outlet end fittings. The design objective is to limit the leakage from the closures under these conditions to a maximum of 10 g (0.35 oz) of heavy water per day per closure. Actual long term leak rates have been found, typically, to be in the range of zero to 1 g (0.035 oz) per day per channel closure.

11.2 COMPONENT DESCRIPTION

11.2.1 Closure Locking Mechanism

The basic element of the closure design is a flexible metallic seal disc (Figure 3-43, Item 12), which makes a face seal against a shrunk-in ring in the end fitting. The seal disc is supported and retained by the body of the closure, which is held in position by jaws (Item 6) engaging a groove in the end fitting.

During fuel changing, it is necessary to withdraw these closures. This is accomplished by the F/M which connects onto the end fittings, removes the closures and stores them in the magazines. Following the refueling, the closures are reinstalled in the end fittings prior to unclamping the F/Ms.

The locking mechanism in the channel closure is referred to as a toggle-jaw mechanism to differentiate it from the type of mechanism used in the shield plug. In the channel closure, the jaws (Item 6) are moved by toggles (Item 7), which are fastened to a spider (Item 13) and stem (Item 14). When the mechanism is locked in an end fitting, the toggles do not play any part; the jaws are actually wedged against the end fitting by the taper on the spider. To assist in the extension of the jaws, and to keep them extended while the channel closure is in the F/M magazine, the spider is spring-loaded against the front housing (Item 1) by four helical springs (Item 3).

To facilitate the manufacture of this closure, the housing is made in two pieces, the front housing (Item 1) and the rear housing (Item 2). These two housings are held together by four cap screws (Item 8), which are installed from the rear in such a way that it is possible to dismantle the channel closure, if it ever became jammed in an end fitting.

The seal disc (Item 12) is retained in position on the front of the closure by means of a loosely fitted seal disc pin (Item 9). The pin is, in turn, kept in place by one of the four cap screws. The raised annular ridge on the front housing, where it contacts the back of the seal disc, is called the rocker seat.

11.2.2 Safety Mechanism

Independent safety mechanisms prevent one of the F/M rams, operating inadvertently, to unlatch one of these closures. Each of these safety devices consists of a bar spring (Item 10), located in the spider, and a safety latch (Item 11), attached to the other end of the bar spring. If the hydraulic 'C' ram of the F/M was to advance by itself and hit the channel closure, the safety latches would be jammed axially between the stem end (Item 5) and the inner sleeve of the rear housing. This would prevent complete movement of the spider and stem assembly into the closure, and would prevent the withdrawal of the jaws from the end fitting. In normal operation, the F/M latch ram is used to unlatch the safety latches, after all three rams are in their correct position. If the 'B' ram advances with the latch ram in the 'unlatching' position, the protruding 'B' ram balls would prevent it entering the channel closure housing.

11.2.3 Seal Disc

The seal disc is installed in the following manner:

The seal disc is deflected by the 'B' ram at both the center, through the plunger (Item 4), and the rocker seat on the front housing. The plunger has a 0.89 mm (0.035 in) offset to provide a greater disc deflection at the center. As the jaws are wedged into the end fitting groove, the reaction of this force on the front housing rocker seat provides additional force on the disc.

12. COOLANT CHANNEL SHIELD PLUG

12.1 PURPOSE

The shield plug serves two main functions:

a. it provides a radiation shield at both ends of the fuel channel

b. it provides the means of locating the fuel bundles in the fuel channel.

12.2 COMPONENT DESCRIPTION

The shield plug consists of three basic parts. The fuel adaptor and flow tube (Figure 3-44, Items 14 and 13) provide a suitable contact face for the fuel column and facilitate free channel coolant flow. The center section of the shield plug is a solid stainless steel body (Item 11) which serves as a radiation shield. The outer end of the shield plug is the latch mechanism (Item 10), which serves to hold the shield plug in place in the end fitting liner tube.

The shield plug rests on two wear rings. One is machined from the latch assembly casing, and the other is a separate wear ring (Item 12) press-fitted onto the shield body.

The fuel adaptor is press-fitted onto the flow tube and spot welded in two places. The flow tube, in turn, is a press-fit on to the end of the shield body and is locked in place by means of a groove pin (Item 15) inserted on assembly. At the other end of the body, the latch mechanism casing is a press-fit onto the body, and, in addition is locked in place by two tangential roll pins (Item 9).

The latch mechanism consists of a spider and jaw assembly housed in a casing (Item 1) in which the spider stem assembly can move back and forth. As the spider (Item 6) is moved axially, the eight jaws (Item 4) move radially, riding on the angled fingers of the spider. Four spider springs (Item 8) situated between the spider and body of the shield plug, maintain the spider in the position at which the jaws are extended. The stem end (Item 2) is fastened to the outer end of the spider stem (Item 3), onto which the F/M 'C' ram can be locked. Advancing the F/M ram into the assembly will overcome the spring force on the spider and retract the jaws.

In addition to the basic mechanism described so far, there is a safety mechanism to prevent the jaws being withdrawn if an accidental axial force is put on the stem end. This might happen if the 'C' ram of the F/M were to advance uncontrolled. This safety mechanism consists of a safety latch (Item 5) and a safety spring (Item 7). When the shield plug is stored in the magazine, or is properly installed in the end fitting, the safety latch has its major diameter underneath the jaws of the shield plug. If an accidental axial force is applied to the stem end, the jaws can only move inwards about 0.5 mm (0.02 in.) before they jam up on the major diameter of the safety latch sleeve. This prevents the removal of the shield plug from the magazine or from the end fitting except when the entire F/M ram head assembly is in the proper position to do so.

The F/M cannot release the shield plug at a position where the jaws will not extend into a groove, since the F/M ram head is provided with mechanically interlocking balls to prevent the release of the shield plug in any position other than where the jaws are fully extended.

It is dimensionally possible for the shield plug to enter the reactor core, but the 'B' ram stroke is physically restricted to safeguards against this. Provision has been made to ensure that the coolant channel flow is not entirely blocked should the ram stroke limit be reached. Two possibilities of blockage could exist if the shield plug detached from the ram head and went down the channel. The first case is when the shield plug is in the main coolant channel, in which case it would obstruct flow in the axial direction. The second case is when the shield plug body or the casing is situated directly underneath the flow holes in the fuel channel liner tube. In this case it would obstruct flow in or out of the channel.

The first flow blockage problem was solved by providing a series of holes through the latch mechanism past the rear wear ring, then reducing the outside diameter of the solid shield plug body, and providing a series of holes past the second wear ring, to permit at least 33% of the normal flow to pass the shield plug. The second flow blockage problem was partially solved in solving the first. Since the outside diameter of the body is reduced, there is no longer any problem of the shield body blocking the flow holes in the liner tube. In the situation where the shield plug latch mechanism casing is opposite the flow holes in the liner tube, there is not quite enough flow area, so two additional rows of eight holes were drilled through the casing on either side of the jaw holes. With these two sets of holes and the clearance around the outside of the casing, there is sufficient room to prevent any significant blockage of flow should the casing come into a position in front of the flow holes in the linear tube. It must be emphasized, however, that this occurrence would be extremely unusual. The F/M 'B' ram, cannot move the shield plug any further forward than about 50 mm (2 in) from the nominal installed position, since the ram then reaches its forward mechanical stop. In addition, there are checks by the F/M separators, every time a shield plug is removed, to ensure that there actually is a complete shield plug there.

13. FLOW ASSIST RAM EXTENSION (FARE) TOOL

13.1 INTRODUCTION

During fueling operations with the coolant flow, additional force must be applied to the upstream end of the fuel string to move it (and bundles in the discharge machine) downstream when the coolant flow drag on the fuel is insufficient to move the string on its own. This force can be produced either by the 'C' ram of the upstream machine or by a restrictive element in the channel which develops the necessary coolant-flow drag force without the use of the F/M ram. This drag force is created by the FARE tool.

The FARE tool is used in place of the upstream F/M ram so that the latter does not enter the core and become activated and contribute to the dose rate of maintenance personnel working on the machine. The FARE tool (which also becomes activated when it passes into the core) is discharged from the F/M in the same manner as irradiated fuel bundles before maintenance work is started.

The FARE tool concept was developed and used first in Pickering reactors in channels with coolant flows ranging from 21.5 kg/s (1.47 slug/s) down to the core minimum of 15 kg/s (1.03 slug/s). These tools have a fixed geometry and develop a drag force proportional to the square of the coolant flow rate. The range of coolant flow rates in Pickering reactors is small enough that the force developed at both extremes is satisfactory. In the case of the CANDU 6 reactors, however, because of the lower coolant flows in the outermost channels, the range of flows from 21.5 kg/s (1.47 slug/s) to 9.5 kg/s (.651 slug/s) is too large for use of a single fixed geometry FARE tool. The alternatives were to provide a number of fixed geometry tools, each with a specific range of operation, or a single variable geometry tool which would cover the entire range of coolant flows. The latter was chosen for design of the CANDU 6 FARE tool to avoid the hazard of misuse and for economy. The CANDU 6 FARE tool permits the usual number of fuel bundles (eight) to be changed in one channel visit.

13.2 DESCRIPTION

The FARE tool (Figure 3-45) is similar to that used in Pickering reactors, except that the ring orifice instead of being fixed, is spring loaded to move and open flow bypass slots at a predetermined ring orifice pressure drop (tool drag force). The pressure drop across the FARE tool and thereby the drag force on the tool is almost independent of flow for the full range of flows of interest.

The fuel adaptor at the downstream end of the FARE tool supports the end plate of the fuel. It has three concentric rings which bear on the three concentric rings of the 37 element fuel bundle end plate.

The upstream end of the tool is primarily for the interface with 'C' ram. The flow area between the lands which support the tool in the pressure tube is larger than in the Pickering tool in order to decrease the pressure drop and to reduce the amount of vibration that is incited by the flow in this area of the tool. The plug prevents flow from passing through the bore of the upstream casing.

The tube adaptor section is the major departure from the fixed orifice design of the Pickering tool. Most of the total tool pressure drop is across the tube adaptor section. This section comprises the tube adaptor body ring orifice, spring, spring holder, and four pins. The four bypass slots in the tube adaptor are sufficiently wide that when the ring orifice moves a small amount axially, the total flow area in the tube adaptor section increases significantly.

The spring length supporting the ring orifice is such that full ring orifice travel results in a small increase in the spring force which is balanced by the hydraulic drag across the ring orifice. Therefore, the hydraulic drag (and pressure drop) across the tube adaptor section increases very little for large increases in flow through the bypass slots in the tube adaptor. The ring orifice has circumferential grooves machined into its outside diameter in order to increase its pressure drop. By this means, the annular gap between the pressure tube and ring orifice can be large thereby making the pressure drop less sensitive to pressure tube bore variations.

The zircaloy tube makes the total length of the tool equal to approximately the length of two bundles so that it can be handled conveniently by the fuel handling system. This component is made of zircaloy in order to reduce the neutron capture cross section of the tool to a minimum. The two planes of eight drain holes in the tube section ensure that the pressures inside and outside of this tube section are approximately equal.

13.3 OPERATION

The tool is carried in the F/M magazine and is pushed into the channel in the same manner as fuel bundles after the last new bundle is inserted in the channel. The 'C' ram pushes the tool and fuel string until the ram adaptor face is just inboard of the coolant inlet and the tool is functioning under the influence of the coolant. Irradiated fuel bundles are discharged from the downstream end of the channel in the normal manner with the tool pushing against the upstream end of the string and following its movement back and forth until the remaining twelve bundles are placed in their normal in-core position. With the string in position, the FARE tool is removed from the channel by the charging (upstream) machine 'C' ram which latches onto it in the same manner as to the ram adapter. The tool is withdrawn and stored in the magazine until it is needed again, or until it is discharged to the irradiated fuel bay while the F/M is being serviced.

Eight fuel bundles are normally changed during FARE fueling. Normal fueling operations on non-FARE channels also change eight bundles. The main difference between the automatic sequences controlling each fueling mode is the extra steps required for FARE tool insertion and recovery.

As the FARE tool first intercepts the flow from the liner tube holes, the flow will pass over the tool OD and through the drain holes in the zircaloy tube section to pass through the fuel adapter. The channel flow restriction at this condition is insignificant. As the ring orifice passes the liner tube holes, the flow is divided by the ring orifice and with further tool movement the total channel flow passes through the tube adapter section. This is the tool position for the maximum channel flow restriction. At this position the ring orifice will have moved and uncovered the bypass slots for all channel flows. As the tool moves into the core pushing fuel bundles into the downstream F/M, the channel flow will increase and the ring orifice will move to increase the bypass slot flow area.

The movement of the ring orifice will be reversed as the fuel column is pushed upstream by the downstream F/M until the FARE tool is pushed out of the channel flow.

In any specific channel, the ring orifice will move slightly to accommodate changes in flow as bundles are removed or added to the channel flow steam, but the ring orifice will assume a gross position depending on the flow in the channel.

14. F/M BRIDGE

14.1 PURPOSE

The F/M bridge provides the means of supporting the F/M and its carriage at the reactor face. It positions the F/M to the desired horizontal row of fuel channels, using the coarse 'Y' drive system, and holds this position during subsequent carriage traverse (coarse 'X'), fine homing, locking on and fuel changing procedures.

14.2 COMPONENT DESCRIPTION

14.2.1 Bridge Assembly

Each bridge assembly consists of two fixed columns and a bridge beam, which travels vertically on the columns by means of four ball screws, two on each column (Figure 3-46). The bridge beam is fabricated from two hollow L-shaped steel beams, which are interconnected and diagonally braced by a series of rectangular section steel beams. It is supported at each end by two cam followers supported on bearing blocks on the column elevators. The cam followers permit limited axial and horizontal movement between the bridge and the elevators. Each cam follower is seated in a bearing block attached to the elevator. Two of these bearing blocks have oversized grooves to allow for axial movement of the bridge beam at one column, while the other two bearing blocks hold the cam followers rigidly to axially locate the bridge beam to the opposite column. The bridge beam incorporates rails, on which the F/M carriage travels horizontally and parallel to the reactor face.

The total vertical travel of the beam is the distance from the maintenance lock port elevation to the uppermost fuel channel plus 76 mm (3 in) overtravel. This is equal to a total travel of 6.66 m (21.9 ft). Solid stops position the bridge in line with the maintenance lock tracks. The arrow side of each bridge beam extends beyond the column, such that, when the beam is in its lowest position, the carriage, F/M and catenary are free to pass under the lower end of the column during transfer operations between the maintenance lock and the reactor vault.

The bridge must span approximately 11 m (36 ft) between the two columns. The two bridge assemblies, one at each end of the reactor, are approximately 15 m (50 ft) apart. Each column is a welded T-shape fabrication. Two 76.2 mm (3 in.) diameter roundways on each column guide the elevator. Two stationary ball screws are supported from a head bracket bolted to the top of the column, and are located laterally by two brackets at the bottom.

One column is supported from the floor on a fabricated lower column and restrained near the top and at mid-height by horizontal bracing to the building wall. The opposite column is entirely supported from the building wall, and terminates at the lower end of the elevator travel. This enables the F/M carriage to pass under the column, when transferring from the reactor vault to the maintenance lock. The column support structure terminates above the bottom of the column to leave space for the shielding door to traverse between the column and the building wall. An elevator is mounted on each column to support the bridge beam, and is guided and secured to the two column roundways by eight roundway bearings. The four bearings in contact with each roundway are rigidly mounted while those on the other roundway are spring-mounted to compensate for tolerances in the parallelism of the two roundways.

14.2.2 Drive Unit Assembly

Each elevator is supported and moved vertically up and down the column by two ball screw jacks mounted on the elevator and engaged with stationary ball screws on the column. The two ball screw jacks on each elevator are driven by a double-ended, two-speed induction motor through two miter gear boxes. An electrically released, spring-actuated brake is mounted on each ball screw jack and is connected to one end of the ball screw jack worm shaft (inset Figure 3-46).

The two elevator drive systems on each bridge are interconnected through two of the miter gear boxes by a drive shaft mounted on the bridge. This allows the bridge to be driven by either motor. A shaft encoder is coupled to the second miter gear box on each elevator to provide position information to the control system. The bridge position is normally sensed by the encoders, but limit switches are provided to stop motion if the normal limits of travel are exceeded. Mechanical stops are also provided.

14.2.3 Instrumentation and Control

Motor control is normally performed automatically by the control computer, but it may be controlled manually by switches on the control console. A single MAN/AUTO switch allows manual control of both motors and the four brakes. When in the MAN position, each bridge motor can be controlled independently for UP/STOP/DOWN and FAST/SLOW operation, the UP/DOWN selections automatically releasing the bridge brakes through contacts in the motor starters. Motor control is interlocked by a series of relays in related systems to prevent hazardous operation, and are effective during both manual and automatic operation. An interlock bypass switch, located under a locked cover, permits the interlocks to be overridden.

Four spring-actuated, electrically released brakes are mounted on each bridge, two on each elevator. They are normally controlled from the control computer, but they may be controlled manually from the control console through a MAN RELEASE/ENGAGE switch in conjunction with the AUTO/MAN switch.

The position of each bridge is detected by two shaft encoders, driven from the input shaft of each ball screw jack. A relay is actuated to stop bridge motion, when the encoder outputs are out of synchronization.

Electrical power and control signals are connected to the bridge assembly through two power tracks on one column.

15. F/M CARRIAGE

15.1 PURPOSE

The carriage supports the F/M head in the maintenance lock and at the face of the reactor. It travels along the tracks in the maintenance lock and along the tracks on the bridge in the reactor area. In addition to the coarse 'X' motion (horizontal), the carriage also provides fine 'X' motion, fine 'Y' motion (vertical) and 'Z' motion (direction of reactor axis) and allows a controlled amount of rotation of the head about the horizontal and vertical axes. Coarse 'Y' motion is provided by the bridge that supports the carriage. The carriage also serves as the termination point for the main catenary loop and carries the catenary frames and 'Z' motion hose and cable loop. The clamping mechanisms securely anchor the carriage to the bridge rails when the F/M is clamped to a channel end fitting, to ensure that excessive loads are not applied to the end fitting by the F/M during a seismic event.

15.2 COMPONENT DESCRIPTION

The F/M carriage (Figures 3-47 and 3-48), can be divided into a drive unit assembly including four carriage clamping mechanisms, and a gimbal assembly.

15.2.1 Drive Unit Assembly

The drive unit assembly consists of three subassemblies, an 'X' drive unit, an idler unit and a fine 'Y' drive unit. The 'X' drive unit and the idler unit each have four double-flanged wheels, mounted in pairs; which run on the crane rails on the maintenance lock track and on the bridge. The four wheels on each unit are interconnected to enable the carriage to cross the gap between the maintenance lock track and the bridge.

The 'X' drive unit consists of a welded box frame, which supports the carriage drive wheels and drive components.

The four wheels are mounted on and keyed to shafts, each of which runs in two flanged bearing assemblies. A spur gear is mounted on the inboard end of each shaft and the two gears on each side are interconnected by idler gears. The idler gears are in turn driven from a double-worm speed reducer through spur gears.

The coarse 'X' drive motor is a two-speed motor with an integral electrically-released, spring-applied brake. The motor is connected to one end of the gear reducer input shaft while the other end is connected to a fine 'X' drive planetary gear reducer through an electromagnetic clutch. The clutch must be energized to engage the fine 'X' drive.

The idler unit is of similar construction to the 'X' drive unit, but without the drive system components. The two wheels on each side are interconnected by spur gears and the spur gears are interconnected by a shaft. A toothed sprocket is mounted at the center of the shaft to drive a shaft encoder through a roller chain. This encoder provides 'X' motion position information to the control system.

The fine 'Y' drive unit forms the central part of the carriage drive unit assembly and supports the gimbal assembly. It contains the fine 'Y' drive mechanism, a turntable bearing, and the 'X' centering mechanism. The fine 'Y' drive mechanism consists of three machine screw jacks, which elevate a horizontal bearing plate to which the gimbal assembly is bolted. The jacks are interconnected by drive shafts and two miter gear boxes, and are driven by two hydraulic motors. The jacks have a nominal travel each side of the center position, which is the position maintained prior to coarse homing.

The gimbal suspension plate, to which the gimbal is bolted, is mounted on the bearing plate through the turntable bearing. The bearing allows some rotation around a vertical axis of the gimbal assembly, together with the head, the amount of movement being limited by an 'X' centering mechanism, which also centers the gimbal assembly when deflected.

The 'X' centering mechanism consists of two pre-loaded springs and a plunger assembly, contained in a housing. A linear potentiometer is mounted parallel to the centering mechanism and provides a signal proportional to the amount by which the head is off center. Similarly, there is a 'Y' centering mechanism, which is attached to the lower gimbal unit to allow for head tilting in the vertical plane.

The four carriage-to-bridge clamping mechanisms are arranged in pairs, one at each side of the fine 'Y' drive unit assembly, on each side of the carriage (Location A on Figure 3-52). Each clamping mechanism is a pair of caliper-type jaws, which clamp onto the side of the bridge rail, and is actuated by a machine screw via two lever arms integral with the clamping jaws.

The actuating screw is driven by a reversible oil-hydraulic rotary motor powered by the F/M oil hydraulic system via remotely controlled solenoid valves. The motor is located on the lower trunnion block and the motor shaft is keyed to the lower end of the actuating screw shaft. A double-thrust ball bearing takes the thrust between the screw shaft and the lower trunnion block. The upper trunnion block is threaded to accept the threaded portion of the screw shaft. The clamp, screw shaft and motor are all supported by the clamp fulcrum shaft and are free to move about it, thus ensuring equal clamping pressure on each side of the bridge rail.

In the event of failure of the control system to release the clamps, when required for carriage 'X' motion, a manually operated screw is provided to remove the pressure on the rail. With no hydraulic pressure to the motor, the clamp will not back off as the screw pitch is such that the clamp is self-locking.

15.2.2 Gimbal Unit Assembly

The gimbal unit assembly consists of an upper unit and a lower unit. The upper unit is bolted directly to the gimbal suspension plate of the fine 'Y' drive mechanism and carries eight roundway linear bearings, two at each corner. The lower unit is supported in the roundway bearings on two roundways which allow the lower unit to move in the 'Z' direction, relative to the upper unit. The 'Z' motion is provided by two double-acting hydraulic cylinders. The cylinder piston rods are secured to the lower unit, while the cylinders are bolted to the upper unit. Two gear racks are mounted on each side of the upper unit, adjacent to the hydraulic cylinders. Pinion drive units are mounted on each side of the lower unit and engage with the gear racks to permit the head to be moved manually, in case of failure of the hydraulic system.

15.2.3 Instrumentation and Control

Motor, clutch and brake control for the coarse and fine 'X' motion drives is normally performed automatically from the control computer, but manual control from the control console is possible.

The position of the carriage on both the maintenance lock tracks and on the bridge is detected by a shaft encoder, driven by a roller chain from the carriage idler unit wheel shaft. This provides a signal which is utilized by the control computer to provide carriage position control and console CRT display. There are also two position switches, mounted on the carriage, that are actuated at a point just beyond the end of normal carriage travel. When actuated, the switches provide signals to the control computer and also illuminate indicating lights mounted on the fuel handling control console.

A solenoid valve controls the operation of the two double-acting 'Z' drive hydraulic cylinders that provide 'Z' motion of the carriage. Position detection is by a shaft encoder driven from a gear box in the 'Z' drive mechanism. A limit switch provides positive indication, to the control computer, that the head is fully retracted and also operates a relay in the interlock systems for the coarse 'X' and 'Y' motions.

Position indication for the 'Y' drive mechanism is also from a shaft encoder. The 'Y' correction drive system hydraulic motors are controlled by a solenoid valve, for which normal control is from the control computer in response to signals originating from the 'Y' correction potentiometer.

During the homing operation, the head is allowed to pivot through an angle of approximately 40 minutes each side of the center position in the horizontal and vertical planes. This movement is sensed by two linear potentiometers, one mounted on the 'X' centering mechanism and one on the 'Y' centering mechanism. The signal from the potentiometers is used as an analog input to the control computer, to drive the 'X' and 'Y' correction drive systems, and to drive a digital voltmeter on the control console.

16. CATENARY SYSTEM

16.1 PURPOSE

The catenary system transfers the electric power supplies and control signals, and the D_2O and hydraulic oil flows, between the system connection points in the maintenance lock and the F/M head and carriage.

16.2 SYSTEM DESCRIPTION

The system, shown in Figure 3-49, consists of a catenary loop, a powered catenary trolley, a 'Z' motion loop, and a hose and cable carrier. The catenary loop is connected, at one end, to the F/M carriage, and at the other, to the powered catenary trolley, which travels on tracks in the maintenance lock. The flexibility and length of the catenary loop, and the travel of the trolley, permit the head to connect with all the service ports in the maintenance lock and with all reactor end fittings. System connections between the ends of the catenary loop on the catenary trolley and the termination points in the maintenance lock are made through a flexible hose and cable carrier. The 'Z' motion loop connects the end of the catenary loop on the carriage with the F/M head and provides the flexibility required to permit all motions of the head relative to the carriage, that is 'Z' motion, fine 'Y' motion and fine 'X' motion, including 'X' and 'Y' centering.

The catenary trolley is normally driven, under computer control, by the fuel handling control system. It is positioned such that minimum tension is applied to the catenary loop, and the loop is held clear of the floor, except when the head and carriage are in the maintenance lock.

16.2.1 Catenary Loop

The catenary loop consists of a series of flexible metal and rubber hoses and cables, supported and protected by a catenary chain. The chain is made up of two lengths of flat side plates interconnected by pairs of cross bars. The side plates are hinged together and can pivot in each direction, the amount of movement being restricted to limit the minimum bend radius of the hoses and cables in the loop. Wheels are provided on each side of the chain, in the area where the loop makes contact with the floor, to prevent damage to the floor and the catenary loop.

The loop is rigidly connected to the catenary trolley, on one end, and to the frame on the F/M carriage, on the other end, via two loop supports. Couplings are provided at each end of the hoses. These are secured to the loop supports, in pairs, through mounting plates. The cables, which are installed in a continuous length from the junction boxes in the maintenance lock to the bulkhead on the F/M, are clamped to the loop supports. A bar is installed across the loop support at the carriage end to keep the catenary loop clear of the F/M, if the F/M has to enter the maintenance lock with the catenary trolley at the end of its tracks nearest the shielding door (Figure 3-50). This would only occur during breakdown conditions. The bar can also be used, in conjunction with holes in the trolley loop support, to allow the catenary loop to be lifted by the maintenance lock crane for maintenance purposes.

16.2.2 Catenary Trolley

The catenary trolley supports the end of the catenary loop in the maintenance lock. It consists of two longitudinal beams, interconnected by two transverse members. A dual roundway bearing is located at each end of the longitudinal beams. These bearings run on two roundways mounted on two wide flange beams which extend almost the full length of the maintenance lock.

A bracket is mounted on top of one of the trolley transverse beams to allow the trolley to be moved if the drive system fails. This bracket is shaped so that the hook of the maintenance lock crane will automatically engage it, when the hook is correctly positioned. When the hook is engaged, and the trolley drive system is disconnected, the crane can be traversed to pull the trolley in either direction.

The catenary trolley is chain-driven from a drive unit mounted below the trolley rails. The drive unit consists of a double-reduction worm-gear reducer, a drive motor, a torque limiter coupling and an output shaft, which carries a drive sprocket. The gear reducer is driven by a directly coupled reversible induction motor. The drive motor shaft is double-ended. A square-ended adaptor is mounted on the lower end of the shaft to allow the trolley to be manually driven under breakdown conditions, or for maintenance purposes.

Trolley position is continuously detected by a shaft encoder, driven from the end of the drive unit extension shaft. The control system positions the trolley relative to the F/M carriage such that the tension in the catenary loop is kept to a minimum, while keeping it clear of the floor as much as possible.

16.2.3 Flexible Hose and Cable Carriers

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

Each carrier consists of two flexible chain loops, which run on a steel frame secured to the maintenance lock outer wall. The fixed end of each loop, connecting to the various supplies, is secured to the support frame, while the other end is attached to, and moves with, the catenary trolley. A series of rollers, mounted on a frame, run between the two loops and support the upper run of each loop. There is also a set of wheels, attached to every other roller, in order that the hose and cable carrier can move along its track and follow the progression of the carriage.

The electric power and control signal cables are installed in a continuous length from the junction boxes in the maintenance lock, through the hose and cable carrier, the catenary loop and the 'Z' motion loop to the junction boxes on the F/M cradle. The hoses, however, are installed in three sections, one extending from the fixed piping in the maintenance lock to the trolley, one in the catenary loop and one in the 'Z' motion loop. Joint Industry Conference (JIC) hydraulic couplings are used at each position, except at the connection to the F/M bulkhead, where quick-disconnect couplings are used.

16.2.4 'Z' Motion Loop

The hoses and cables at the F/M machine end of the catenary loop are led either directly to the termination points on the carriage, or through the 'Z' motion loop to the bulkhead connections and junction boxes on the head cradle. Figure 3-47 shows the 'Z' motion loop supported at its upper end on two support beams, which are mounted on the F/M carriage drive unit assembly. Two vertical chain deflectors extend down from the support beam on the catenary side of the carriage and deflect the catenary loop away from the F/M head when the carriage approaches the catenary trolley. A horizontal support frame is mounted on each side of the lower gimbal assembly of the carriage. These frames move with the lower gimbal and the F/M head during fine 'Y' motion, 'Z' motion and F/M head tilting, and support the lower ends of the cables and hoses of the 'Z' motion loop.

16.2.5 Instrumentation and Control

The catenary trolleys are ea[illegible] reversible three-phase induction motor. Two methods of control are available, au[illegible]ual. The control computer utilizes these signals, in conjunction with sim[illegible]nals from the F/M carriage shaft encoder, to position the catenary trolley.

17. F/M D_2O CONTROL SYSTEM

17.1 INTRODUCTION

Fuel changes in the reactor are carried out by using two F/Ms working together, the machines being clamped one at each end of the appropriate channel.

In order to remove irradiated fuel and introduce new fuel it is necessary to remove the snout plug which normally closes the end of the F/M and to "open" the coolant tube by removing the closure plug and shield plug from each end.

Three rams, 'B' ram, the latch ram, and 'C' ram of the F/M are used to remove these plugs and to move the fuel along the reactor channel into or out of the F/M as required.

Two "separator" assemblies on each F/M assist in controlling fuel and plug movement. The 'B' ram and latch ram are mechanically operated by ball screws driven by oil hydraulic motors. The 'C' ram and the separators are hydraulically operated by D_2O actuated cylinders.

A heavy water environment in the magazine housing is required because:

a. this region is in contact with the heavy water of the reactor primary system during fuel changing, and

b. a liquid coolant is required to prevent overheating of irradiated fuel bundles in the F/M.

The F/M D_2O control system provides the heavy water environment at the required conditions to different parts of the F/M and the controlled motive power for the F/M mechanisms driven by water-hydraulic actuators.

17.2 PURPOSE

The purposes of the D_2O control systems are:

a. To supply a controlled flow of heavy water to the F/M sufficient to maintain the magazine at various desired temperatures and pressures, and, when required, to raise or lower the temperature and pressure to a new desired level.

b. To supply a controlled flow of cooling water to various seals in the F/M.

c. To supply a flow of heavy water to the 'C' ram in such a manner as to control the direction, force and speed of movement of the ram.

d. To supply a flow of heavy water to the separators, to operate the actuators of the feelers, pushers and stops at controlled speeds and pressures.

e. To supply a flow of heavy water at controlled temperature to the ram housing.

f. To provide a method of detecting leakage of heavy water from the snout cavity (i.e., the cavity between the F/M snout plug and the channel closure plug) when the F/M is mechanically coupled to an end fitting.

g. To provide a means of filling, venting and draining the F/M.

17.2.1 Temperature Considerations

The heavy water for control of the environment in the F/M magazine housing is provided at temperatures between 40°C and 180°C (356°F). When the F/M is on-reactor the temperature control point for the magazine is 93°C (200°F). The magazine D_2O supply temperature is maintained at a higher temperature to compensate for cooling flow at 53°C to the F/M rain assembly.

The temperature difference between the primary system fluid and the fluid in the F/M is limited to avoid excessive thermal shock to the irradiated fuel bundles which have been exposed to the stress conditions in the reactor.

17.3 SYSTEM DESCRIPTION

17.3.1 Introduction

The D_2O system, or group of circuits, which directly serves one F/M is covered in the flowsheet general arrangement of Figure 3-51. The same flowsheet applies to the circuits for each F/M.

The physical location of the various circuit elements which are represented above the row of the catenary arcs is at the valve station, and the elements represented below the catenary arcs are located at the F/M. Some of the F/M water hydraulic circuits given in Figure 3-51 are process water and the others are power wa

The process water circuits provide environmental control in the magazine housing and in the ram housing; environmental control at the local regions of hydrodynamic seals on the drive shafts for the magazine, the 'B' ram and the latch ram; and the detection of leakage into and out of the cavity between the F/M snout plugs and the end fitting closure plug.

The power water circuits are for hydraulic actuation of the 'C' ram; feeler, pusher and stop of the fuel separator, and the safety lock of the snout clamp.

For convenience in the process description, the total D_2O system may be broken down into a number of sub-circuits associated directly with individual F/M components (Figures 3-52 to 3-55). In the following sections the text is generally in terms of one F/M since the circuits are identical.

17.3.2 Magazine Supply Line

The magazine is supplied with D_2O at approximately 38°C (100°F) and maintains this temperature when empty or with new fuel. On receiving a full load of irradiated fuel, the temperature rises approximately 8C° (14.5F°).

The magazine D_2O control circuit is given in Figure 3-52. The magazine supply line is shown on the left side of the sheet. Water enters the valve station via manual shut-off valve and flows via the magazine supply line through the catenary hoses to discharge into the magazine.

Before leaving the valve station and returning to the low pressure side of the supply system, this process water is throttled by the pressure control valve which controls magazine pressure.

The water temperature in the magazine is detected by resistance temperature detectors (RTDs) mounted in the magazine housing. The signals from the RTDs are averaged and give temperature indication.

Two calibrated orifices FE-22 and RO-21 are at the upstream end of the supply line. Orifice FE-22 is a flow monitoring element, across which is a differential pressure transmitter FT-22.

Orifice RO-21 is a simple flow resistance element whose function is to provide a pressure drop, which in addition to the pressure drop in tubing and catenary hoses, sets the flow to the F/M magazine.

In the magazine supply line, the motorized valve PV-17, shown downstream of orifice RO-20, shuts off the flow when the F/M operates at reduced water level at the new and irradiated fuel ports.

Check valve NV1 prevents reverse flow from the F/M in case of a catenary hose failure.

17.3.3 Magazine Return Line

The return flow of heavy water from the F/M can take different routes depending on the mode of F/M operations. One of these routes is via the "magazine return line" which goes back through the catenary, while another is a direct route into the reactor primary system via the F/M snout. A third route is a line provided at the fuel transfer port through the weir to tank, TK3.

17.3.4 Magazine Supply Pressures

Four magazine pressure levels for the corresponding F/M operating conditions are listed below:

1. Park Condition - 3.10 MPa (450 psi)

   "Park" describes the situation when the F/M is not performing any particular task but is kept in a state of readiness. The F/M when at "Park" condition may be clamped to the new fuel port, or may be in transit between the new fuel port and reactor or between the reactor and irradiated fuel port.

2. Off-Reactor (High) Condition - 11.40 MPa (1650 psi)

   In this situation the F/M is mechanically clamped to a reactor channel end fitting but is hydraulically isolated from the reactor.

3. On-Reactor Condition - 11.04 MPa (1600 psi)

   The F/M is clamped to reactor channel and hydraulically connected. The magazine pressure is slightly higher than the channel pressure to provide positive flow from magazine to reactor.

4. Fuel Transfer (Low) Condition - Atmospheric Pressure

   The F/M is clamped to fuel ports and either receiving new fuel or discharging irradiated fuel.

When the F/M is at either condition (1) or (2) the return flow is through the magazine return line and the pressure is controlled by valve PCV-1 in this line.

Valve positioning is derived from pressure transmitters monitoring the magazine sense line, the resultant pressure being determined by the selected set point. Duplicate catenary hoses, each with its own isolating valve, are provided for the magazine return flow. In the event of a ruptured hose that line may be isolated while magazine return flow is maintained through the other line.

The check valves NV23 and NV24 are provided to prevent return of flow in the event of a burst catenary. Two accumulators, TK1 and TK2, in the magazine return line upstream of the control valves, dampen any sudden pressure fluctuations.

To prevent over-pressurization in the F/M head, two safety relief valves RV1 and RV2 on top of the magazine housing are set to operate at 12.64 MPa (1835 psi) and 13.24 MPa (1922 psi) respectively.

17.3.5 Shaft Seals Circuits

The four ball screws driving the 'B' ram and the latch ram and the drive shaft of the magazine pass through the pressure containment boundary of the F/M.

Hydrostatic seals are provided on the heavy water side to accommodate the high pressure differential with a minimum of frictional losses.

A controlled flow of heavy water at a nominal temperature of 54°C (130°) is supplied to the seals to maintain efficient operation. This heavy water is taken from the actuator supply line.

Duplicate catenary hoses are provided to guarantee a supply to the seals in the event of a hose failure. Under failure condition check valves NV4 or NV5 provide remote isolation from F/M, but hand-valves V30, or V31 must be closed to prevent continued flow from supply.

A reduction in flow below the minimum acceptable level causes the flow switches to give an alarm in the console room indicating "Seals Flow Failure".

17.3.6 Superflow Circuit

For some operations on the reactor it is necessary to increase the total flow into the F/M. This additional flow is intermittent and is brought to the F/M through the "superflow" circuit.

A fixed orifice and needle valve upstream of the catenary are provided to establish the required flow rate. A remote shut-off valve is actuated when the flow is required. In case of catenary hose failure a check valve automatically isolates the F/M side against D_2O loss, while the valve station side again must be manually isolated by closing the needle valve.

17.3.7 'C' Ram Hydraulic Control Circuit

This circuit is shown in Figure 3-53.

The 'B' ram and 'C' ram together form a telescopic ram assembly having an extended stroke capable of reaching through the F/M magazine half way into the reactor channel. Their functions include the provision of appropriate forces and movements to withdraw and replace the snout plug, closure plugs and shield plugs, and to move fuel as required.

A third mechanism, the latch ram, has a short stroke superimposed onto the 'B' ram to assist in these operations. Both the 'B' ram and the latch ram are driven mechanically by ball screw assemblies, whereas the 'C' ram is powered by D_2O hydraulics.

The 'C' ram is a telescoping hydraulic ram carried within the latch ram and 'B' ram. The 'C' ram motion is produced by differential pressures applied during operation.

Heavy water from the actuator supply line passing through a flow element and control valve, is directed by a directional control valve to the advance or retract side of the same cylinders with exhaust water returning to the valve station.

The force produced by 'C' ram results from the pressure, which is determined by the setting of a control valve. The setting of the control valve is derived from the differential pressure existing between the ram ports. The pressure is monitored by a differential pressure transmitter which provides the feedback. One side of the pressure transmitter is connected to the magazine sense line, thus the ram operating pressure is always referred to the magazine pressure.

Five 'C' ram forces are provided, each of which is produced when the appropriate setpoint is selected. Ram operating speed is regulated by friction within the ram, line impedance and a throttling valve in the return line.

Downstream of the control valve is check valve, followed by a relief valve. This relief valve is connected to relieve to the return line and is referenced to the upstream side of the check valve. The relief valve will open when the pressure across the check valve exceeds 70 KPa (10 psi).

The differential relief valve is included to prevent hydraulic locking in the circuit, which would otherwise occur under three separate modes of operation as follows:

a. 'C' ram stalled against a component in the advanced position and held in this position while 'B' ram is advanced.

b. 'C' ram fully retracted within 'B' ram while 'B' ram retracts.

c. During "on reactor" fueling operations, 'C' ram set for "advance" but is moving in the retract direction, that is, being pushed by the fuel string which in turn is pushed by the 'B' ram of the other F/M.

A 'C' ram by-pass flow is provided from downstream of the control valve to the return line. This ensures a flow which does not fall below a minimum level to maintain control and thus hold the pressure at a given setpoint. This is required when the ram has been driven to a desired position and is stalled, consuming only leakage flow. In addition, the by-pass is required to prevent overpressurization of the supply line which would raise the reference power (and thus the cracking pressure) of the overhaul relief valve.

Emergency differential pressure relief valves are provided to prevent build-up of excessive ram force. Two pressure transmitters connected in parallel across the actuating line sense the pressure differential between the actuating lines and provide an independent check on the direction of motion selected.

17.3.8 Separators Control Circuit

The fuel separators are two similar mechanisms, mounted on the F/M to separate fuel bundles, shield plug or ram adaptor. They perform identical actions which are carried out simultaneously.

Three independent water-hydraulic circuits are associated with the two separator assemblies of a F/M (Figure 3-54). One circuit is for the feelers, one for the pushers and one for the side stops.

The hydraulic supply pressure to the actuators is referenced to magazine pressure, since the mechanisms operate against magazine pressure.

D_2O is taken from the actuator supply line at a temperature of about 54°C (129°F) and a pressure of 3.43 (491), 7.84 (1138) or 16.37 MPa (2380 psi) depending on the mode of operation, and is fed to the different circuits through a pressure reducing valve.

The pressure reducing valve has its pilot line connected to the 'C' ram return line which in turn is referenced to magazine pressure. The valve is set to give an outlet pressure 3.43 MPa (490 psi) above magazine pressure.

The feeler circuit controls two feeler actuators, one for each of the two separators per F/M. The two separators are identified as 'left hand' and 'right hand' as viewed from the rear of the F/M. The feeler circuit provides three hydraulic conditions known as 'feelers inserted', 'feelers removed' and 'feelers float'.

The basic feeler circuit consists of supply and return lines connected through a four-way directional valve, actuating lines and a double-acting actuator. The circuit provides simple two-way directional control of the actuator, that is, insertion and withdrawal. Both sides of the actuators are connected through an additional directional valve, thereby equalizing the pressure to obtain the float condition.

The 'feelers float' condition applies when the feelers are riding on a moving fuel bundle in readiness to drop into the approaching gap between bundles, and to check the presence of fuel or shield plug.

The 'float' condition not only requires zero hydraulic forces on the actuators, but also zero hydraulic restraint to movement of the actuators as the feelers must be free to move up and down with irregularities on the surface of a spent bundle, and must drop into the gap between bundles without delay. A light downward force is exerted by a spring in the feeler's position feedback assembly.

The D_2O circuits for the pushers and fuel stops are identical except that the pushers do not have a float condition and thus the directional valve for this function is not present. In addition, twice the number of actuators are used on the fuel stop mechanisms. Again D_2O at 3.43 MPa (500 psi) above magazine pressure is taken to the actuators on the F/M via solenoid operated directional valves.

17.3.9 Snout Cavity Leak Detection Circuit

Two separate checks are required during F/M sequences to ensure that no F/M snout D_2O leakage exists and that the primary heat transport system boundary remains intact after a fueling operation. Each check is carried out after the respective seal has been made as described below, and in Figure 3-55.

The snout cavity leakage check is carried out after the F/M has been mechanically clamped to the end fitting, and before the snout plug is removed. The test ensures that a good hydraulic seal exists at the interface between the F/M snout and the reactor channel end fitting, that is, that D_2O will not leak from the snout cavity to atmosphere.

The channel closure leakage check is carried out after completion of the fueling operation and when the channel closure and snout plugs have been replaced, but before the F/M is unclamped. The test will ensure that the channel closure has been properly replaced in the end fitting and that D_2O will not leak past the closure to atmosphere after the F/M has been unclamped.

Leak detection is carried out by the use of a differential pressure transmitter and suitable valving to join or isolate the cavities from the D_2O system. The pressure transmitter is deflected by the flow of water into or out of it, resulting from any leakage. The electrical signal produced is differentiated and the value representing rate of leakage is displayed.

17.3.10 Snout Clamp Lock Hydraulic Circuit

Snout clamping action is carried out by rotation of the clamping barrel, driven by two gear racks which are oil hydraulically operated.

To ensure clamping action is maintained one of the racks is locked by the insertion of a pin. This pin is pushed into position by a water hydraulic actuator which is pressurized from the snout cavity. The piston in the actuator operates against a spring pressure so that when the pressure is reduced the piston is pushed back and the lock pin is withdrawn. Thus as long as the snout cavity pressure remains above a specified level inadvertent unclamping cannot take place.

17.3.11 D_2O Discharge Port Mechanisms

All operations on the new fuel, spent fuel and ancillary port are performed with the F/M magazine depressurized and its D_2O level lowered below the snout opening.

At each port a discharge mechanism connects the F/M to the drain to lower its D_2O level. Each mechanism has pneumatic actuators to raise it into contact with the drain port on the F/M. Through a suitable linkage, pneumatic actuators on each discharge port operate the drain valve on the F/M. A further actuator at the new fuel port can be operated to open a valve which allows the drainage of the D_2O/oil collection tank on the F/M.

D_2O from the drain tank on the F/M drains by gravity to a holding tank, from which it is pumped to the main D_2O storage tank. The mixed D_2O and oil is drained from a holding tank on the F/M to another tank and disposed of manually.

17.4 EQUIPMENT DESCRIPTION

17.4.1 Directional Control Valves

The directional control valves which are used in the 'C' ram and separator circuits are special poppet type valves designed for AECL CANDU.

The valve is a magnetically operated, latching, four-way, two-position valve with manual override. A latching mechanism holds the valve in the last energized position when the solenoids are de-energized. In the event of solenoid failure, a spring or latch mechanism holds the poppet in the last energized position, regardless whether the poppet was moved by solenoid or manual override.

17.4.2 Overhaul Relief Valve

The 'C' ram hydraulic control circuit is fitted with an overhaul relief valve to prevent hydraulic locking in the circuit, which would otherwise occur under some modes of operation. The valve is a pilot controlled, poppet type pressure relief valve specially designed for this application.

17.4.3 Pressure Reducing Valve PRV-1

The separator hydraulic circuit is required to provide close control of the actuator forces to avoid damage to the fuel, as the separator actuators contact and act against the relatively fragile spent fuel bundles. As well, the displacement volumes of the separator actuators are small and so uncontrolled pressure fluctuations could quickly produce complete repositioning of the actuators.

For close control of actuator pressures it is necessary that the actuator supply and return pressures be referenced to magazine pressure, which is accomplished by a pressure reducing valve. This valve is essentially a poppet type of special design which provides a high degree of internal hydraulic balancing both statically and dynamically.

17.4.4 Piping and Tubing

All the lines on the valve station and F/M equipment are made of stainless steel.

18. F/M OIL HYDRAULIC SYSTEM

18.1 INTRODUCTION

Several functions on the F/M and carriage are carried out by means of oil hydraulic power provided by power supplies and their associated control systems through the catenary system.

The oil hydraulic system operates actuators, which, with their associated valves and tubing, are mounted on the F/M and carriage.

18.2 PURPOSE

The purpose of the F/M oil hydraulic system is to provide controlled conditions of flow, pressure and temperature to operate its associated actuators on the F/M and carriage. A block diagram of the complete system for one F/M is shown in Figure 3-56.

18.3 SYSTEM DESCRIPTION

The overall F/M oil hydraulic system consists of two identical and completely separate systems, one for each side of the reactor. Each system is comprised of an oil hydraulic power supply system and oil hydraulic control circuits, servicing the F/M and carriage.

18.3.1 Oil Hydraulic Power Supply System

The hydraulic power supply is composed of:

1. The pressure generating unit (power pack) including the oil storage tank.
2. The smoothing and filtering unit with its isolating valves (valve station). The description of this system is outside the scope of this document.

18.3.2 F/M and Carriage Oil Hydraulic Control Circuits

The oil hydraulic power is supplied via flexible catenary hoses which terminate with quick disconnects at the F/M and carriage manifolds and operates the following actuators:

Magazine Drive

'B' Ram Drive Speed and Force Control

Latch Ram Drive

Snout Clamp

Lubrication Pump Drive

D_2O Valves
'Z' Drive
Fine 'Y' Drive
Carriage to Bridge Clamps.

18.3.2.1 Magazine Drive

The magazine is driven by an oil hydraulic motor (Figure 3-57) operating through gears and a 'Ferguson' drive. Direction of rotation is determined by the selection of two solenoid valves. With one solenoid energized rotation is clockwise and with the other energized rotation is counterclockwise. Stop is produced by both solenoids being de-energized.

The supply pressure of 12.54 MPa (1820 psi) is reduced by a pressure regulating valve to 3.45 MPa (760 psi). Return flow resulting from rotation in either direction passes through a flow control valve to regulate the speed of rotation.

Pilot operated check valves in the motor feed lines prevent flow when the solenoid valves are not energized thereby stopping motor rotation.

18.3.2.2 'B' Ram Drive Speed and Force Control

The 'B' ram is a ball screw type ram driven through gears by an oil hydraulic motor (Figure 3-58).

A pilot directional control valve directs oil to the motor to operate the ram in the advance or retract direction. In the stop position both lines to the motor are blocked to prevent oil flow and ram movement.

By the use of three flow regulator valves and a further pilot directional control valve, three flow rates can be selected for the oil in the return line. In this manner three speeds of operation are obtained.

The 'B' ram operates at five levels of force. Force selection is regulated by a pressure regulating valve in the supply line. This valve is controlled by a pilot pressure derived from one of four pressure regulating valves, each of which is set to a specific pressure. Associated with each pressure regulating valve is a solenoid valve. Thus by energizing a solenoid valve a pressure regulating valve becomes operative to produce the desired ram force. In the fifth force level the main regulating valve is closed resulting in zero pressure across the drive motor and consequently zero force is produced.

18.3.2.3 Latch Ram Drive

The latch is a ballscrew type ram driven through gears by an oil hydraulic motor.

Oil supply pressure is reduced to 2.74 MPa (400 psi) by a pressure reducing valve to provide the required latching force when applied to the drive motor. A flow regulating valve in the return line determines drive speed.

A directional solenoid valve operates to select advance or retract. When the solenoid is de-energized both lines to the motor are blocked and thus the motor is prevented from rotating.

18.3.2.4 Snout Clamp

The snout clamp mechanism clamps the F/M snout to the reactor end fitting and provides a pressure tight connection.

The mechanism is driven by four single-action oil-hydraulic pistons (Figure 3-59) which are installed at either end of two racks. The racks mesh with a gear-screw which in turn moves the clamping barrel in an axial direction to produce the clamping and unclamping action.

A solenoid directional valve determines the direction in which oil pressure is applied to clamp or unclamp.

18.3.2.5 Ram Lube Pump Drive

Lubricating oil for the 'B' ram and latch ram is supplied to their various bearings, gears and moving parts.

From the hydraulic oil supply, oil at reduced pressure is supplied to a hydraulic motor which drives a pump to circulate the lubricating oil. The oil is fed to a distributor which regulates the flow to the various components. Having passed through the components the lubricating oil collects at the bottom of the ram gearbox, from where it returns to the pump to be recirculated.

A relief valve limits the oil pump's output which is normally greater than the consumption of the distributor. A filter is included in the output line from the pump to ensure the cleanliness of the lubricating oil.

The solenoid valve controlling oil flow to the hydraulic motor is energized when the 'B' ram or latch ram are operated.

18.3.2.6 D_2O Valves

The F/M system includes on/off D_2O valves operated by oil hydraulic actuators.

Oil for these functions is derived from the oil hydraulic supply with the operating pressure reduced by a pressure reducing valve. Directional solenoid valves are employed to control the hydraulic oil flow. A relief valve is installed across the supply to provide overpressure protection.

18.3.2.7 'Z' Drive

The 'Z' motion is the F/M movement in the line of the fuel channel axis. The F/M is advanced for clamping to an end fitting and following unclamping, it is retracted for clearance between snout and end fitting to permit the machine to traverse the reactor face. The 'Z' motion drive is actuated by two double-acting hydraulic cylinders, mounted at the top of the upper gimbal, one on each side, with the cylinder rods connected to the lower gimbal.

Hydraulic oil from the supply is reduced in pressure by a pressure regulating valve to limit developed forces. A directional solenoid valve determines the application of oil to the operating cylinders to produce advance or retract 'Z' motion. In both 'Z' advance or 'Z' retract the pressure is applied through a check valve but the return is through the regulating valve. In this way the advance and retract speeds may be adjusted independently.

Connected between the cylinder supply lines is a fixed flow element. This permits a low flow between the supply lines when the solenoid valve is de-energized, that is, in the stop position. Thus the F/M can move, due to thermal effects, when clamped onto an end fitting. The flow through this element is very small and thus does not adversely affect the advance-retract operation.

18.3.2.8 Fine 'Y' Drive

The fine 'Y' drive consists of two oil hydraulic motors connected together through suitable gearing to three screw jacks.

Hydraulic oil from the supply is reduced in pressure to give the required torque to raise the F/M. A pilot operated directional control valve directs the oil to the motors for raising or lowering.

Check valves in parallel with regulating valves are in both lines to the motors so that the raise speed and lower speed can be adjusted independently.

A pressure regulating valve across the input is set to prevent overpressurization.

18.3.2.9 Carriage to Bridge Clamps

The carriage to bridge clamping mechanism is driven by four oil hydraulic motor driven screw jacks. The oil to the hydraulic motors is applied through two solenoid valves (Figure 5-60). When one valve is energized the motors are driven to clamp the mechanism and energizing the other valve causes the motors drive to unclamp. With both solenoids de-energized the system is held stationary.

Two solenoid valves are employed since the force applied to clamp differs from that to unclamp and the two related oil pressures are set by two independent pressure regulating valves.

18.4 MAJOR EQUIPMENT

18.4.1 Oil Reservoir

The oil reservoir is a totally sealed tank internally treated to prevent corrosion and suitably sized to minimize oil foaming and air entrainment. The tank is provided with a clean out panel, oil sight glass and filter breather assembly. A level switch provides indication of critical, low and full levels and also controls the pumps.

An electric heater ensures the minimum temperature is adequate for satisfactory operation of the oil system.

18.4.2 Supercharge and High Pressure Pumps

The pressurization of hydraulic oil is performed by two electrically driven pumps in series. The first pump provides an adequate supply of oil to the second pump for efficient operation. The second pump delivers oil at the required supply pressure and flow.

A duplicate pair of similar pumps provides a backup in case of failure. Normally only one set of pumps is operated at one time.

18.4.3 Strainers and Filters

Strainers and filters are installed in the oil system to ensure the cleanliness of the oil. In each pump circuit, a strainer is located in the reservoir in the suction line. The air filter between the priming pump and pressure pump will automatically bypass in the event of filter blockage. A further filter located in the output line gives final protection against foreign material in the oil before it enters the system.

18.4.4 Heat Exchanger and Accumulator

An accumulator in the output line reduces the effects of pressure transients. Oil returning to the reservoir passes through a heat exchanger which removes the heat acquired from the F/M and generated by fluid friction.

18.4.5 Piping and Tubing

The lines of 1/2 inch nominal size and smaller are constructed from stainless steel tubing. All other lines are carbon steel pipe. On the F/M all tubing is from stainless steel, regardless of size.

18.4.6 Location

The power pack, valve panel and heat exchanger are located in the reactor building and are accessible during reactor operation.

The oil hydraulic drive actuators and oil hydraulic control elements for the balance of the system are located on the F/M and its support cradle and carriage. They are generally not accessible at the reactor face during reactor operation.

18.4.7 Instrumentation and Control

The general method of controlling the F/Ms is by computer.

The conditions within the oil hydraulic system are monitored by various control elements. Oil level and pump operation are determined by a level switch within the oil reservoir tank. Return oil temperature is monitored and the cooling water to the heat exchanger regulated to limit oil temperature during operation. The oil temperature within the oil reservoir tank is monitored to ensure operation within a specified range. Above the limit an alarm is given and below the limit an electric heater is turned on.

Pressure switches are used to indicate the condition of the filters and a pressure switch in the output line gives an alarm if the oil pressure falls below a desired level.

19. IRRADIATED FUEL TRANSFER AND STORAGE SYSTEM

19.1 INTRODUCTION

The irradiated fuel transfer system covers the process and equipment of the irradiated fuel transfer operations from the reception of irradiated fuel bundles, at the irradiated fuel port, until the irradiated fuel bundles are stored, under water, in the irradiated fuel storage bay. The general arrangement of the irradiated fuel transfer system is shown in Figures 3-2 and 3-61. The associated building areas are listed below.

Dimensions of Irradiated Fuel Bays

BAY	BAY SIZE	WATER DEPTH	REMARKS
Discharge Bay	T Shape, Top 7.6 x 24 m (25 x 78.75 ft)	5.3 m (17.5 ft)	Height of Bay Floor to Ceiling is 9.7 m (31.75 ft)
Transfer Canal	Area in R.B.: 1.8 x 1.8 m (6 x 6 ft). Opening: 1.5 x 1.2 m (5 x 4 ft). Area in Service Bldg.: 2.4 x 2.6 m (8 x 8.5 ft)		
Reception Bay	8.5 x 4.6 m (28 x 15 ft)	7.6 m (25 ft)	
Storage Bay	11.6 x 22.5 m (38 x 74 ft)	7.6 m (25 ft)	
Defected Fuel Storage Bay	2.4 x 5.5 m (8 x 18 ft)	6.0 m (20 ft)	
Irradiated Fuel Shipping Area	4.6 x 8.5 m (15 x 28 ft)		Part of Recept[illegible] Bay

The expected average radiation dosage to operating personnel in the bay is 6 to 10 μSv/h (0.6 to 1.0 m rem/h).

19.2 PURPOSE

The irradiated fuel transfer system is designed to transfer and handle the irradiated fuel bundles on route to the irradiated fuel storage bay from the irradiated fuel port, after the bundles have been discharged by the F/M. A separate defected irradiated fuel storage bay and associated equipment accommodates fuel bundles with cladding failure, due either to inadvertent core exposure beyond maximum rated bundle power or mishandling on transfer.

The irradiated fuel storage bay is designed to provide the nuclear generating station with underwater shielding and cooling for the irradiated fuel bundles, which are potential radiation and heat sources. The storage bay capacity allows for ten years of reactor full-power operation.

19.3 SYSTEM DESCRIPTION

19.3.1 Irradiated Fuel Transfer and Handling System

19.3.1.1 Normal Operation

After the F/M receives a certain number of irradiated fuel bundles (normally eight) from the reactor fuel channel, it travels to the F/M maintenance lock from the reactor vault. The following operations are then performed automatically under digital computer control and access control interlocks prevent entry into the irradiated fuel discharge room during irradiated fuel discharge. The machine clamps onto the irradiated fuel discharge port, withdraws the snout plug, installs the guide sleeve, picks up the ram adaptor and lowers the magazine D_2O level. Before the irradiated fuel bundles are pushed into the irradiated fuel discharge port, the cart with an empty rack must be on the discharge bay conveyor under the irradiated fuel elevator with the rack indexed to its first-loading position, the elevator ladle must be in line with the irradiated fuel discharge port and the elevator bundle stop in the correct position, the two irradiated fuel port valves must be fully closed, and the irradiated fuel cooling system and ventilation system must be operational.

The two irradiated fuel port ball valves are then fully opened, and the 'C' ram advances to push the first bundle pair onto the ladle. Fuel is normally transferred in pairs. The bundles are stopped by the irradiated fuel elevator bundle stop. The 'C' ram retracts into the F/M magazine and the irradiated fuel elevator's bundle stop moves away from its stopping position. The irradiated fuel ladle is then lowered into the discharge bay water to deposit the irradiated fuel bundles on the rack.

Once the elevator is fully down, the conveyor rack indexes to the second-loading position, and the elevator bundle stop moves back to the stopping position. The F/M magazine indexes to the next full fuel station and the discharge of irradiated fuel continues until all irradiated fuel bundles in the F/M magazine are discharged onto the conveyor rack. Then the discharge port ball valves are closed, and the guide sleeve is withdrawn into the F/M magazine. The F/M snout plug is reinstalled, the magazine re-pressurized and the F/M head unclamps from the irradiated fuel port. The F/M is then ready for its next assignment.

The irradiated fuel transfer operation continues underwater in the discharge bay. The loaded rack on the conveyor cart is driven from the discharge bay to the reception bay by electric motors mounted above the water on the bay walkway floors. The two conveyors are normally controlled by the station digital computer but a manual operating facility is also available.

Once the cart reaches the gap between two conveyors, one slotted bracket of the cart disengages the discharge bay conveyor, and automatically aligns with the reception bay conveyor, which drives the cart further to the reception bay. The cart will stop at its end travel in the reception bay. After stopping, semi-automated irradiated fuel handling equipment transfers the irradiated fuel bundles from the cart onto irradiated fuel storage trays. The cart will then be driven back to the discharge bay, to the rack first-row-bundles loading position under the elevator ladle, for the next loading.

Each tray holds a total of 24 bundles, placed in two rows. The reception bay usually has one week's supply of empty storage trays for operational flexibility. After the loading of irradiated fuel bundles to the storage tray, the tray is moved onto a storage tray conveyor for transferring the storage tray from the reception bay to the storage bay through an opening in the wall between the two bays. Once in the main bay, the irradiated fuel storage tray is lifted by a hoist on the manbridge and placed on a tray stand for interim storage. The storage tray conveyor then retracts. Once completely retracted, it seals the opening in the wall with a flow obstruction plate, in order to minimize the movement of water between the two bays.

The manbridge is electrically driven, and spans the width and runs the full length of the storage bay to provide a movable working platform for the operator to handle the irradiated fuel. The operator on the manbridge above the bay water manoeuvres all storage trays, and stacks them up to 19 trays high, using the manbridge electrical hoist and storage bay handling tools.

Stacking up to 19 trays high provides a minimum depth of water shielding of 4.1 m (13.5 ft) from the top row of the irradiated fuel bundles to the water surface, in order to maintain acceptably low radiation levels in the irradiated fuel bay.

The irradiated fuel bundles are expected to be stored in the storage bay for the next 10 years, or more. Irradiated fuel will then be loaded into shipping flasks in the reception bay for shipping from the station to permanent storage that is scheduled to commence in 2035. By using the Service Hall crane, the loaded shipping flask would be passed through a removable hatch above the reception bay, at the elevation of the air lock level. The shipping flask would then be removed and be loaded onto a transfer truck to transport the irradiated fuel to a permanent storage site.

19.3.1.2 Abnormal Operation

19.3.1.2.1 Stuck Fuel Bundles

An abnormal operating state exists when the fuel bundles become stuck in the irradiated fuel port, or on the elevator before entry into the water of the discharge bay.

When the operator is alerted to this situation, either by the monitoring of equipment operations or due to the pre-set timed alarm indication, he must initiate the appropriate steps to ensure that the fuel bundles are kept cool, thereby preventing rupture due to overheating. Four minutes is allowed before spray cooling is initiated and 12 minutes where flooding is used.

Standby cooling water is applied in accordance with the applicable mode of operation.

Since H_2O is used for cooling, there is a possibility of downgrading the D_2O in the F/M, resulting in significant cost penalty. If irradiated fuel is exposed to air for a prolonged period, there is possibility of fission release. The operator will consider the different options before cooling is initiated.

Once cooling of the bundles is assured, means to free the stuck fuel and lower it into the bay can be decided upon and executed. If the fuel bundles have been damaged, they will be placed in the defected fuel storage carousel for defected fuel canning at a later time.

19.3.1.2.2 Semi-Automated Irradiated Fuel Handling Equipment Out of Service

If the semi-automated irradiated fuel handling equipment in the reception bay is out of service, the conveyor cart may be unloaded manually by the operator from the walkway floor. The loaded rack is transferred from the cart to a rack stand, using the transfer rack handling tool. An empty rack is then placed on the cart, and the cart is moved back to the discharge bay, and positioned under the irradiated fuel elevator for the next loading operation. In the reception bay, the operator manually transfers all irradiated fuel bundles from the loaded rack onto an irradiated fuel storage tray and continues the operation.

19.3.2 Defected Fuel Transfer and Handling System

The defected fuel detection system is used to detect the presence of defected fuel in the reactor core. By monitoring the bulk coolant, it detects and indicates in which reactor loop the defected fuel is in. The purpose of the defected fuel location system is to identify in which channel of the particular coolant loop the fuel defection occurred and to find, in this particular channel, which bundle pair contains the defected bundle(s).

The design target for defected fuel bundles at station maturity is 0.3%, average, of discharged fuel bundles, with 1.5% maximum over a short term.

After the F/M receives the defected fuel bundle, it is transferred onto a rack in the discharge bay. The rack is indexed two rows of loading positions after receiving a defected fuel bundle. The defected fuel bundle is then manually removed from the rack and set into a 'carousel' for temporary storage. After a decay and degassing period of four weeks or more, it is manually moved from the carousel, inserted into a can and sealed with a lid. The operator, using a canning device and a set of extension tools, performs the bundle handling and canning operations from the discharge bay walkway. This method prevents continued fission-product escape from the defected fuel bundle.

After canning, the canned defected fuel (one bundle per can), is transferred, one can at a time, by the discharge bay/reception bay conveyor. Using the defected fuel handling tools, the operator on the reception bay walkway floor manually opens the defected fuel bay isolation port valve, fully advances the defected fuel transfer mechanism into the reception bay from the defected fuel bay, and moves the canned-defected fuel bundle onto the mechanism from the reception bay conveyor. Then he manually retracts the transfer mechanism, closes the bay isolation port valve and moves the canned-defected fuel bundle onto a defected fuel storage tray, which is supported by a tray stand in the defected fuel storage bay. Each tray contains 10 canned defected fuel bundles in a single row and is stacked to a 10-tray height.

19.4 EQUIPMENT DESCRIPTION

19.4.1 Irradiated Fuel Ports

Spent fuel must be discharged from the F/M to the discharge bay, and then to the main storage bay area. Two irradiated fuel ports are mounted in the wall between the two F/M maintenance locks and the irradiated fuel discharge room. The two irradiated fuel ports (Figure 3-62), are mounted in port sleeves in embedments in the walls. Each port consists of an end fitting, a housing and two ball valves.

The discharge room is located in the reactor building, with the room walls forming part of the containment boundary. The two ball valves, mounted in series on the bay end of each port, seal the ports and complete the containment boundary when fuel is not being transferred. When fuel is being transferred, the F/M is locked onto the port, thus forming part of the containment boundary.

A carbon steel framework, approximately 1.5 m (5 ft) high by 1.5 m (5 ft) wide, is embedded in the concrete containment wall. Centered in this embedment is an opening to accommodate the irradiated fuel port assembly.

A port sleeve is mounted in the wall embedment opening and is aligned using eight radially mounted centering bolts. After alignment, the space between the embedment and the port sleeve is packed with lead wool for shielding purposes. A ring is installed at each end of the lead wool cavity and welded to the embedment and port sleeve.

A port housing flange, at the F/M maintenance room end, and a flange, at the discharge room end, are mounted inside the port sleeve and are secured to the sleeve at the discharge room flange. The port is thus cantilevered from the discharge room end to provide the degree of flexibility necessary for F/M machine lock-up. A split-sleeve spacer bolts around the port housing, filling the void between the housing and the port sleeve for shielding purposes.

The port slopes down towards the F/M end, at a slight angle, to ensure that D_2O carried into the port with the fuel bundles drains back into the F/M.

An end fitting mounts to the flange at the F/M maintenance lock end of the port. It accommodates the clamping action of the F/M snout. A channel closure can be installed in the end fitting to seal the port, but is normally not required.

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 ten holes along the top and five holes around the F/M 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.

The two ball valves are of similar construction, metal-sealed, with an adjustable open-position stop, to provide a clear bore for the passage of the fuel bundles. The valves are operated by double-acting pneumatic actuators. Each valve is controlled separately, either by handswitch, from the control console, or automatically, by the fuel handling control system. Manual operation of the valves is possible using a handscrew on the valve actuator. Adjustable position limit switches indicate the fully-open and fully-closed valve positions.

19.4.2 Elevating Ladles and Drives

Two electrically driven elevating ladles (Figure 3-63) accept the irradiated fuel bundles from the irradiated fuel ports and lower them onto a rack on a conveyor at the bottom of the discharge bay room.

The two elevators consist of two ladles (Item 5) running on tubular and angle rails (Item 7). The rails are inclined at 30° to the vertical, except for the lower 1.2 m (4 ft), which are vertical. The 30° inclination of the rails allows both elevators to terminate at the single conveyor at the bottom of the discharge bay, providing that only one ladle enters the vertical section at any time.

Each ladle accommodates two fuel bundles and is suspended by a stainless steel cable from a drum mounted above the rails. The drum is driven by an electric motor and gear reducer, mounted in the adjacent new fuel room to facilitate access under conditions where irradiated fuel is located inside the discharge room

The rails are manufactured and assembled in three major sections, two upper sections and a lower section. The lower section, which is underwater, is mounted in slots for easy removal without draining the bay. The joints between the upper and lower sections are spigoted for ease of assembly and disassembly.

The ladle assembly consists of a frame, which runs on two gimballed guide roller assemblies and a fixed guide roller assembly. The gimballed rollers run on the tubular rails, while the fixed rollers run on the angle rail. The gimballed rollers allow the assembly to accept rail mounting tolerances, so that accurate positioning of the rails is only critical at the fully-up and fully-down positions. During installation, the rails are set up to position the ladle at a slight slope at the top of its travel, so as to align with the slope of the irradiated fuel port. At the bottom, the ladle is horizontal.

The ladle assembly has deliberately been made heavy to reduce the risk of jamming. The ladle itself is semicircular and slotted. It is made of stainless steel, with chrome plating on the wear surfaces to reduce the wear from the sliding fuel bundles. The slots in the ladle coincide with the frame of the conveyor rack to allow the bundles to be transferred onto the rack. The ladle mounts to a frame with shoulder screws permitting the ladle to move horizontally, relative to the frame, against a spring. This ability to move in the direction of fuel loading is provided to guard against possible damage. Should a fuel bundle snag the ladle while being pushed onto it by the F/M ram, the ladle will move horizontally until it contacts a stop on the fuel positioning arrangement. This stops the F/M ram, thus preventing high ram forces from being transferred to the ladle guide rollers and rails, which would be damaged.

The hoisting units (Item 3) are mounted directly above the elevators, and each consists of a cable wound on a grooved drum, a slack-cable detector, adjustable ladle stops and the ladle upper-position detector. The drum is of painted carbon steel, with nickel plated grooves, and is mounted in two flanged cartridge bearings.

The stainless steel hoisting cable, tested to 3200 kg (7050 lb), connects to the ladle frame through a spring-loaded attachment consisting of a stack of disk springs. The cable has a safety factor of 15.

When the ladle reaches the top of its travel, it contacts a mechanical stop that accurately aligns the ladle with the irradiated fuel port and immediately actuates a switch to cut off power to the hoisting unit motor and brake. Motor inertia compresses the disk spring assembly until the motor comes to rest under the action of the brake. The ladle is then held against the stop by spring compression through the brake.

The slack-cable detector consists of a roller held in contact with the cable by a counterweight. If the cable becomes slack due to the ladle jamming, or contacting the stops at the bottom of the elevator, the detector switch actuates and stops the motor.

The ladle-position detector mounts on the hoisting unit frame. The detector is a limit switch activated by a spring-loaded contoured plunger, which contacts a plate on the cable attachment assembly mounted on the ladle frame.

A retractable stop (Item 8) is mounted at the elevator ladle upper position to provide a positive stop for the fuel bundles as they are discharged onto the ladle. The stop must be retracted prior to the elevator lowering because the elevator moves at an angle of 30° to the vertical and interference would result. The stop assembly consists of a vertically sliding plate, on which mounts the fuel positioning stop, a ladle guide and a mechanical ladle latch. The plate is offset 5° from the vertical to minimize sliding of the stop on the fuel bundle end plate. The plate is retracted by a double-acting pneumatic cylinder powered from the irradiated fuel transfer auxiliaries.

The fuel positioning stop has a spring-loaded plunger, which, when depressed by a fuel bundle, actuates a switch to provide a signal to the control system. The ladle guide provides positive lateral alignment of the ladle with the irradiated fuel port, while the ladle latch limits horizontal movement of the ladle. Limit switches indicate the retracted and extended positions of the end positioning stop. If the stop fails to retract, it is possible to lower the ladle, but the fuel bundles will be displaced laterally.

The ladle drive unit (Item 4) consists of a variable-speed, reversible DC motor with integral brake. It connects to a speed reducer via a torque limiter coupling. For unrestricted access, the drive unit is located in the new fuel room. The output shaft of the speed reducer is coupled to the hoisting unit in the discharge room by a shaft assembly, which penetrates the containment wall. A flexible coupling is located in the discharge room.

The shaft assembly, penetrating the containment wall, consists of a stepped shaft mounted in a housing on two bearing assemblies a standard cartridge bearing assembly at the discharge room end, and a magnetic-fluid cartridge seal assembly at the new fuel room end. The complete assembly is mounted in an embedment in the containment wall and aligned during installation by eight jacking screws. To prevent radiation streaming, the cavity between the shaft housing and the penetration is filled with lead wool, held in place by welded cover plates.

The magnetic-fluid cartridge seal assembly consists of two ball races and a liquid seal, mounted on a hollow shaft and enclosed in a flanged housing. The entire seal assembly can be removed and replaced as a unit for servicing. The assembly is backed up by a mechanical lid-type seal located behind the standard cartridge bearing at the discharge room end. The two seals provide the double protection necessary for the containment boundary.

19.4.3 Discharge Bay/Reception Bay Conveyor

After being lowered to the discharge bay by the elevator ladle, the irradiated fuel bundles are automatically loaded on a rack, which is supported on a cart moving on two conveyors from the discharge bay to the reception bay, via the transfer canal. The essential equipment of both conveyors are a rack and cart, conveyor track, drive unit, sprocket and chain. The following sections give a more detailed description.

19.4.3.1 Rack and Cart

The rack is mounted on the cart (Figure 3-64, Item 5). The position of the cart is automatically indexed by the drive unit shaft encoder, when it is below the discharge bay conveyor for loading of irradiated fuel bundles. The stainless steel rack weldment consists of four fuel bundle support plates, each having six troughs on the top. Two irradiated fuel bundles are supported end to end in the troughs of the four support plates. The rack, therefore, has a capacity to take 12 fuel bundles at one time.

The stainless steel cart has four pairs of wheels and runs in both directions on the discharge bay/reception bay conveyors. It has two sets of slotted brackets on one side, to engage the pins of each conveyor drive chain, and three pairs of rollers, which engage the two conveyor guide rails at its center. The two slotted brackets are positioned so that, when the cart is driven over the gap in the junction between two conveyors, in either direction, the pins on the first conveyor disengage from one slotted bracket, as the pins go around the first conveyor sprocket. This automatically aligns the other slotted bracket with the pins on the second conveyor chain to drive the cart to its final destination. There are two mechanical stops, one at each end of the cart travel. These stops permit overtravel from the normal end-of-travel positions. A shaft encoder, driven by the shaft of the conveyor drive unit through a reducer, sprockets and a chain, detects the position of the cart when it is on the discharge bay conveyor, thus providing continuous position feedback for indexing and end-of-travel position of the cart.

The cart end-of-travel position on the reception bay conveyor is detected by two cam-operated switches. These switches are also driven by the shaft of the conveyor drive unit through a reducer, sprockets and a chain.

19.4.3.2 Conveyor Track

Both conveyor tracks have the same width and mount at the same level. The conveyors have an upper and lower chain support, a rectangular section guide rail that guides the conveyor cart running along the whole length of the track, a drive gearbox and lifting lugs. Both conveyors are set up in line and secured by captive screws and tapered alignment pins on the two bays' floors. Two conveyors are used to simplify removal for maintenance, if required. The length of the discharge bay conveyor (Item 3) is 7.16 m (282 in) long, starting from the bottom of the irradiated fuel elevator in the discharge bay and ending in front of the entrance of the transfer canal. The reception bay conveyor track (Item 4) is 7.19 m (283 in) long, starting from the transfer canal entrance and running to the reception bay.

19.4.3.3 Drive Train

Each conveyor chain is driven by a reversible motor with an integral brake, through a speed reducer mounted at the bay walkway level (Item 6). The output shaft of the speed reducer is connected with a pai[illegible]el gears on the conveyor to drive the conve[illegible]r chain. A torque-limiter coupling is m[illegible]n the reducer output shaft to limit the torque that can be applied by the motor.

The cart-position feedback mechanism differs for each conveyor to the extent that the discharge bay conveyor has a continuous position feedback, via a shaft encoder, while the reception bay conveyor end-of-travel positions are indicated only via two cam-operated switches. Both shaft encoder and cam switches are mounted above the water level, on the respective drive motor assemblies, and are driven through sprockets and a chain.

19.4.4 Semi-Automated Irradiated Fuel Handling Equipment

Semi-automated irradiated fuel handling equipment is provided in the reception bay for the automatic transfer of the irradiated fuel bundles from the conveyor cart rack onto the storage trays (Figure 3-65).

Empty storage trays are manually positioned, in the reception bay, to receive the bundles from the conveyor. The bundles are transferred from the conveyor cart rack to a storage tray, in pairs, by two J-tools, mounted on a carriage and operated automatically under the control of a microprocessor. The conveyor cart rack normally carries eight bundles, while the storage trays have a capacity of 24 bundles. When a storage tray is full, it is manually removed and replaced by an empty one.

The major component of the equipment is a carriage, which runs on rails at the edge of the bay, and extends over the bay to support the two J-tools, which handle the bundles. Operation of the system is normally initiated by the fuel handling control system control computer, and is then controlled by a microprocessor and related equipment, mounted in a control console located adjacent to the equipment.

System operation is, therefore, integrated with the overall spent-fuel discharge operation. Manual operation of the equipment is possible from switches and pushbuttons on the console, but is only intended for use during maintenance and set-up, or in the event of failure of some part(s) of the system.

The irradiated fuel storage trays are manually positioned to receive the spent fuel bundles from a platform on the carriage. The trays are carried on a storage tray lifting tool, suspended from the reception bay crane. For this operation the carriage is controlled from a pushbutton station on the carriage.

Interlocks are provided to prevent conflict between operation of the bay crane and the semi-automated system equipment.

Canned defected fuel cannot be handled by the semi-automated equipment and must be removed from the conveyor cart using manual tools.

The reception bay semi-automated irradiated fuel handling equipment is described in the following sections.

19.4.4.1 General Arrangement

The mechanism consists of a carriage (outer frame), an elevator (inner frame), and two J-tool assemblies. The cantilevered carriage runs on a rail and a ball-bushing roundway mounted on the edge of the reception bay, parallel to the discharge bay/reception bay conveyor. The elevator moves vertically within the carriage and carries the two J-tools.

Electric power and control signals are transmitted to the carriage through catenary cables secured to junction boxes on the adjacent reception bay wall.

19.4.4.2 Carriage

The carriage is a welded carbon-steel structure of rectangular steel tubing. It is mounted on the roundway on two ball bushings, with an underrunning roller engaging the rail. A drive system, consisting of a stepping motor driving a ball lead screw, is mounted adjacent to the roundway. A squared adapter is fitted to the end of the lead screw to allow the carriage to be driven manually for maintenance.

The motor is controlled by an indexer module (motor controller), which permits the selection of two motor-speed ranges, a base speed range and a high speed range. The actual motor speed in each range is adjustable through potentiometers in the control console. The carriage has a total travel of 2596 mm (102.2 in). It is required to stop at 20 positions: one reference position, six positions for the transfer rack, 12 positions for fuel for the storage tray, one free position for the storage tray. Primary carriage position detection is by counting the number of steps of the motor from the reference position, and is performed by the stepping motor indexer module. The number of steps and direction the drive is to be moved are selected by the microprocessor under automatic control, or by the operator, when under manual control. Confirmation of the location of the carriage is provided by a bank of four proximity switches, while accurate positioning is confirmed by a pair of position switches, actuated by a series of cams mounted on the rail adjacent to the proximity switches. There is one cam per carriage stopping position. The reference position cam has 30° slope while all other cams have 15° slope. This minimizes error in indication for the reference position and minimizes wear on the other cams.

19.4.4.3 Elevator

The elevator consists of a welded carbon-steel structure of rectangular steel tubing, and rides on two ball bushings on a vertical roundway, and on a pair of cam followers, which engage a vertical guide rail. It has a vertical travel of 930 mm (36.625 in) to accommodate the difference in elevation between the rack and the storage tray. Both the roundway and the guide rail are secured to the carriage outer frame. The elevator is driven by an induction motor, driving a ball lead screw through a gear reducer and a torque-limiter coupling. The torque-limiter coupling is adjusted to slip, if the drive is overloaded, to prevent damage to the system. Position detector switches, mounted on the carriage, indicate elevator position to the control system, and are operated by cams mounted on the elevator. Three positions of the elevator are required: elevator up position to clear the rack, elevator at cart level position, about 63.5 mm (2.5 in) below the top position, and elevator at tray level position, which is the bottom position.

A squared adapter is fitted on the input shaft of the gear reducer to allow the elevator to be driven manually, if necessary, for maintenance.

19.4.4.4 J-Tool Assemblies

The purpose of the J-tool assemblies is to lift bundles off the transfer rack and deposit them in the storage tray. The J-tools are mounted on the elevator, which raises the bundles clear of the rack and lowers them to the storage tray elevation.

The bundles on the rack are in pairs, each pair having its two bundles placed end-to-end, touching each other. To place a pair of bundles in the storage tray, it is necessary to separate the two axially by 32 mm (1.25 in). This is required because the storage tray has a central rib, which, in effect, divides the 24 bundles into two groups of 12.

To accommodate this difference, one J-tool assembly is moved laterally by 32 m... ...25 in) during the elevator motion, while the other assem...ly is mounted rigidly on the elevator. The removable assembly is mounted on two ball bushings, running on a horizontal roundway at the bottom of the elevator frame, and is stabilized at the top by two cam followers, that engage a short horizontal rail. The lateral movement is effected by a grooved cam on the elevator. A cam follower on the J-tool engages the groove.

Each tool has a fixed outer thin-wall tube and a sliding inner tube, the full length of the outer tube. A ball spline between the inner and outer tubes maintains their relative orientation. The inner tube has a J-hook attached to its lower end to lift the fuel bundles on its center set of wear pads. To stabilize the bundle, a saddle contoured to suit the two outer sets of wear pads of the fuel bundle, is attached to the outer tube at the lower end. The J-hook has 63.5 mm (2.5 in) of vertical motion, and is driven by a linear actuator mounted on the upper end of the inner tube.

The operation of lifting a bundle off the rack, and placing it in the tray, consists of the following sequences. With the tool open, that is, the J-hook lowered, the tool is moved horizontally by means of carriage motion to align with a bundle on the rack. Then the hook is raised, initially lifting the bundle on its center set of wear pads. When the tool is completely closed, the bundle is stabilized by the saddle mounted on the outer tube. To deposit a bundle on the storage tray, this operation is reversed and the tool is moved horizontally to clear the bundle. The open and closed position of each J-tool are detected by two limit switches mounted near the upper end of the assembly.

The hook and saddle are free to pivot through a limited angle. Pivoting is normally inhibited by a spring mounted at the top of the tool and connected to the hook through a linkage system. The saddle and hook are connected by a pair of rollers, which ensures that each moves in conformity with the other. If the carriage inadvertently overtravels, to cause the hook or fuel to strike the rack or another object, then the system will pivot and operate a switch that will stop all motions.

In addition, the saddle has the capability to travel vertically through a limited distance, and the hook has some excess vertical motion normally resisted by a spring at the lower end of the assembly. If the elevator inadvertently overtravels, to cause the hook or fuel to strike the rack, the spring will be compressed. This will also result in actuation of the switch mentioned in the previous paragraph and will stop all motions.

19.4.5 Reception Bay Manual Defected and Irradiated Fuel Handling Equipment

A series of extension tools and accessories (Figure 3-66) are provided in the reception bay to facilitate the manual handling of canned defected fuel bundles, and empty and loaded irradiated fuel storage trays. These tools and accessories are also used for the manual handling of loaded and empty discharge bay/reception bay conveyor racks, and irradiated fuel bundles if the semi-automated irradiated fuel handling equipment is out of service for any reason. The tools and accessories are described in the following sections.

19.4.5.1 Transfer Rack Handling Tool

This tool (Figure 3-64, Item 9) is used in the reception bay to remove loaded transfer racks (Item 8) from the discharge bay/reception bay conveyor cart (Item 5) and place them on single or triple rack stand-offs. In use, it is suspended from the bay crane (Item 11) controlled by an operator on the bay walkway.

The tool consists of a head connected to a U-shaped handle and a lifting eye by a length of pipe. The head consists of two side plates interconnected by three pipes. Two horizontal plates which run along the inside of each side plate engage with plates on the side of each rack and have lugs to ensure positive engagement. Except for the lifting eye, the tool is of stainless steel. The tool weighs approximately 163 kg (360 lb) and its overall length is 6.3 m (248 in).

The tool can carry a fully loaded rack, or a rack containing any number of bundles, including canned bundles, in any position.

The tool is normally stored directly above the end of the conveyor in such a position that, when the conveyor cart reaches the end of the conveyor, the rack is aligned with the tool. As the tool is lifted, the rack is automatically picked up.

When the rack is removed from the conveyor, water coverage is approximately 3.9 m (13 ft) because of the discharge bay/reception bay conveyor elevation. In order to keep the dose rate below the acceptable 6 μSv/h (.6 mrem/h), personnel are required to stay outside a radius of 3 m (10 ft) from directly above the transfer rack while it is being lowered to a safe depth in the bay. Three indicator rings indicate the position of the tool relative to the bay water level.

19.4.5.2 Bundle Lifting Tool

This tool (Figure 3-64, Item 16) is provided to enable fuel bundles to be transferred, one at a time, from the discharge bay/reception bay conveyor racks, located on the single rack stand-off (Item 12), to the storage tray (Item 15).

Three head-position indicator rings indicate maximum elevation, bundle pick-up from rack elevation (also delivery to storage tray elevation), and travelling elevation to clear the rack and tray.

The tool weighs approximately 35 kg (77 lb) and its overall length is 6.9 m (271.5 in).

19.4.5.3 Rack Stand-Offs

A single (Figure 3-64, Item 12), and a triple (Item 13), rack stand-off are located on the floor of the reception bay. The single rack stand-off is located in line with the discharge bay/reception bay conveyor, and adjacent to the storage tray loading position, while the triple rack stand-off is placed to one side of the bay.

The single rack stand-off is used when the bundles are being transferred onto a storage tray, while the triple rack stand-off is used to store additional racks.

19.4.5.4 Storage Tray Support Table

Empty storage trays (Figure 3-64, Item 22) are supported in the reception bay on two tables (Item14), 2.3 m (7.5 ft) high in the 7.6 m (25 ft) deep part of the bay.

The tables support the trays at a height convenient for pickup by the reception bay tray handling tool (Item 20). Tapered locating pins are provided on the top of the tables and engage with mating slots in the trays.

19.4.5.5 Tool for Lowering Empty Trays

This tool is provided to lower up to seven empty storage trays into the reception bay. It consists of a four-leg frame with a latch mechanism at the bottom of each leg. The tool is lowered over the stacks of empty storage trays, using the bay crane, until the latch mechanism is in line with the lowest tray of the stack to be picked up. The latches are then manually engaged and the tool is lifted with the trays. The tool is lowered into the bay with the trays. When the weight of the trays is off the tool, it is lowered until lever-operated cams disengage the latches. The tool can be removed from the bay and stored in the laydown area next to the reception bay, after use.

19.4.5.6 Storage Tray Lifting Tool

The storage tray lifting tool (Figure 3-64, Item 20) is used to move storage trays after they have been lowered into the reception bay. The tool weighs approximately 136 kg (300 lb) and its overall length is 680 cm (268 in). Two indicator rings indicate the upper and lower storage tray positions of the tool head, relative to the bay water level.

19.4.5.7 Storage Tray Conveyor

The manually driven storage tray conveyor (Figure 3-64, Item 18) has three superimposed frames for telescopic extension. The fixed bottom-frame is mounted on the floor by supports and captive screws in the reception bay, at one end, while the other end extends into a rectangular opening in the wall between the reception bay and storage bay. The bottom frame is essentially a weldment of stainless steel pipes and brackets. Its two guide rails, which run the whole length of the frame, provide a support and guide way for the center frame. The movable center frame consists of stainless steel pipes, support pads, bogie assembly, guide rails, stop pad and a flow obstruction plate. The center frame has a travel of 1.3 m (51 in), by running its rollers in the guide rails of the bottom frame. The flow obstruction plate, attached with two lifting lugs, becomes a seal to minimize the water flow between the storage bay and the reception bay, when the storage tray conveyor is fully retracted. The top frame provides a support for the fully loaded storage tray. It has a travel distance of 2.05 mm (80.5 in), by running its rollers in the guide rails of the center frame. After the top frame hits the center frame stop, the former will pick up the latter, moving together. As soon as the center frame advances, it moves the flow obstruction assembly away from the storage bay wall. The two frames will cease their movement by hitting the bottom frame stop. With the spent fuel storage tray now clear of the storage bay wall, it can be picked up by the storage bay tray lifting tool, via the manbridge.

The storage tray conveyor is manually operated from a handwheel, located on the bay walkway. A drive shaft (Item 19) mounts vertically through the reactor hall floor and connects to the underwater conveyor drive gearbox in the reception bay. A drive sprocket, attached to the horizontal gearbox shaft, engages a single-strand roller chain, which is held up by idler sprockets and tightened by a chain tensioner. No position feedback equipment is associated with the storage tray conveyor. It is driven manually until it stalls in the fully extended, or retracted, position.

19.4.6 Storage Bay Equipment and Tools

19.4.6.1 Storage Bay Manbridge

The storage bay manbridge (Figure 3-2, Item 24), is an above-water crane-girder structure that consists of a monorail crane, an under-slung walkway and a two-ton hoist mounted on an electrically driven trolley. The monorail crane is supported 16 m (52.5 ft) apart across the bay, by wheels running on runways and rails. The under-slung walkway, which is rigidly attached to the monorail crane, provides safe access for operating personnel to handle irradiated fuel or other radioactive components. It spans approximately 12 m (40 ft) and runs the full length (approximately 22.5 m (74 ft)) of the storage bay. It is covered with non-slip checker plates on its decking floor and has kick plates, and handrails along both sides of the walkway. Facilities for extra lighting are provided underneath the walkway decking floor. The 1800 kg (2 ton) hoist has a clear lift of 12 m (40 ft). Whenever the spent fuel storage tray is hooked to the hoist, the operator must keep the spent fuel bundles immersed in the bay water, to a minimum depth of 4.10 m (161.5 in), at all times, to ensure minimal radiation levels at the bay water surface. The trolley, running along the monorail crane, supports the 1800 kg (2 ton) hoist and the bridge pendant control station.

The travel speed of 76 ~ 102 mm/s (3 ~ 4 in/s) is the same for both monorail crane and trolley. The hoist has two travel speeds; a fast speed of 40 ~ 81 mm/s (1.5 ~ 3.2 in/s), and a low speed of one third of the fast speed.

19.4.6.2 Storage Trays

The overall size of the storage trays is 1.08 m (42.5 in) long x 1.52 m (59.8 in) wide x 140 mm (5.5 in) high. Each storage tray can hold 24 fuel bundles in two rows of 12 each.

The trays are of stainless steel welded construction, with contoured cradle strips welded to support the fuel bundles. Two lifting plates are provided in each end rail and correspond to the pins on the tray lifting tools. Cut-outs are provided in the top section of the end rails and, together with an angled guide strip, guide the lifting tool pins into engagement with the storage tray lifting plates. Each tray is provided with two tapered locating pins and two slots, the pins engaging with the slots of the next-higher tray in the stack.

The trays are identified by a letter and three numbers, cut from sheet stainless steel, and located one in each upper corner.

The trays are normally stacked no more than 19 high. This provides a minimum water shielding of 4.42 m (14.5 ft), over the bundles on the top tray, with a minimum shielding of 4.10 m (13.46 ft) of water, above a tray in transit, passing over the top fuel tray.

19.4.6.3 Storage Tray Supports

Storage tray supports (Figure 3-2, Item 25) are provided in the reception bay, and in the main storage bay, to support the stacks of trays. The supports ensure the bay floor loading is not exceeded, provide the necessary clearance between the first row of fuel bundles and the bay floor, and permit the free flow of water around the trays.

Each support consists of a diagonally braced, stainless steel frame, supported on four raised pads. Two tapered locating pins locate the first tray in the stack.

19.4.6.4 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. An eye is provided at the top of the handle for attaching the tool to the hoist on the bay manbridge. The head consists of two plates, interconnected by three lengths of pipe, and is connected to the handle by a vertical pipe. Two pins are mounted in each plate to engage with lifting plates on the ends of the spent fuel trays. The entire assembly, except for the lifting eye, is of stainless steel.

The tool weighs approximately 163 kg (360 lb) and is designed to carry one fuel storage tray, carrying any number of fuel bundles up to the maximum of 24. There are no lifting limitations on the location of fuel bundles on a partially loaded tray.

The tool is stored standing on the bay floor with the handle secured to the bay hand rail.

19.4.7 Defected Fuel Handling Equipment in Discharge Bay

Defected fuel bundles are identified, before being discharged from the F/M, through fuel channel Delayed Neutron (DN) monitoring, via a sample station. The DN count rate will decrease sharply when a defected bundle leaves the channel flow. The bundle or bundles are then recorded via the F/M magazine rotor position. When discharged from the F/M, they are lowered on the elevator, in the same way as normal fuel bundles. However, in the case of a defected fuel bundle, the conveyor rack is indexed two positions, and the defected bundle is removed from the rack and inserted into the carousel, using a fuel handling tool suspended from the discharge bay monorail hoist. The carousel is then indexed to position the bundle under the carousel canopy. The defected bundles remain in the carousel until they have decayed sufficiently to permit canning, between four and eight weeks. After canning, the bundles are transferred, on the conveyor, to the reception bay for storage in the defected fuel storage bay in the service building. The description of tools and equipment required for defected fuel handling follows.

19.4.7.1 Carousel

A carousel (Figure 3-67, Item 1) is located in the discharge bay to provide temporary storage for defected fuel, for a decay period of four to eight weeks after the bundle has been discharged from a F/M. It can be indexed to support a total of 12 defected fuel bundles and is designed to handle 30 bundles per year, 15 bundles per month, eight bundles per week, four bundles per day.

The rate for each period is subject to the limits for the next higher period, as it would be impossible for example, to handle four bundles per day for one week.

The carousel base is a weldment of angles bolted onto the bay floor. The outside walls consist of an octagonal lower wrapper, open at the bottom, with a removable conical hood of octagonal shape covering the top of the tray. The tray is made up of 12 sides, with each side holding one defected bundle. A ventilation pipe connects from the hood to the negative side of the irradiated fuel ventilation system, to purge active gases from the carousel. The hood has lifting eyes for access to the carousel for maintenance. A bundle handling tool places the defected fuel into the tray, through an opening on the top of the hood. The indexing unit (Item 2) is operated manually, from the bay walkway level, via a handle and pipe penetrating the reactor hall floor.

19.4.7.2 Defected Fuel Can

Each defected fuel bundle is inserted into a stainless steel can (Figure 3-67, Item 13), after a necessary decay period in the carousel. The can has one open end for the bundle insertion, while the other end is blanked and punched with a small hole to prevent the internal can pressure from building up, during and after canning operations. The can is sealed by a lid, after the defected fuel bundle has been pushed in it. The empty cans and lids are lowered into the discharge bay by one of the bay elevator ladles.

19.4.7.3 Canning Device

The canning device consists of a can storage rack (Figure 3-67, Item 12), a can support (Item 9), a fuel bundle trough (Item 11), and a bundle transfer ram (Item 14). All these components are mounted on the canning device support frame (Item 15) under the discharge bay water. The can support, which has a stand frame, a guide plate and a blanked end plate, holds the can in a proper position during canning operations. After temporary storage in the carousel, a defected fuel bundle is placed into the canning trough, using a bundle handling tool (Item 4). The bundle transfer ram is supported at the rear by a bearing, which runs in a tube, and at the front by a rectangular bearing. The ram head is slotted to accept the spigots on the can lids. The bundle transfer ram, which is mounted 1.24 m (48.75 in) above the bay floor, is driven by a manually operated drive unit. To clear the irradiated fuel elevator spray-cooling header, the shaft of the drive unit has been cut into two pieces. The drive mechanism (Item 17), consists of a crank handle and a torque wrench on a crankshaft, mounted above the bay walkway level. The drive shaft (Item 16), whose top end is embedded in the reactor hall floor and bottom end has a pinion, meshes with the rack of the bundle transfer ram in the bay water, thus advancing or retracting the ram. The crankshaft and the drive shaft are connected to each other by a set of sprocket gears and a single roller chain in a ram drive base on the bay walkway level. The full travel of the bundle transfer ram is 620 mm (24.5 in) limited by positive stops in both directions.

19.4.7.4 Bundle Lifting Tool

The bundle lifting tool (Figure 3-67, Item 4) is provided to enable defected fuel bundles to be lifted from the discharge bay/reception bay conveyor rack into the defected fuel storage carousel, and from the carousel to the defected fuel canning equipment.

The tool consists of a length of pipe with a U-bolt at the top, and an outrigger and clamping jaws at the bottom. The jaws are operated by a pivoting handle at the top of the tool.

In operation, the bay crane is connected to the U-bolt and the tool is lowered, with the handle in the open position, until it rests on the bundle. When the tool is in position, the handle is rotated 180° to clamp the jaws around the bundle. The outrigger holds the bundle in a horizontal position. The jaw linkage geometry is adjusted to prevent the jaws applying unnecessary pressure to the bundle.

Two indicator rings, on the tool outer tube, indicate the permitted upper and lower positions of the tool, relative to the bay water level, when carrying a defected fuel bundle.

The tool weighs approximately 31 kg (68 lb) and is similar to the bundle lifting tool in the reception bay, except for length and the number of indicator rings on the outer tube.

19.4.7.5 Lid Rack Handling Tool

Racks of defected fuel can lids (Figure 3-67, Item 10), are lowered into the bay on an elevating table, mounted on one of the discharge elevator ladles. The lid storage rack handling tool (Item 5) is used to transfer full racks from the ladle onto the defected fuel canning mechanism, and empty racks back to the elevating table. The tool weighs approximately 3.6 kg (8 lb).

19.4.7.6 Elevating Table

The elevating table (Figure 3-67, Item 18) is a rectangular, carbon-steel 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 on the elevator.

19.4.7.7 Can Handling Tool

The can handling tool, or 'J-tool' (Figure 3-67, Item 7), is used to move empty defected fuel cans between the elevator ladle and the can storage rack, and between the rack and the can loading trough, and to move full cans between the trough, and conveyor rack. A similar handling tool is used on the reception bay to transfer full cans from the conveyor cart to the carrier of the defected fuel transfer mechanism.

The tool consists of a handle connected to a double lifting hook by a length of pipe. The tool is of stainless steel except for the lifting eye. In use, it is suspended from the bay monorail. When not in use, it is stored in the bay, suspended from a bracket at the walkway level.

It is fitted with a series of five indicator rings, which indicate the position of the hooks relative to the water level.

19.4.7.8 Lid Handling Tool

The lid handling tool (Figure 3-67, Item 6), picks up can lids from the storage rack and places them in position in the defected fuel canning equipment ram.

The tool consists of a length of pipe, with a hook at the top and a contoured fork at the bottom. A spigot on the can lids engages with the fork, the lid being held in engagement with the fork by a hook. The hook is operated through a toggle clamp at the top of the tool and allows the operator to lock the lid to the tool, or release it, as required.

The tool weighs approximately 108 kN (24 lb). A single indicator ring is provided to indicate the position of the hook relative to the water level.

19.4.8 Defected Fuel Storage Bay Handling Equipment

The defected fuel bay (Figure 3-68, Item 11) is used to store canned defected fuel. The bay is fully enclosed to prevent possible spread of contamination from defected fuel. A separate 900 kg (1 ton) crane (Item 13) facilitates handling of extension tools to manipulate defected fuel cans and storage trays.

After the fuel is canned in the discharge bay, the canned fuel is transferred to the reception bay on the discharge/reception bay conveyor. The reception bay can handling tool (Item 2) is used to transfer the canned fuel from the conveyor rack on to the carrier of a defected fuel transfer mechanism (Item 6). This transfer mechanism is located underwater in the defected fuel bay and extends through a circular port into the reception bay. The port is sealed when the mechanism is not in use by a manually operated isolation mechanism in the reception bay (Items 3 and 4).

Canned defected fuel is stored in the defected fuel bay on storage trays, each stack of trays being supported on a tray support (Item 9). The supports limit the bay floor loading and provide the required clearance between the bottom row of canned bundles and the bay floor. Each tray contains 10 canned fuel bundles and the trays can be stacked 10 high.

The individual canned fuel bundles are moved inside the defected fuel bay using the can lifting tool (Item 2) suspended from the crane which spans the bay. Trays of fuel are moved using a tray handling tool (Item 12), also suspended from the crane. For operator convenience, the tray handling tool is designed to permit the trays to be stacked only five high. The ceiling restricts stacking any higher. When all stacks are five trays high, the tool must be shortened to permit higher stacking.

Space is available in the bay for the installation of a defected fuel bundle examination facility, if required.

Underwater lighting is provided by portable underwater lights connected to receptacles around the bay.

Defected Fuel Storage Bay Isolation Mechanism

The bay isolation mechanism (Item 3) consists of a seal plate, operated from a handwheel (Item 4) at the bay walkway level, which seals against a sealing face on a mounting base, which forms an extension of the port.

The mounting base consists of a length of pipe, cut at an angle of 45° and welded to a base plate, with a flange to form the sealing surface. The operating mechanism consists of a stainless steel threaded shaft, running in an Ampco 18 shaft guide. A shaft guide is bolted to the mounting base and the shaft is connected to the handwheel. The lower end of the shaft is connected to the sealing plate through a clevis and a fork, and a seal plate lever. The seal plate has limited freedom about the lever, to ensure alignment with the sealing surface. The seal is made with an O' ring in the sealing plate.

The handwheel and the short section of the drive shaft, which extends above the walkway, is normally removed to prevent obstructing the walkway, except when the mechanism is being operated, and is stored on a bracket on the adjacent walkway handrails. The drive shaft is flush with the walkway, when the sealing plate is closed.

The operating mechanism is secured to the mounting base by tapered alignment pins and captive screws to permit removal for servicing. The drive shaft is connected to the operating mechanism and to the handwheel by hexagonal joints, which permit the handwheel and the shaft to be easily removed.

Defected Fuel Transfer Mechanism

The transfer mechanism consists of a carrier, which runs on tracks machined into two slide rails. The carrier is driven by a roller chain from a bevel gearbox, via a vertical shaft from a handwheel at the bay walkway level (Item 7). The carrier is essentially a cantilevered tube that extends into the reception bay to accept a canned fuel bundle when the carrier is at the reception bay end of its travel. With the carrier retracted into the defected fuel bay, the port valve is normally closed to prevent flow between the two bays.

The transfer mechanism is mounted on a support frame in the defected fuel bay. The frame is, in turn, secured by tapered locating pins and captive screws to two plates fixed to embedments in the bay floor. This facilitates installation and removal of the mechanism. A captive screw is provided on the mechanism to allow the carrier to be locked in the retracted position, to prevent carrier movement when the assembly is being moved during servicing.

The handwheel and vertical drive shaft can be lifted out of the transfer mechanism gearbox for servicing, the vertical shaft being coupled to the gearbox by a key fixed to the bore of the gearbox input shaft.

Defected Fuel Bay Tools and Accessories

The can handling tool in the defected fuel bay is identical to the one in the reception bay. The tool consists of a handle connected to a double lifting hook by a length of pipe. The tool is of stainless steel, except for the lifting eye. When not in use, the tools are stored in the respective bays, suspended from brackets at the walkway level. Two indicator rings on the tools indicate the vertical position of the tool hooks relative to the water surface. The tool weighs approximately 25 kg (55 lb).

The storage tray lifting tool is similar in construction to the reception bay main storage bay tray lifting tools.

The defected canned fuel storage trays are similar to the main storage bay trays, but contain only 10 canned fuel bundles in a single row.

The defected canned fuel storage tray supports are similar to the main storage bay tray supports and perform the same functions.

Irradiated Fuel Auxiliaries

The irradiated fuel auxiliaries comprise a series of systems to provide air and water for the irradiated fuel discharge mechanisms. Auxiliary systems are provided for: standby cooling, D_2O leak collection, fuel stop actuating, port relief, F/M overflow detection, and port valve actuating. Duplicate systems are provided for both F/M sides, except for the standby cooling system pump.

The station instrument air supply system provides air pressure at a nominal pressure of 690 kPa (100 psi) for purging the D_2O leak collection system, the port ball valve, and the fuel stop actuators. A separate regulator provides 35 kPa (5 psi) for purging the D_2O port. Isolating valves are installed in all lines passing through the wall between the new fuel room and the irradiated fuel discharge room. They can be closed during servicing of any irradiated fuel equipment to maintain the reactor containment integrity.

The irradiated fuel is transferred in air, from the time it leaves the D_2O in the F/M head until it is submerged in the discharge bay. If, due to a delay, the irradiated fuel remains in air longer than a predetermined time, an alarm is provided to the operator. He then selects the standby cooling system 'on' to supply cooling water to the exposed fuel bundles to prevent bundle overheating, and possible subsequent bundle failure.

The water supply is provided by a single stage centrifugal electrically driven pump, mounted vertically in the discharge bay with the pump submerged. It provides a flow of 10 kg/s (.68 slug/s), at a pressure of 330 kPa (48 psi).

Two pneumatically operated globe valves control the flow of cooling water to either the port or elevator or both, depending on where the fuel bundles are located. If the fuel bundles are struck in the port, and the outer ball valve can be closed, the level of the F/M D_2O can be raised to flood the port with D_2O and cool the fuel. The standby cooling system would not be used.

The standby cooling system has three modes of operation:

i. If the fuel becomes stuck in the port such that the outer ball valve cannot be closed, the port cooling portion of the system would be used. To prevent downgrading of the head D_2O, the guide sleeve would be removed and the snout plug installed to isolate the F/M from the port. The cooling water then flows over the stuck fuel and discharges into the bay.

ii. If the fuel bundles are stuck with one bundle on the ladle and one in the port valve, both the elevator ladle and the port cooling systems must be operated. As in (i), the F/M should be isolated from the port.

iii. If both bundles are on the elevator the outer ball valve should be closed and the elevator cooling system operated. The outer ball valve is closed to prevent downgrading of the F/M D_2O.

During F/M operation on the irradiated fuel port, the F/M and port are filled with D_2O and pressurized. Some D_2O will leak past the inner ball valve seal into the cavity between the inner and outer valves. Prior to the opening of the ball valves for fuel transfer, the water level in the F/M is reduced below snout level.

Whenever the F/M is connected to the port and the F/M D_2O level is being raised or lowered, or the F/M is full, the D_2O leak collection system is in operation. A pneumatically operated drain valve connects to the cavity between the port valves. It opens, through a solenoid valve, to drain any D_2O into a tank in the F/M D_2O system. At the same time, the cavity is supplied with air at a nominal pressure of 35 kPa (5 psi), through a solenoid valve, to assist in clearing any D_2O from the cavity. Two check valves, mounted in series in the line between the solenoid valve and the port, provide double protection against loss of D_2O, when the port is pressurized by a F/M. A leak detector, mounted between the valves, detects leakage and energizes a warning lamp on the control console, so that corrective action may be taken.

A port relief valve connects to the port and is set to relieve at 3.5 MPa (500 psi), with a flow of up to 4 L/s (63 U.S. gal/min), to prevent excess pressure being applied to the port and port ball valves. D_2O discharged from the valve is returned to a tank in the F/M D_2O.

A D_2O collection container is located below the discharge end of the port and connects to the port. The container drains into the discharge bay through a removable orifice. If the F/M level control system fails and the flow of D_2O from the F/M into the container exceeds the flow through the orifice, a liquid level detector probe in the container actuates a transmitter. A lamp on the control console energizes, providing a signal for corrective action to be taken. This detector also operates if the standby cooling system flow to the port is operated with the port ball valves open.

The port ball valves are operated by pneumatic actuators, the air supply to each actuator being controlled by a four-way, two-position, double-solenoid valve. A hand valve connects across the two lines to each actuator and is normally closed. If the ball valves are to be operated manually, the hand valves are opened to equalize the pressure across the ball valve actuators.

The fuel stop can be raised from its stop position by a double-acting pneumatic ram, controlled by a four-way two-position, single-solenoid valve. When energized, the ram raises the stop to allow the ladle to be lowered. The stop is held in the raised position until the ladle has been returned to the fuel discharge port, at which time the solenoid valve is de-energized to allow the fuel stop to be lowered, ready for the ladle to receive the next fuel bundles.

20. IRRADIATED FUEL DRY STORAGE

20.1 INTRODUCTION

When the original irradiated fuel storage bay becomes full, auxiliary storage bays are provided at some nuclear power stations. However, with the need to place used fuel from decommissioned nuclear power plants in interim dry storage, a viable process has been developed and is being implemented at some CANDU 6 stations.

It has been demonstrated that used CANDU fuel can be placed in dry storage within five years after discharge from a reactor. The future size of the storage bays on CANDU stations now can be reduced to as little as six years capacity, including capacity for a full core load.

The process that is used for irradiated fuel dry storage in canisters was evolved from the WNRE, Gentilly-1 and Douglas Point projects and is well established. The storage element is the basket (Figure 3-69) which stores fuel vertically, thus minimizing the structural needs. For the CANDU 6 system 60 bundles are stored per basket. The baskets are stored 9 high, one on top of each other inside the concrete canister (Figure 3-70).

The fuel is stored horizontally in the storage fuel bay, in trays of 24 bundles. Twelve of the 24 bundles are placed in the vertical position, transferred one by one into the basket and followed by the 12 additional bundles. The fuel transfer to the basket is made with a manual tool. Once filled, a basket cover is placed over the basket base and is transferred to the shielded workstation for welding of the cover.

The fuel is then dried with hot air circulation through the basket. The basket cover is subsequently welded to the basket bottom and to the top of the basket center post to seal the basket and form a rigid structure. The welded baskets are lifted into a shielded transfer flask. The flask is moved on a transporter to the concrete canister. The flask is lowered on the canister loading platform, the canister plug is removed and the flask moved over the canister. The basket is lowered into the canister and the flask is returned to the shielded workstation where the basket transfer cycle is repeated.

The process is capable of handling a quantity of 6,000 bundles per year from the plant. As a guide, the manual fuel handling equipment will be able to handle the normal loading of a quantity of approximately 20 baskets per week for one shift.

The dry storage of irradiated fuel is covered by CSA N292.3 "Concrete Canister Storage of Used Fuel". It covers the requirements, codes and standards which are generic to dry irradiated fuel storage in canisters, including seismic conditions.

"Pool Storage of Irradiated CANDU Fuel" is referenced in the CSA N292.3 standard and will apply to new structures implemented in the bay for basket loading and temporary storage in the bay.

When storage of irradiated fuel is considered, the following five licensing concerns must be satisfactorily addressed:

i. adequate fuel cooling;

ii. effective containment of radioactive release in the event of fuel failure;

iii. adequate radiation shielding;

iv. adequate physical security and ease of safeguards verification;

v. long term structural integrity against natural events.

20.2 SYSTEM DESCRIPTION

20.2.1 Basket Loading

Manipulation of the individual fuel bundles takes place underwater, using manual tools and hoists (Figures 3-71 and 3-72). The empty fuel basket is first placed on the underwater work table. The fuel bundles from a tray are tilted from the horizontal to the vertical position, twelve at a time. Using the bundle lifting tool, the bundles are removed from the tray one-by-one, and loaded into the fuel basket.

After the basket has been filled to capacity and the bundles in it noted for IAEA safeguards purposes, the cover is placed over the basket and the basket is ready for removal from the bay.

20.2.2 Basket Drying and Welding

These operations are performed in a shielded welding station (Figure 3-73). The basket is lifted through the shielded loading chute into the shielded welding station and placed on the turntable. It is spray washed, moved into the drying position, and both it and the fuel bundles inside it are dried by means of a hot air blast. The basket is then moved to the welding area in the shielded welding station and the cover seal-welded to the baseplate and the center post.

20.2.3 Flask Transportation

After the seal-welding has been verified, the fuel basket is hoisted out of the shielded work station, into the fuel transport flask, which has been in place over the opening in the top of the shielded work station while the basket has been in the shielded work station (Figure 3-73). The loaded flask, with its door closed and locked, is transferred to the trailer. The trailer is pulled out of the building and towed for a short distance to the Waste Management Area, where the Canister Site is located.

20.2.4 Concrete Canister Loading

At the Canister Site the flask is brought under the gantry crane, and lifted onto the loading platform using a hoist. An auxiliary hoist is used to remove the canister plug (Figure 3-70). As the plug is removed, the flask is positioned over the canister opening to maintain shielding.

The fuel basket inside the flask is then hoisted just enough to take its weight off of the gate. The door is opened, and the basket lowered into the concrete canister, using the flask winch. The canister plug is put back into place and the flask lowered back onto the trailer, to be returned to the station for the next iteration.

When the canister contains nine baskets, the canister plug liner is seal-welded to the canister liner. An IAEA seal is affixed.

20.3 EQUIPMENT DESCRIPTION

20.3.1 Fuel Basket

The fuel basket (Figure 3-29) is approximately 1050 mm (41 in) outside diameter and 550 mm (22 in) in height. Type 304L stainless steel is used in its construction to assure compatibility with bay water and high resistance to any potential corrosion.

Each basket has a capacity of 60 bundles, arranged in four rings. The bundles are held in position by means of two retaining plates. A 102 mm (4 in), schedule 80, stainless steel pipe, located along the axis of the basket, serves to uniformly transfer the weight of the 60 bundles (which rest on the baseplate) up to the ring at the top into which the grapple engages during the lifting operation.

20.3.2 The Fuel Bundle Tilter

The fuel bundle tilter (Figures 3-71, 3-72) will reside permanently on the underwater work table, which is at an elevation of 2.75 m (9 ft) above the bottom of the irradiated fuel bay. Its function is to reorient the fuel bundles from the horizontal to the vertical position. A grapple is used to transfer the bundles underwater, one-at-a-time, from the trays on which they have been stored to the fuel baskets.

The undercarriage arrangement tilts the inner row of 12 bundles, in unison, so that the axis of the respective bundles is vertical and, hence, amenable to grapple attachment. After these 12 bundles have been removed and transferred to the basket which is positioned alongside, the tray is lifted to just above the fuel bundle tilter, rotated 180°, and lowered back onto it. The remaining row of bundles now rests over the tilter's undercarriage arrangement and these bundles can now be tilted, removed from the tray, and placed into the basket.

The tilter is designed to accommodate the standard CANDU 6 fuel tray design, which is a two-row fuel bundle tray arrangement. The previous fuel bundle tilters were designed and fabricated to accommodate a single-row tray arrangement.

20.3.3 Shielded Welding Station

The shielded welding station that has been designed for the CANDU 6 fuel storage program is quite similar to the design employed during several earlier CANDU spent fuel dry storage programs.

There are two rails inside the welding station (Figure 3-73) running along the length of the station, on the base section. The turntable that rests on these rails is moved by a drive mechanism, transporting the basket so that the following activities take place:

- the washing and draining of the basket,
- the air drying of its interior (and the fuel bundles), and
- the semi-automatic seal-welding.

The shielded work station has two lead-glass windows in the walls for visual observation, and two TV cameras inside for monitoring of the seal-welding operation.

The main departure from previous projects is related to the irradiated fuel bay layout. A crane will be added over the shielded work station and a new building extension constructed to facilitate the flask transfer to the transporter. The station will be constructed of sections assembled into a unit, with its base section anchored to the bay wall concrete in the region of the wall where the transfer canal was to have been located. The walls and ceiling sections of the shielded work station will be fabricated from 10 mm (0.40 in) steel plate on the inside and outside, with 190 mm (7.5 in) of lead in between to provide sufficient shielding so that the radiation field at the exterior is restricted to less than 25 μSv/h (2.5 mrem/h) on contact.

20.3.4 Fuel Transport Flask

The fuel transport flask that will be used for the CANDU 6 is different in design from the design used in previous CANDU programs, in three significant areas:

- the flask will be circular in cross-sectional configuration (not square), and
- a sliding bottom door will be employed, in lieu of the hinged bottom "shutters" used in the past, and
- its internal diameter can house a larger basket.

The manual hoist used for lifting and lowering the basket (into and out of the flask) uses chain rather than cable, to prevent basket rotation while these activities are underway.

The shielding consists of 190 mm (7.5 in) of lead between inside and outside steel plate, 9.5 mm (.37 in) in thickness. Radiation fields on contact with the outside surface of the fuel transfer flask are expected to be less than 25 μSv (2.5 mrem).

20.3.5 Canister

The canister (Figure 3-70) is a cylindrical, reinforced concrete structure with an internal liner of 9.5 mm (3/8 inch) standard weight carbon steel pipe. The canister is approximately 3 m (10 ft) in diameter, 6.2 m (20 ft) tall and the liner is 1.12 m (44 in) in diameter. The canister provides a combined shielding of 0.94 m (37 in) of concrete and 9.5 mm (.37 in) of steel. The opening at the top is circular and sized to accept the canister plug and adapt to the flask. The carbon steel lined canister plug is seal-welded to the liner at the completion of the loading operation, and the IAEA safeguard seals are installed.

The CANDU 6 concrete canister design is similar to that in use at Douglas Point and is an adaptation of the original WNRE design. The canisters are designed for deadweight, thermal, wind and tornado driven missiles and seismic loads. They are supported on a common reinforced concrete foundation that rests on a deep bed of crushed stone.

The concrete mix is designed to provide a 28-day design compressive strength of 27.6 MPa (4000 psi). The mix incorporates 5% air entrainment to provide resistance to alternate freezing and thawing cycles.

Two main rebar cages serve to reinforce the canister. One is located alongside the canister liner, the other envelops the canister periphery. Supplementary rebar is also present along the plug/liner interface and between the canister and the base. The rebar at the base anchors the canister to the foundation pad.

The conceptual design and licensing of these concrete canisters took place in the early seventies and actual demonstration testing in 1975-1976. Quarterly surveillance inspections have been carried out during the ensuing years and no significant deterioration has been observed to date.

20.3.6 Canister Site Description

The canisters will be arranged in two arrays of 150 each (i.e., 30 rows of five canisters per row). The two arrays will be separated by a road, which will serve to provide access to both of the arrays.

The canisters will be sequentially built, at a rate of 10 per year. About nine are needed for an 80% capacity factor.

Ten of these canisters will be filled during the first year. During each subsequent year ten canisters will be constructed and ten canisters filled. The loading schedule will be such that the canisters in the row being loaded and canisters in the row being constructed will be separated by two rows of empty canisters.. Construction of the canisters in the second array will commence in the fifteenth year.

The canister site will require an area of about 55 m (180 ft) by 130 m (430 ft). The site fence will enclose an area of about 80 m (260 ft) by 155 m (510 ft).

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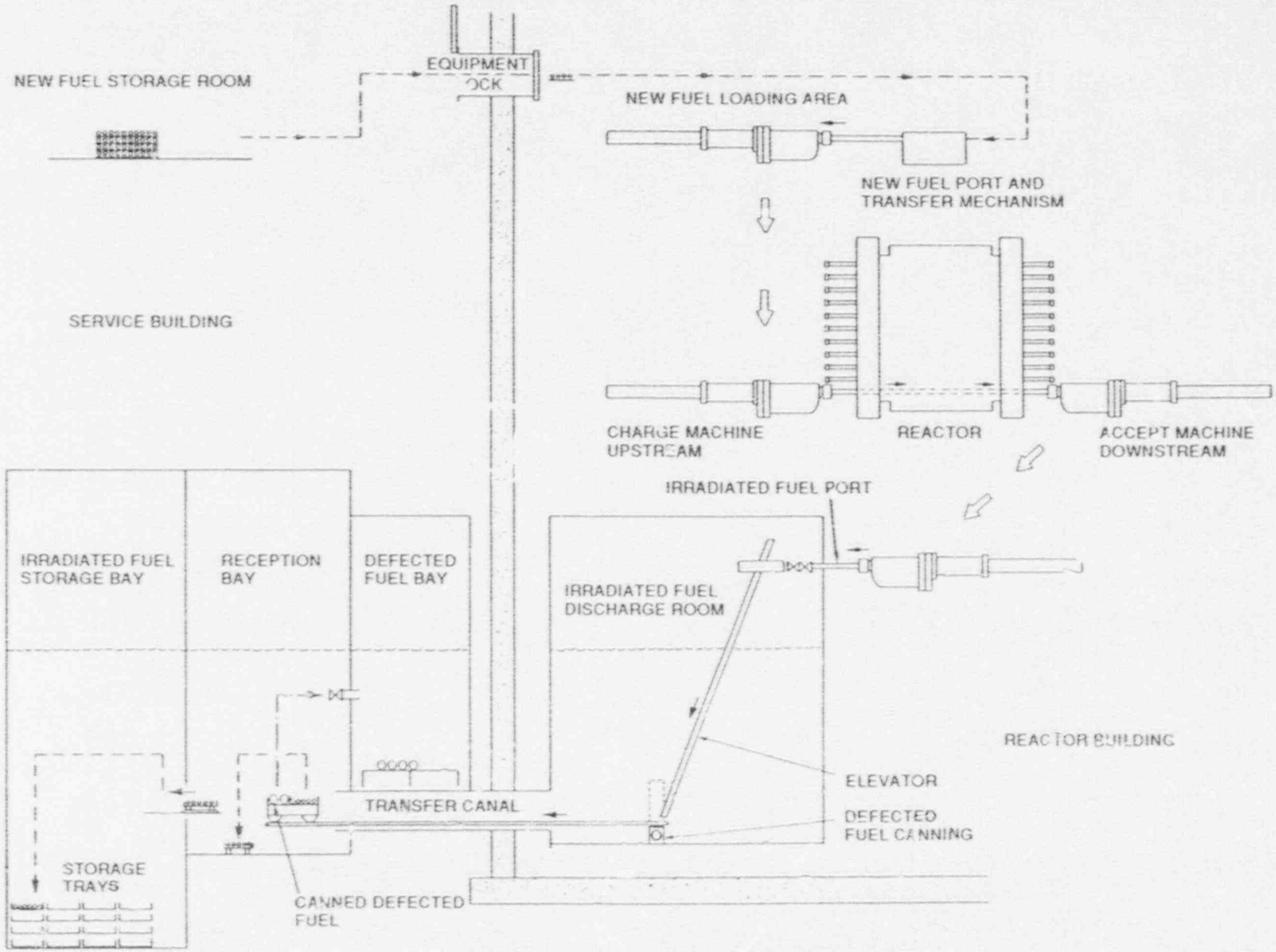


FIGURE 3-1 FUEL HANDLING SEQUENCE

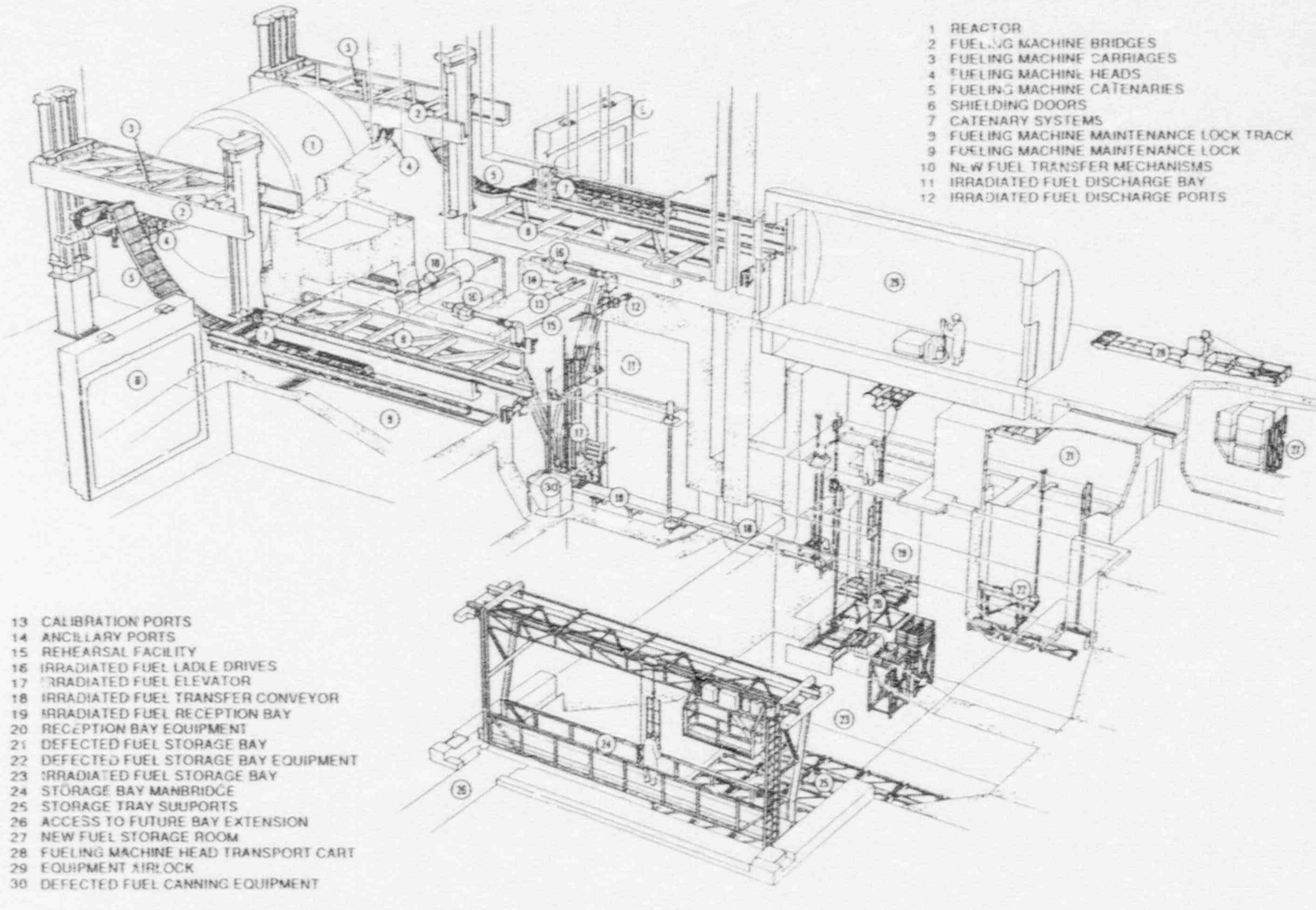


FIGURE 3-2 CANDU 6 FUEL HANDLING SYSTEM

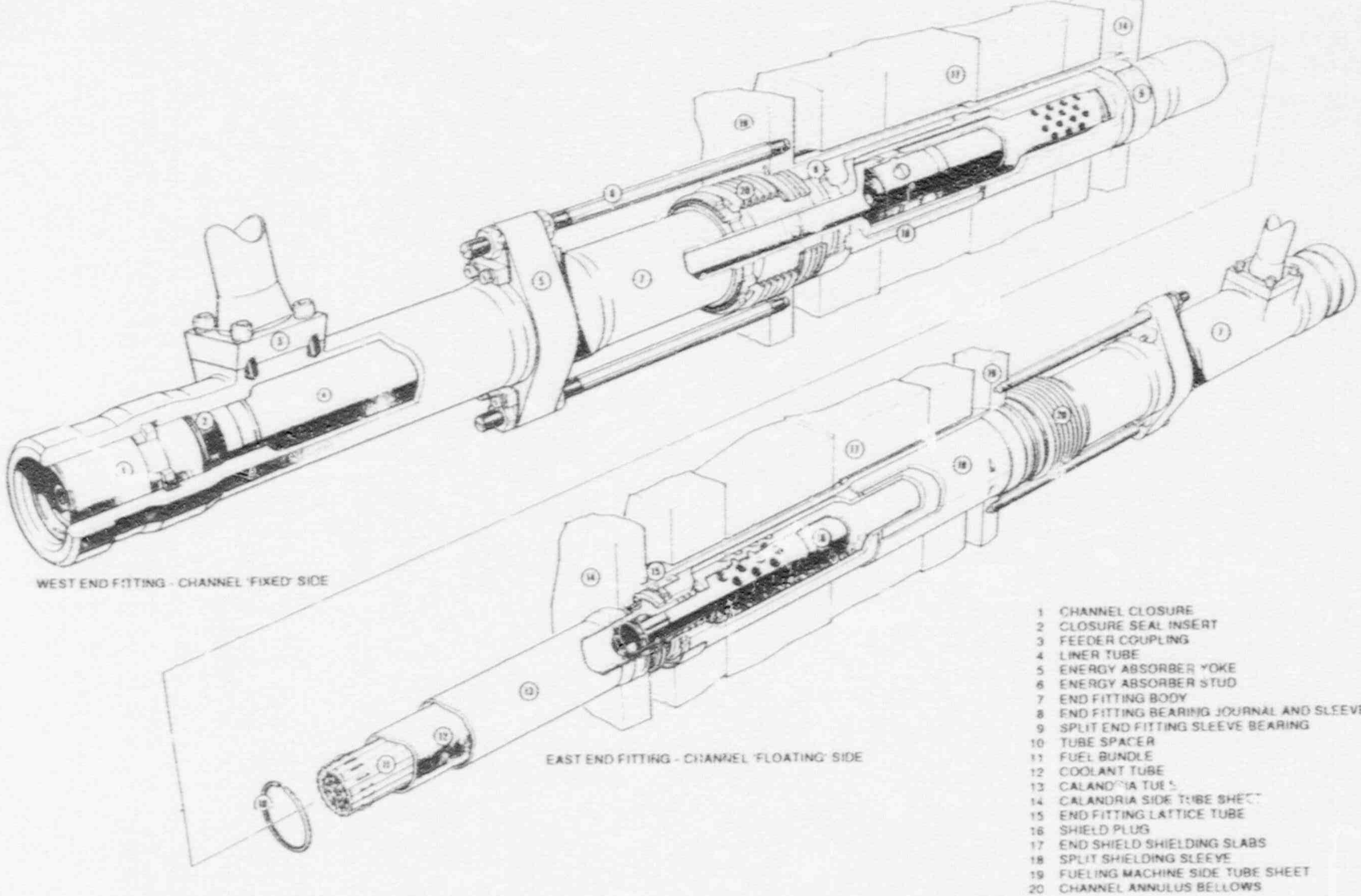


FIGURE 3-3 FUEL CHANNEL ASSEMBLY

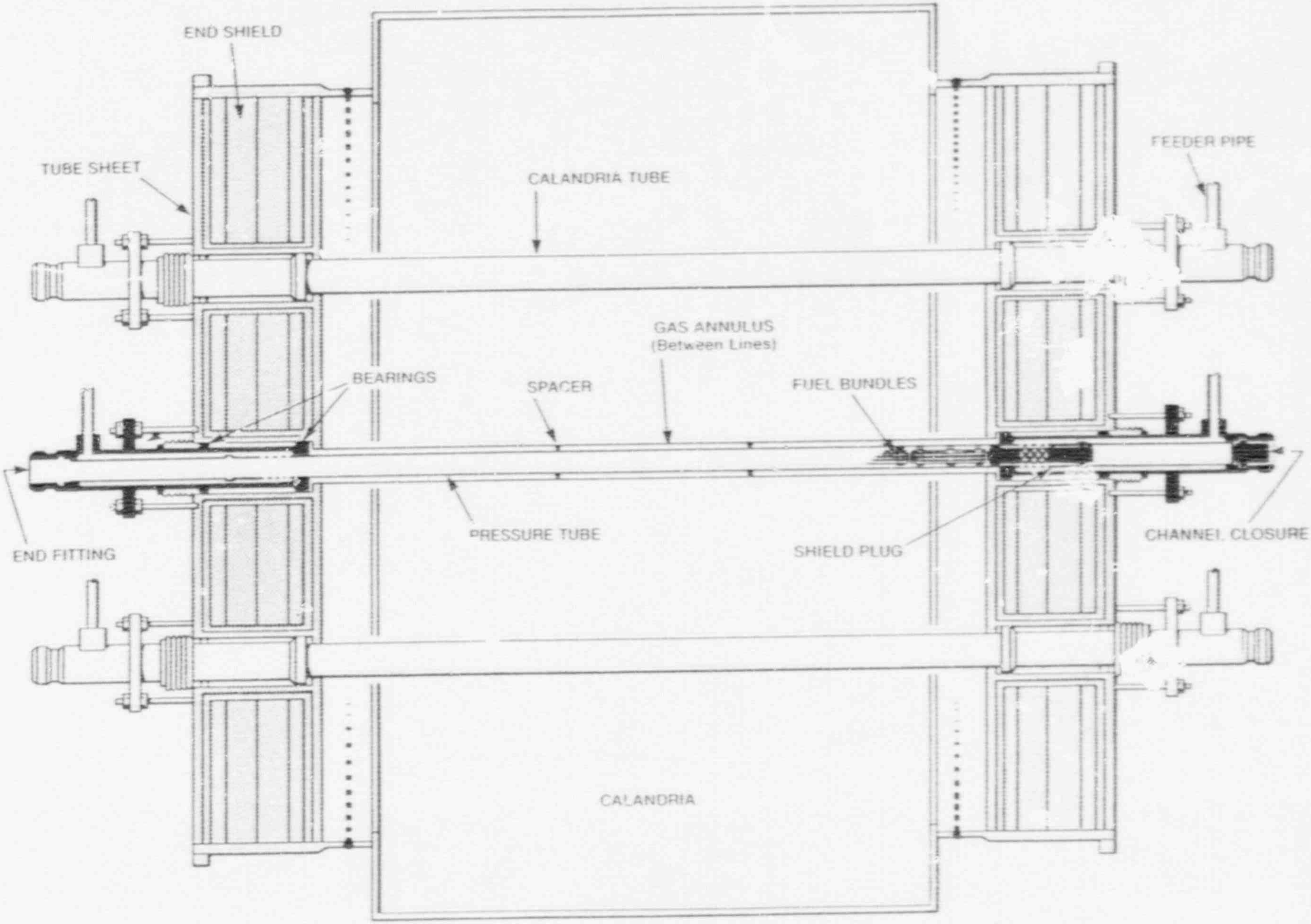


FIGURE 3-4 SIMPLIFIED DIAGRAM OF CANDU REACTOR

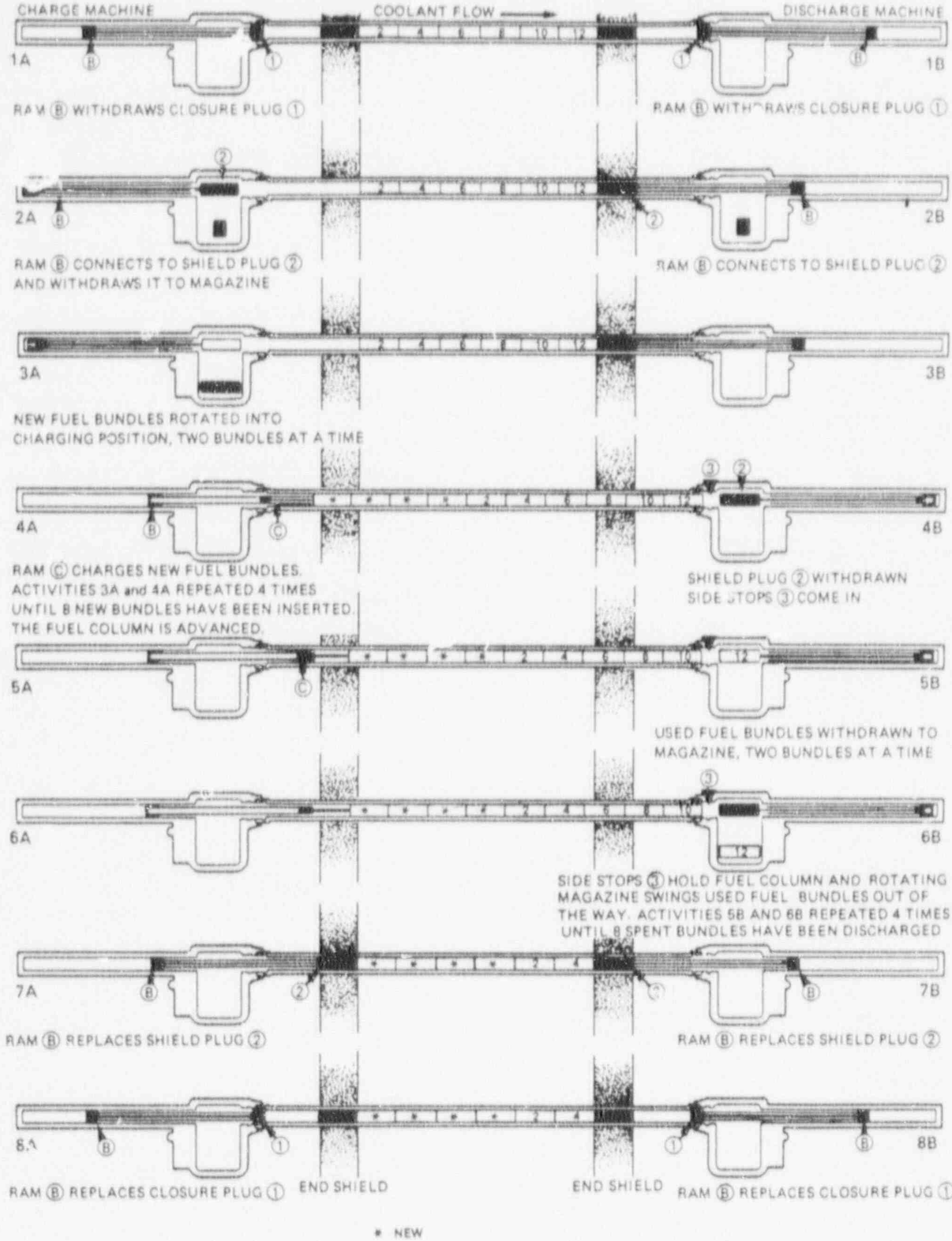


FIGURE 3-5 FAF 8-BUNDLE FUEL CHANGING SEQUENCE

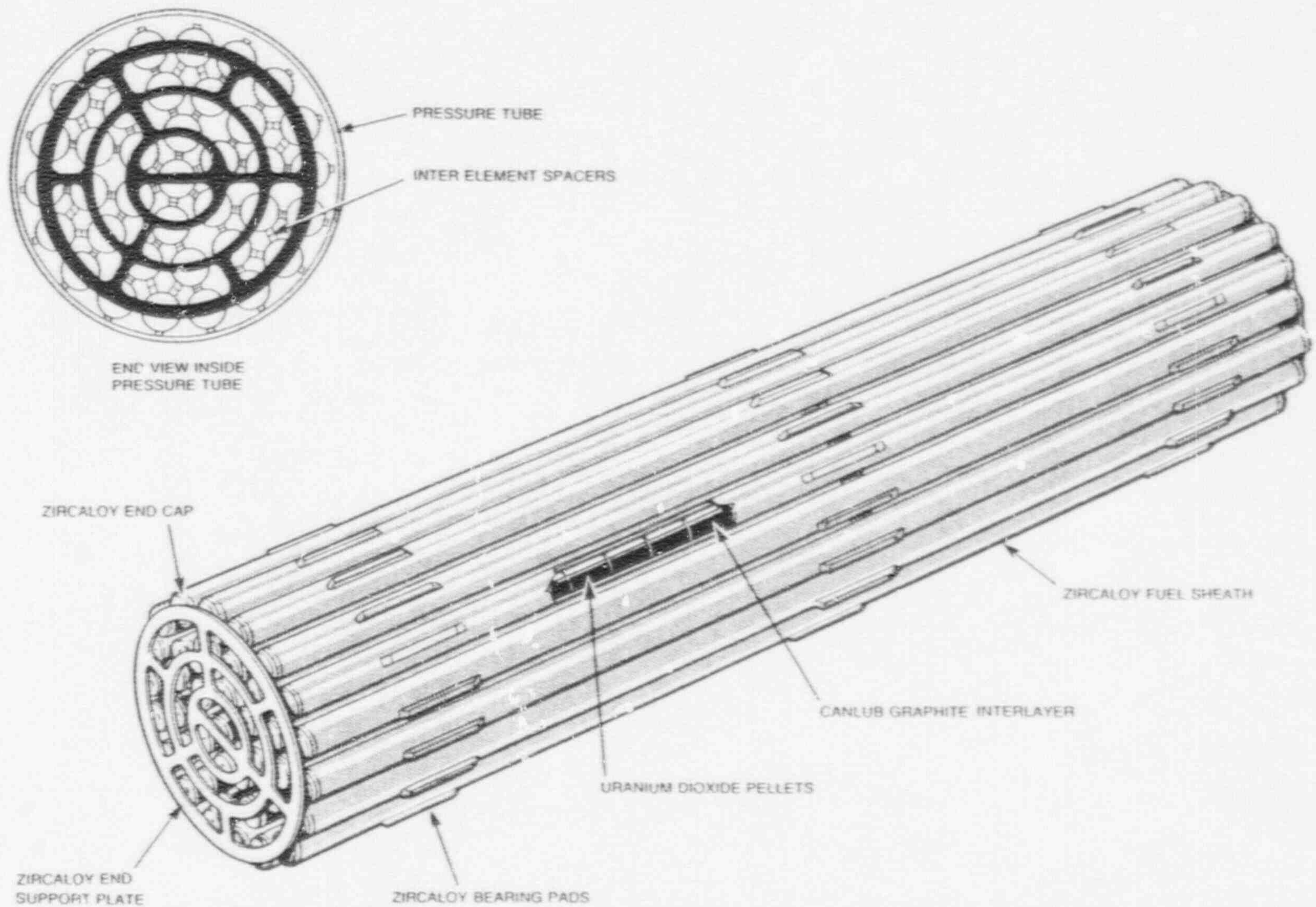


FIGURE 3-6 37 ELEMENT FUEL BUNDLE

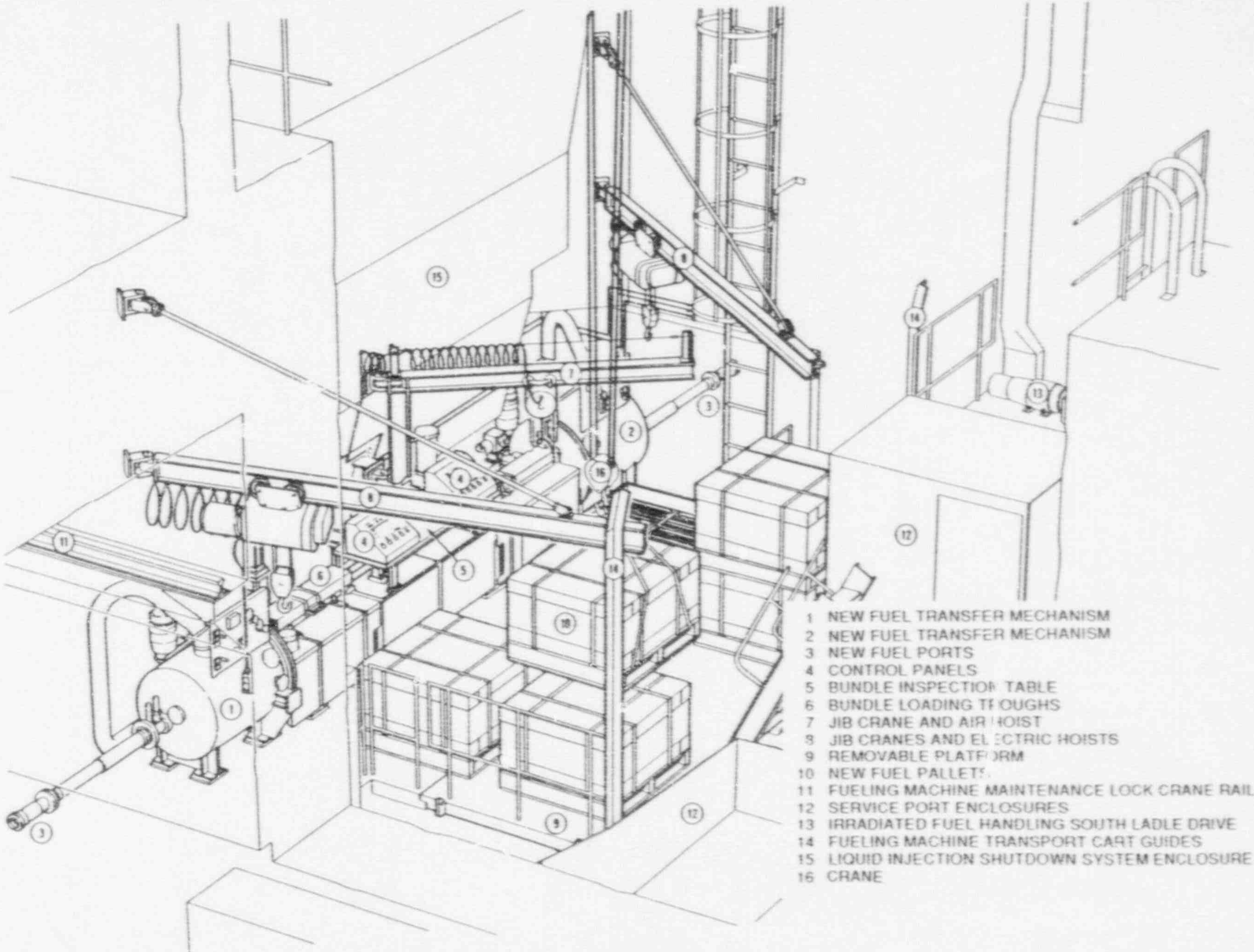


FIGURE 3-7 NEW FUEL ROOM EQUIPMENT

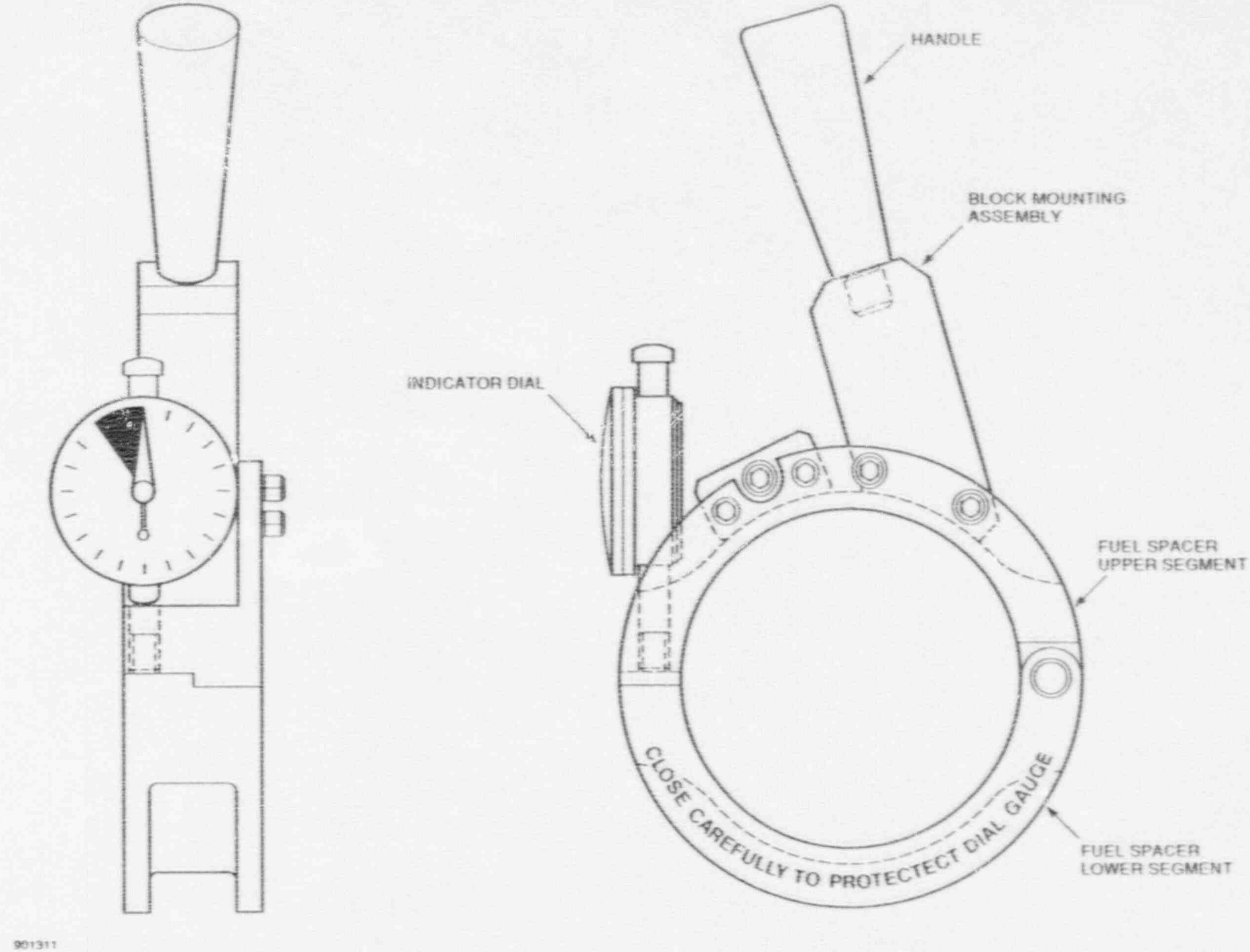


FIGURE 3-8 NEW FUEL BUNDLE SPACER INTERLOCK GAUGE

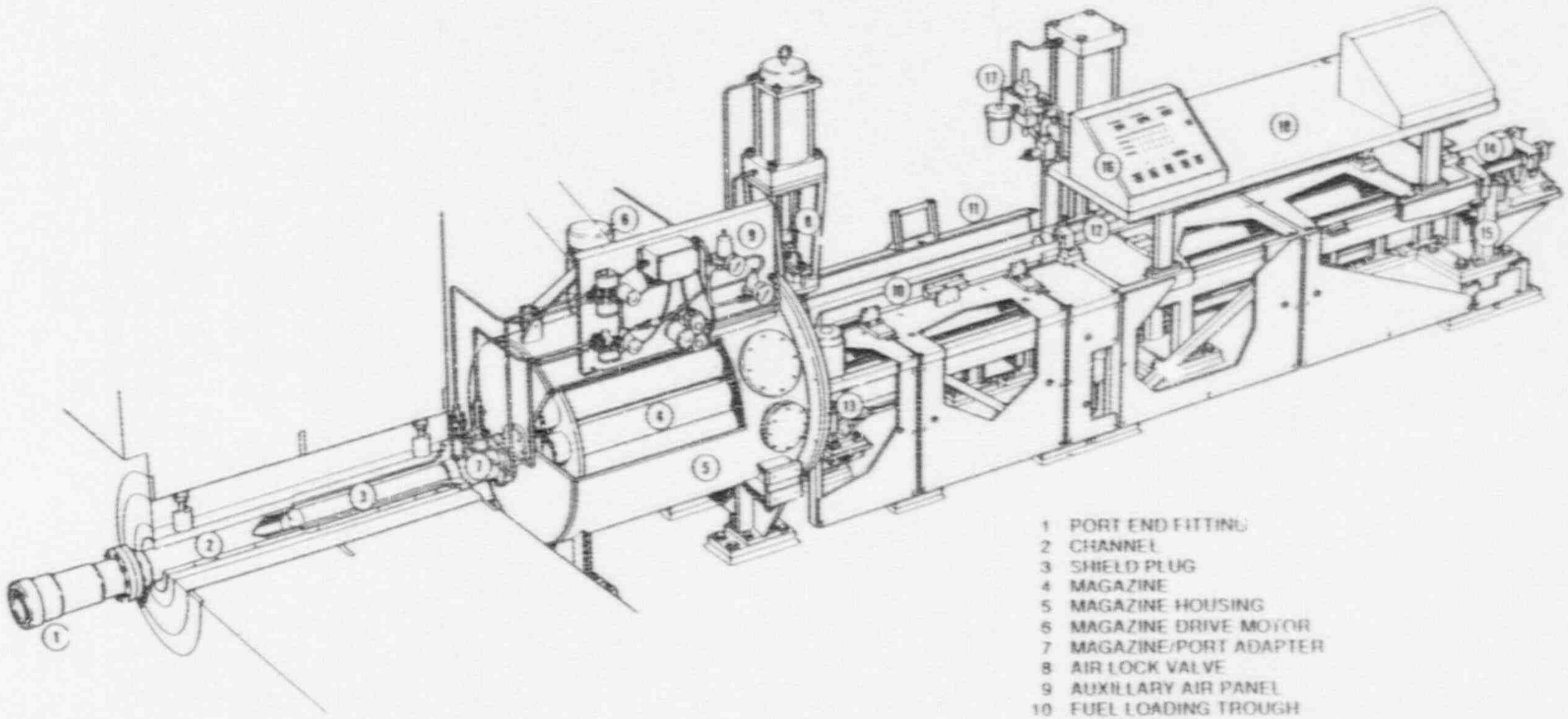


FIGURE 3-9 NEW FUEL TRANSFER MECHANISM

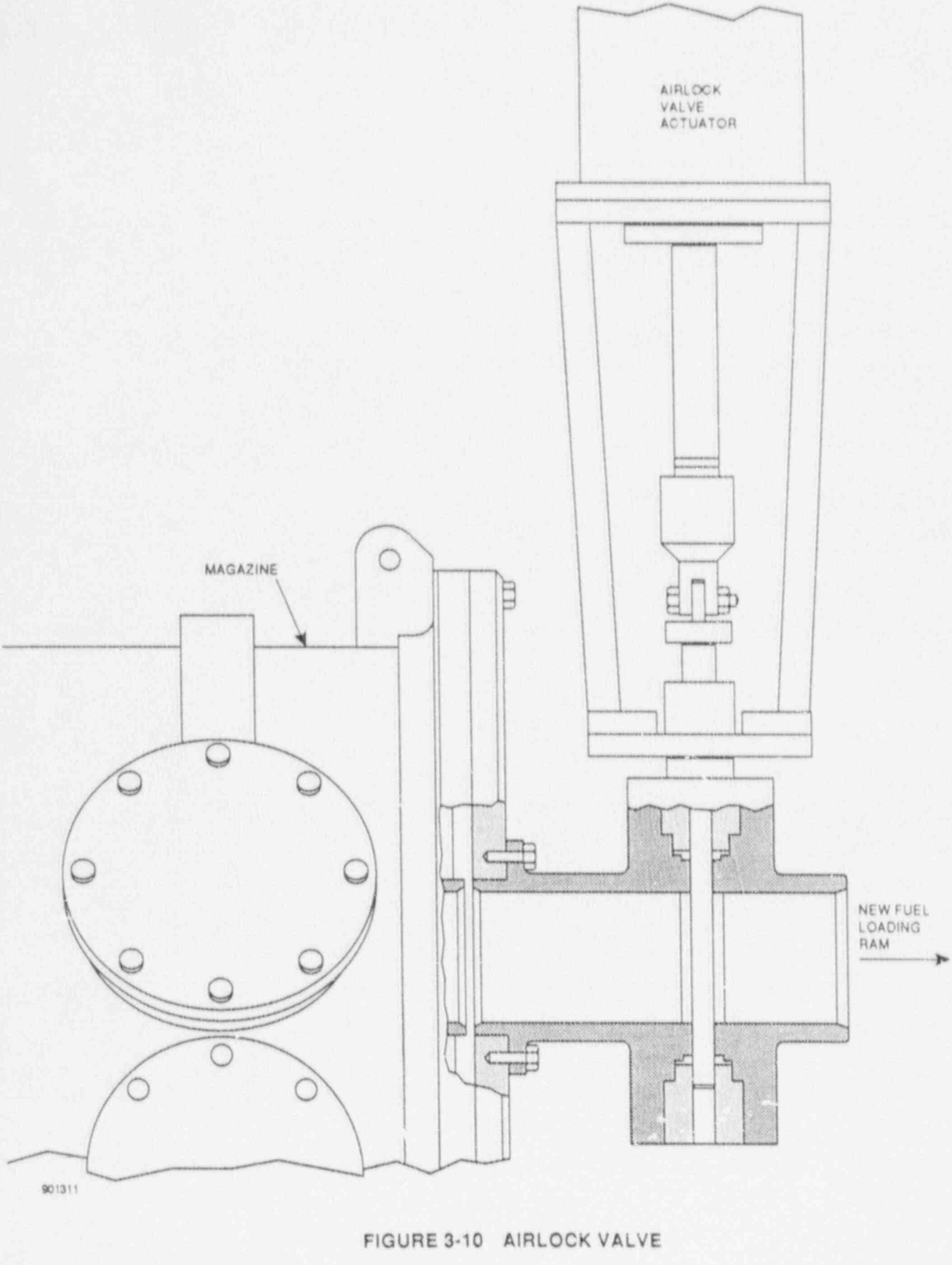


FIGURE 3-10 AIRLOCK VALVE

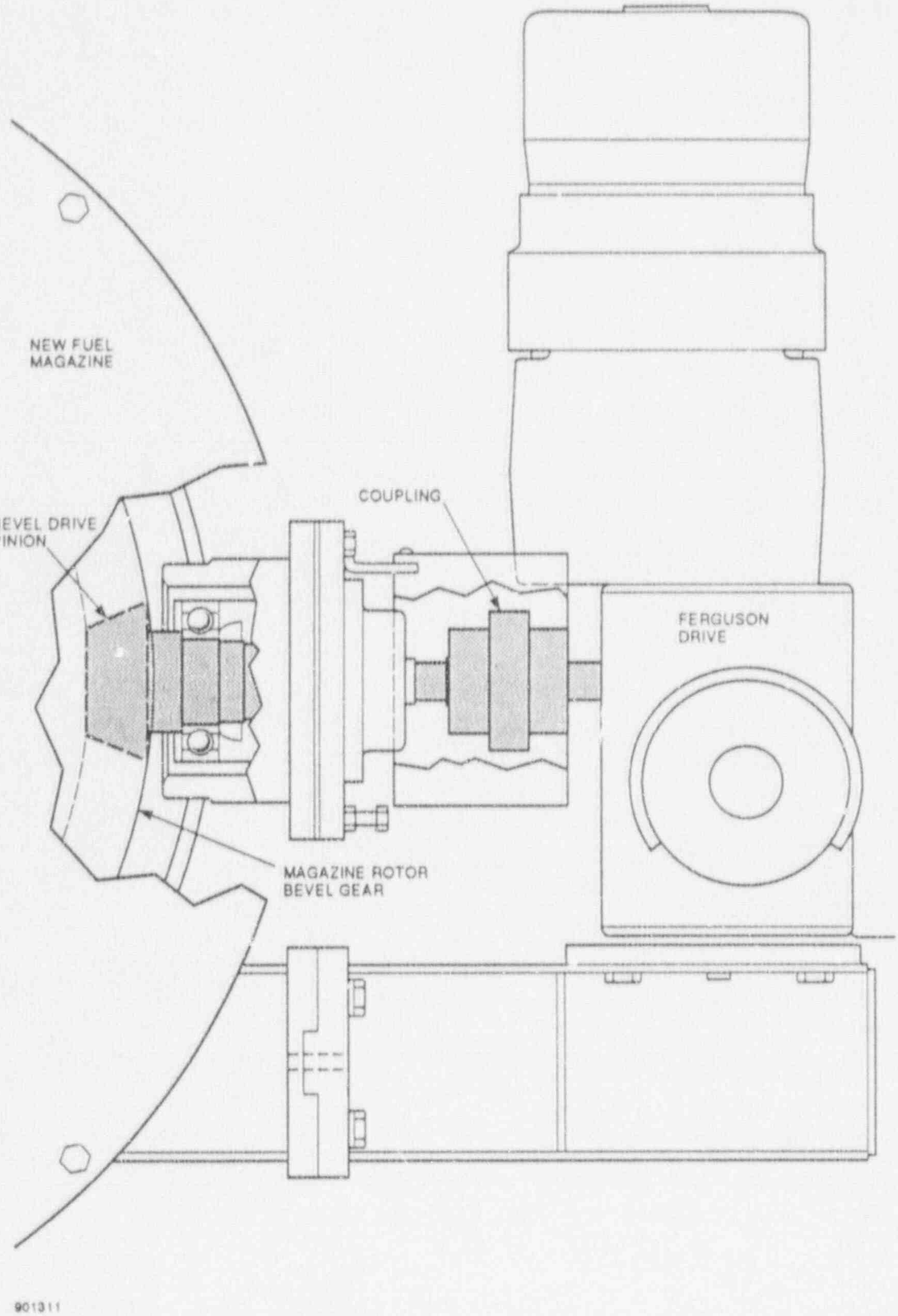


FIGURE 3-11 NEW FUEL MAGAZINE DRIVE

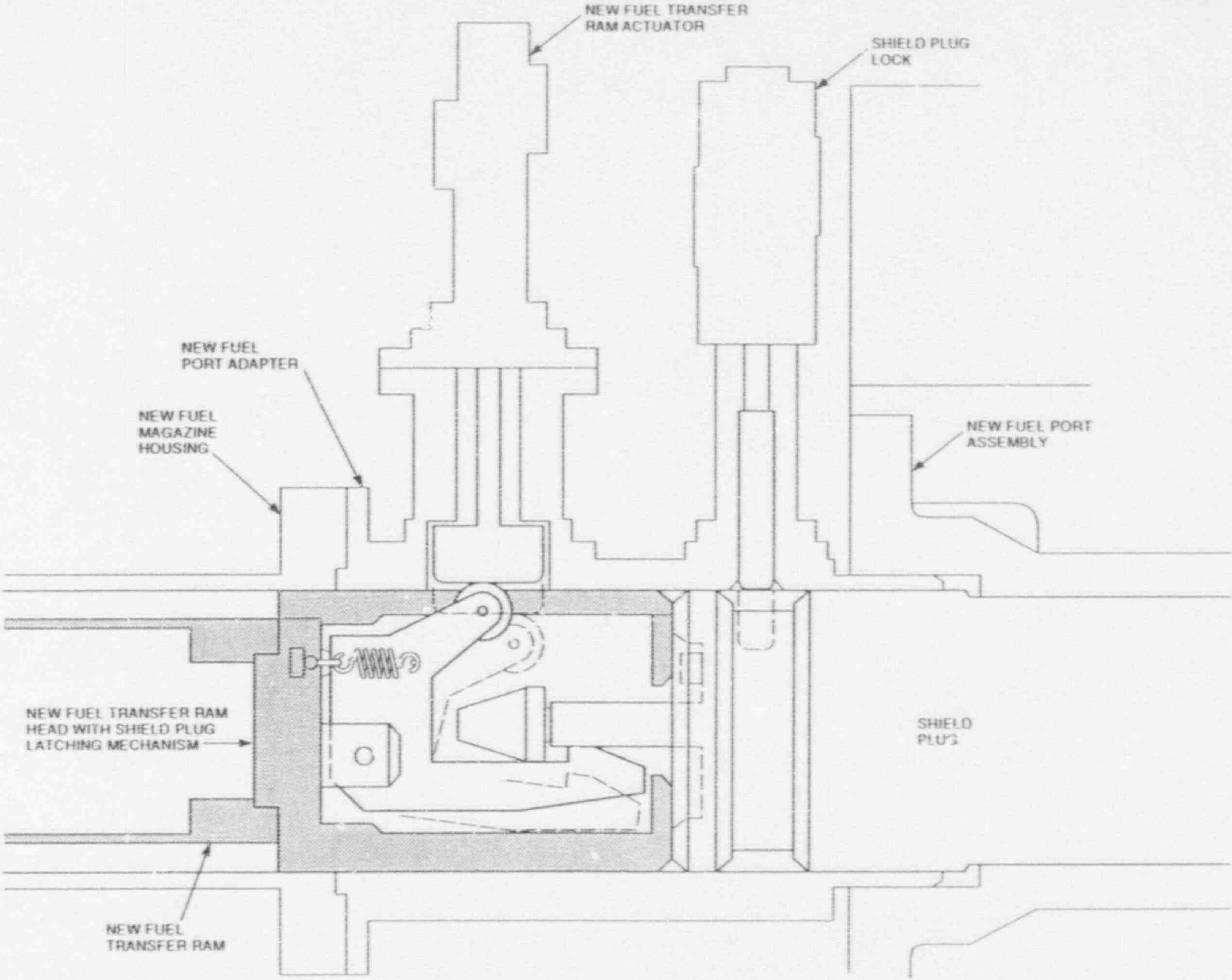


FIGURE 3-12 SHIELD PLUG IN NEW FUEL PORT

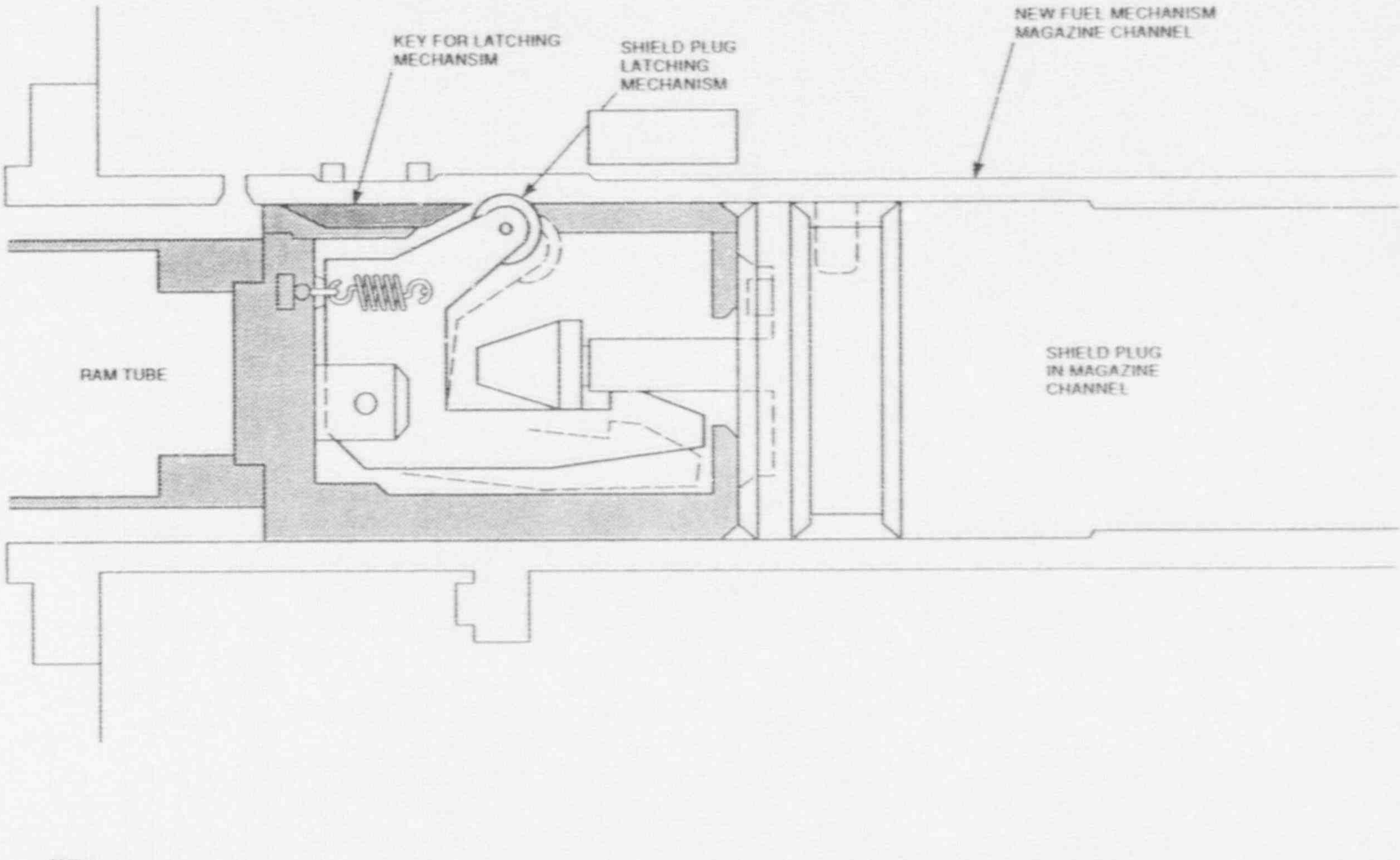


FIGURE 3-13 SHIELD PLUG IN NEW FUEL MECHANISM MAGAZINE

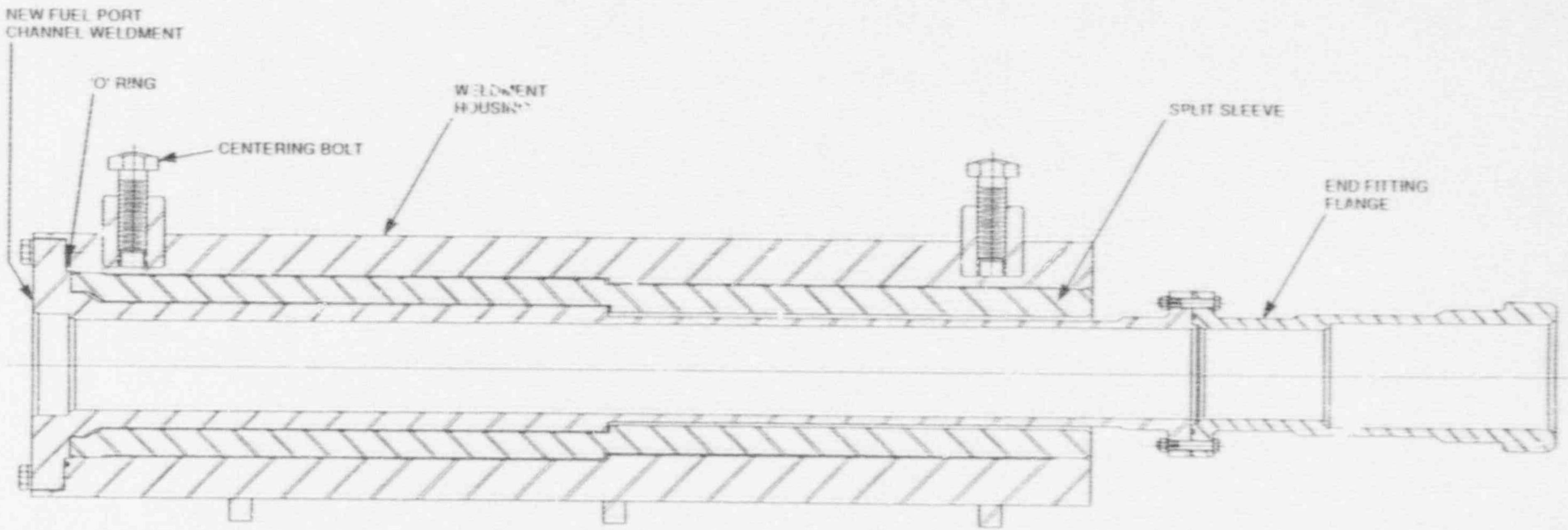


FIGURE 3-14 **NEW FUEL PORT ASSEMBLY**

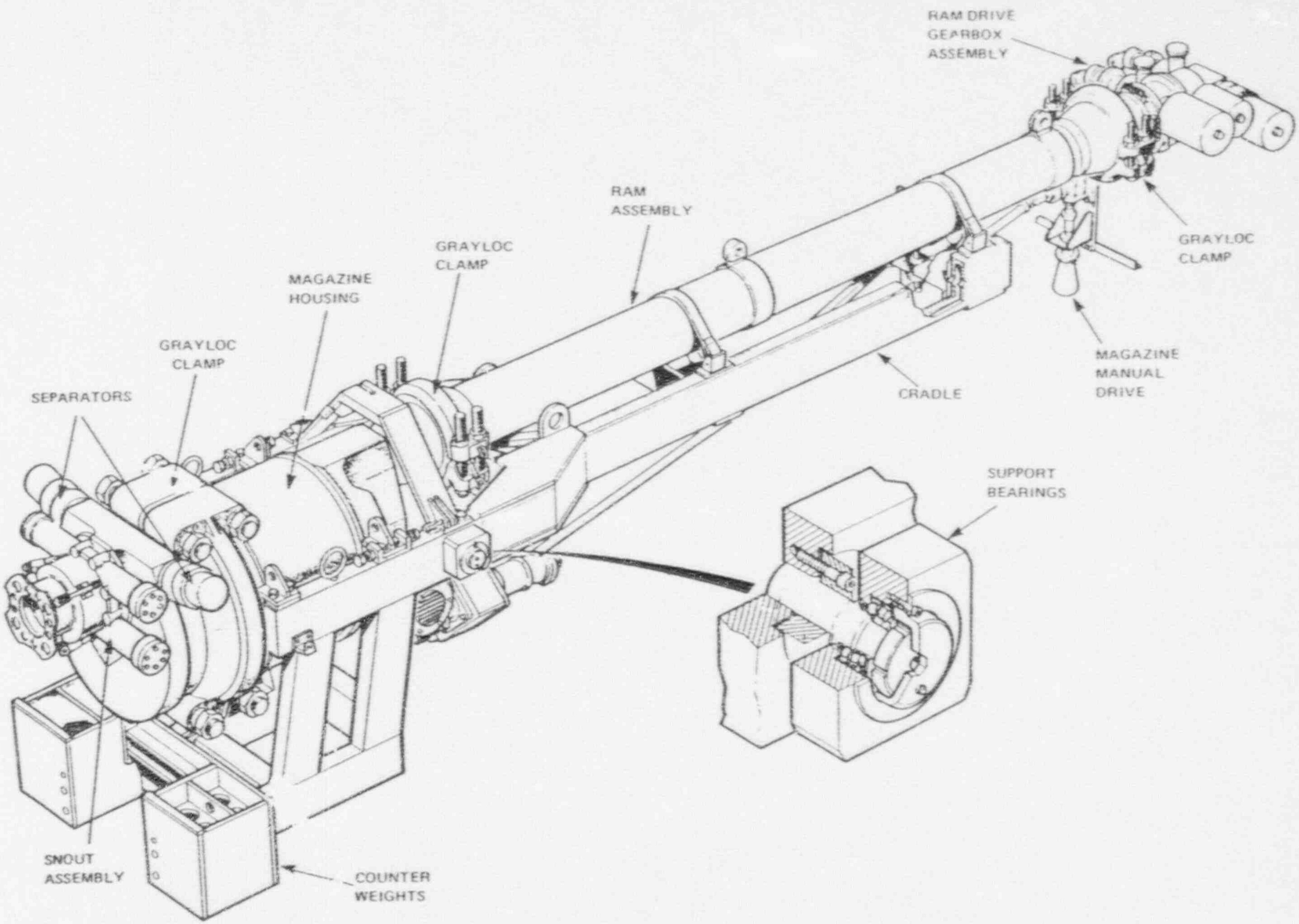


FIGURE 3-15 FUELING MACHINE HEAD AND SUPPORT CRADLE ASSEMBLY

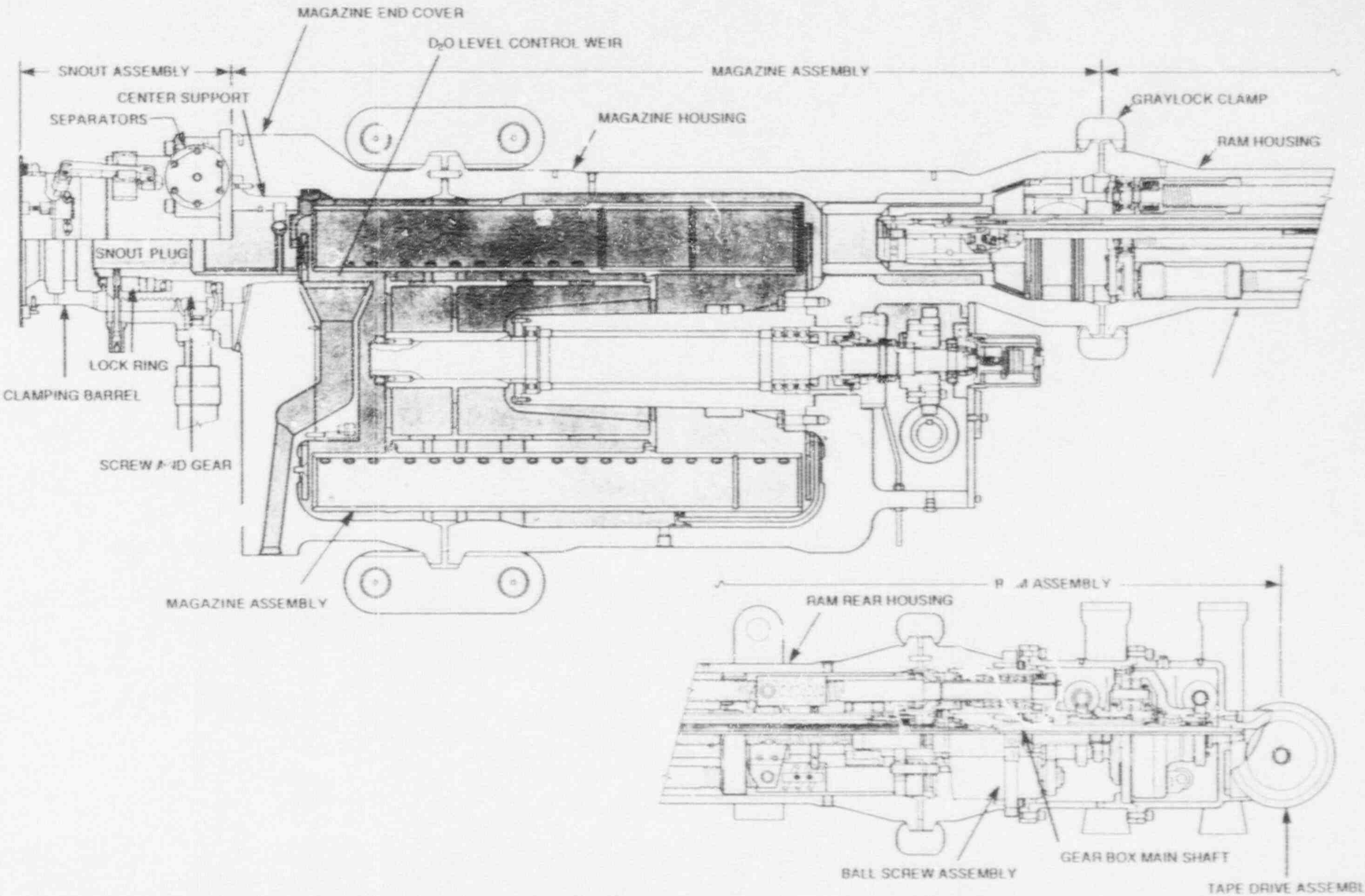
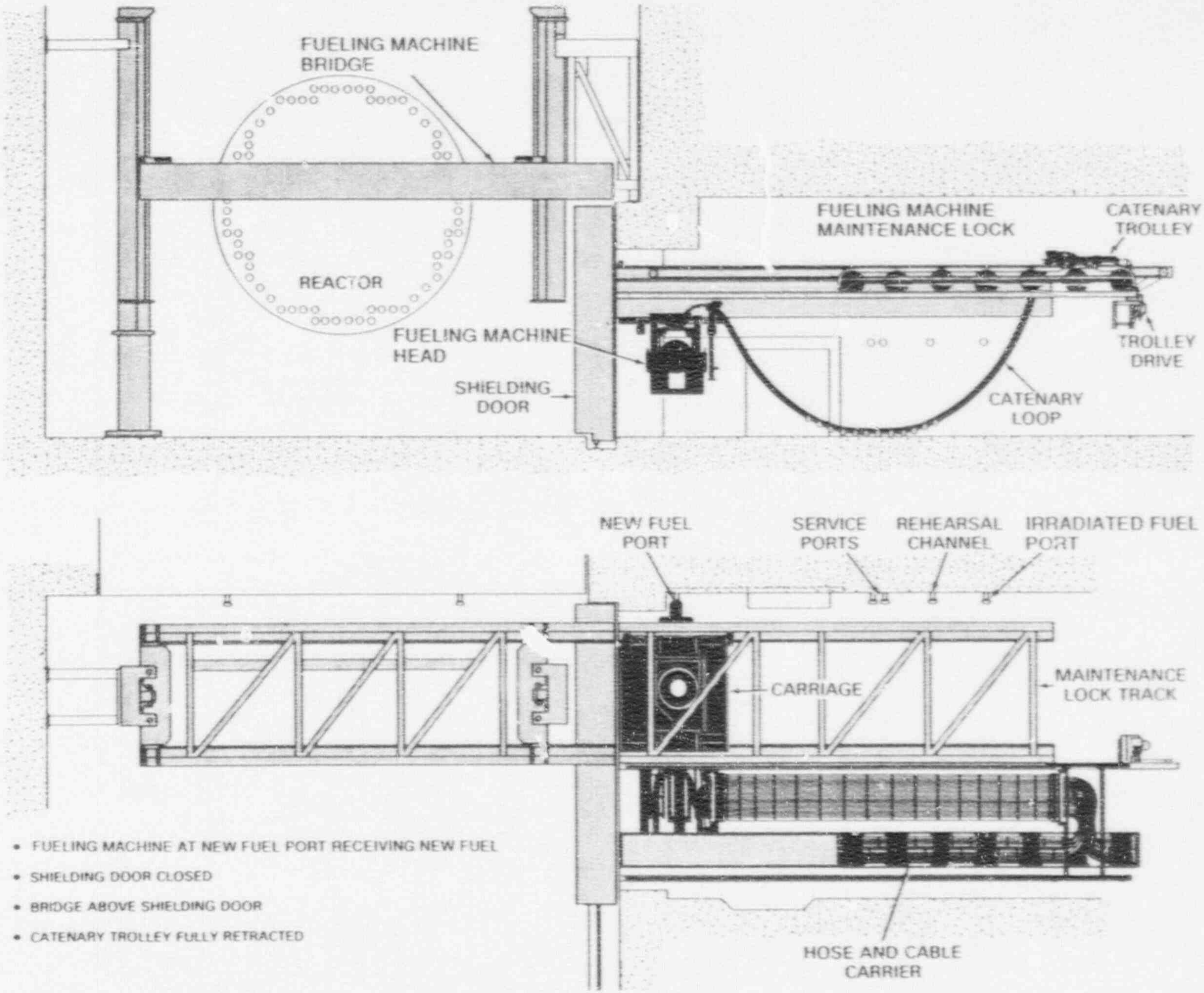


FIGURE 3-16 FUELING MACHINE HEAD (SECTIONAL VIEW)



- FUELING MACHINE AT NEW FUEL PORT RECEIVING NEW FUEL
- SHIELDING DOOR CLOSED
- BRIDGE ABOVE SHIELDING DOOR
- CATENARY TROLLEY FULLY RETRACTED

FIGURE 3-17 FUELING MACHINE AT NEW FUEL PORT

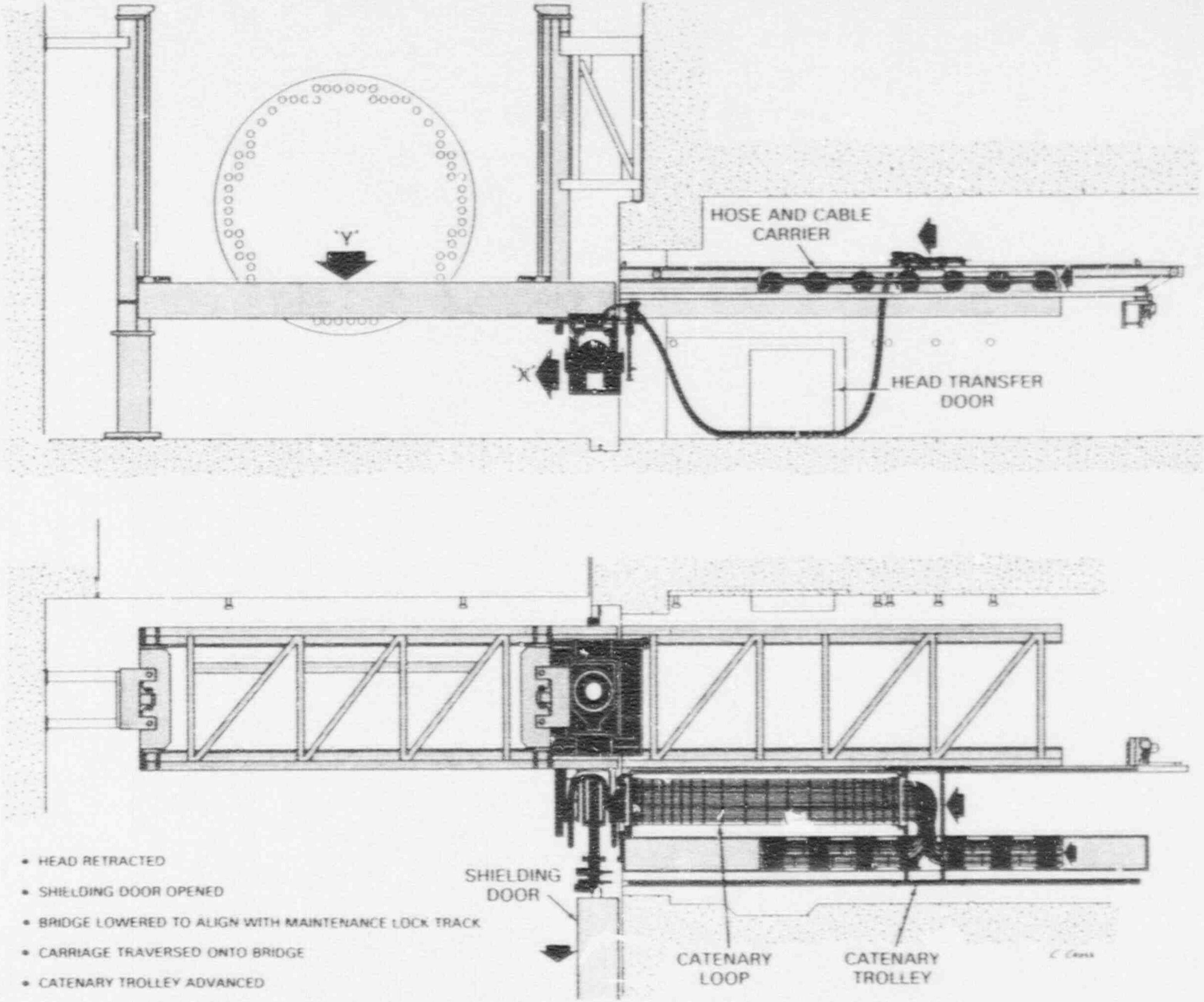
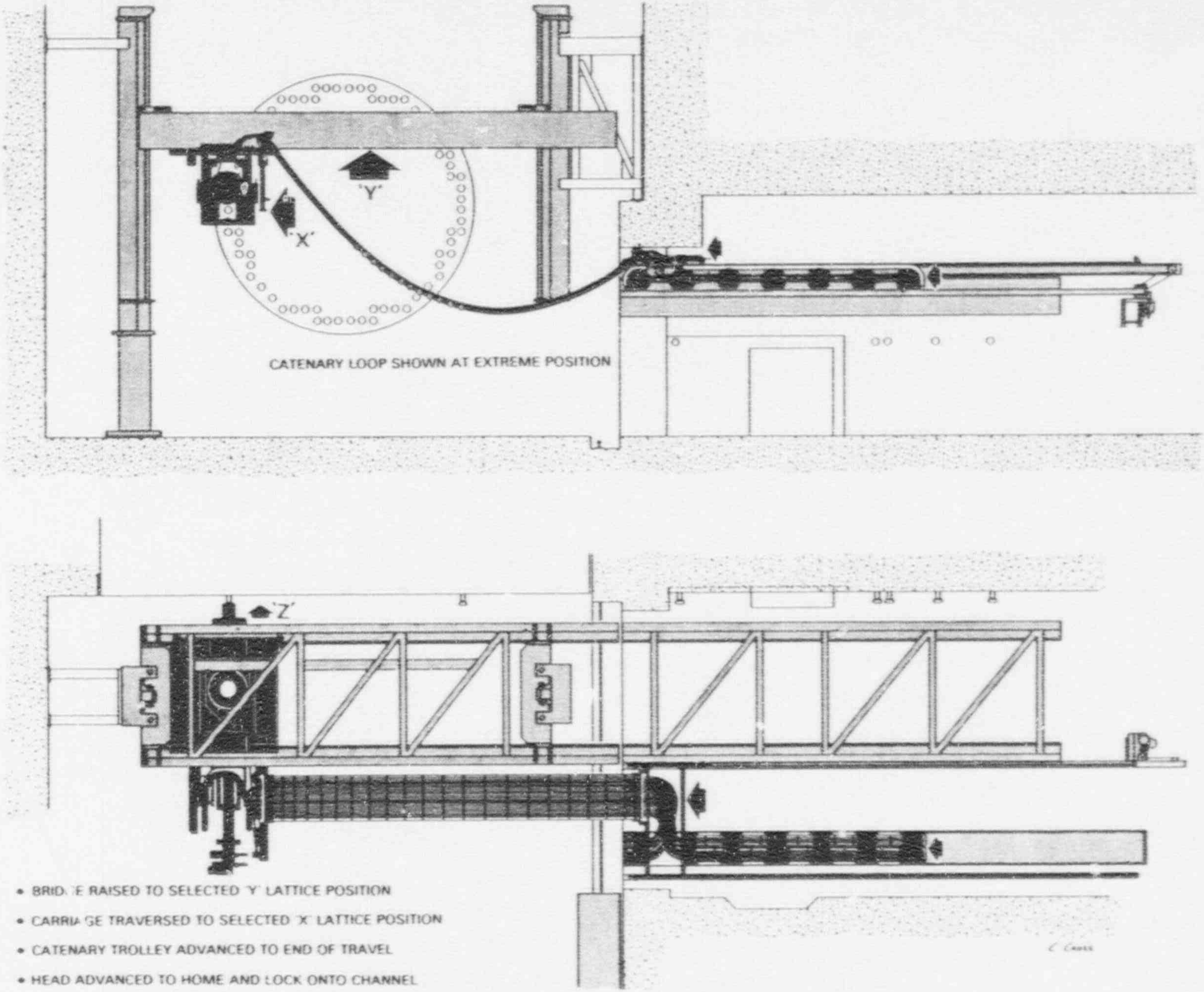


FIGURE 3-18 FUELING MACHINE TRAVERSING ONTO BRIDGE



- BRIDGE RAISED TO SELECTED 'Y' LATTICE POSITION
- CARRIAGE TRAVERSED TO SELECTED 'X' LATTICE POSITION
- CATENARY TROLLEY ADVANCED TO END OF TRAVEL
- HEAD ADVANCED TO HOME AND LOCK ONTO CHANNEL
- HEAD REMOVES CHANNEL CLOSURE AND SHIELD PLUG AND DISCHARGES NEW FUEL

FIGURE 3-19 FUELING MACHINE AT REACTOR FACE

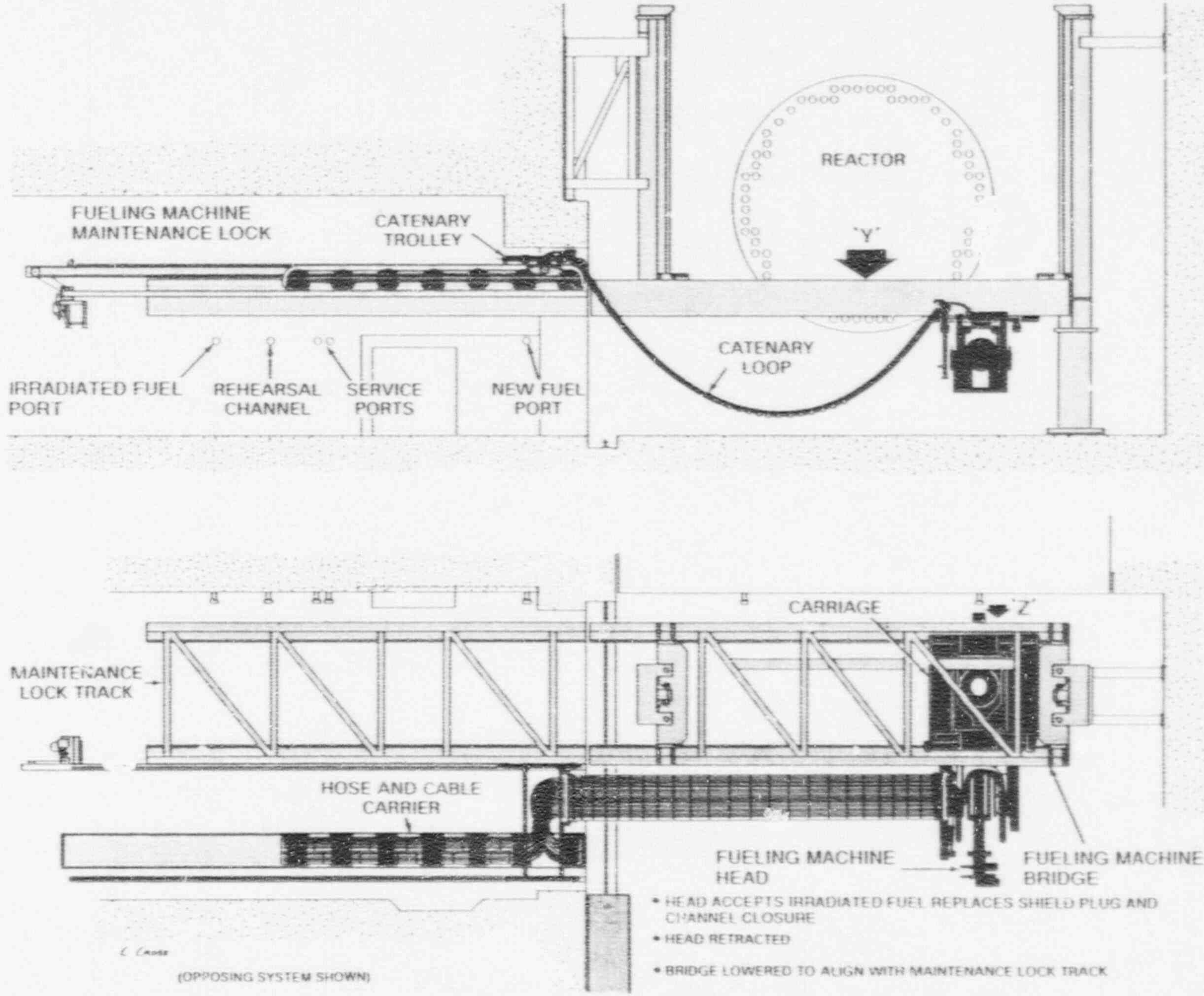


FIGURE 3-20 FUELING MACHINE LEAVING REACTOR FACE

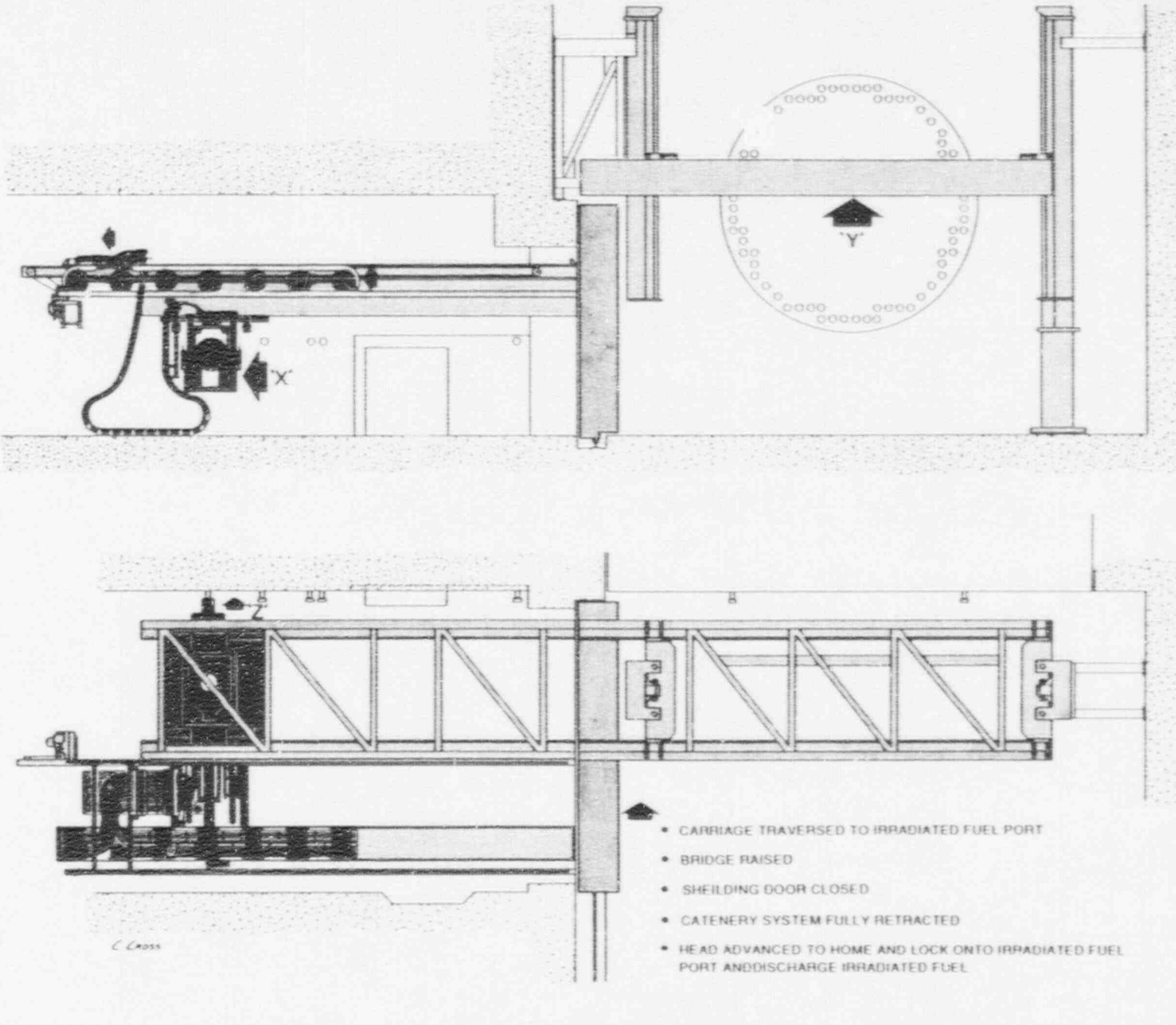
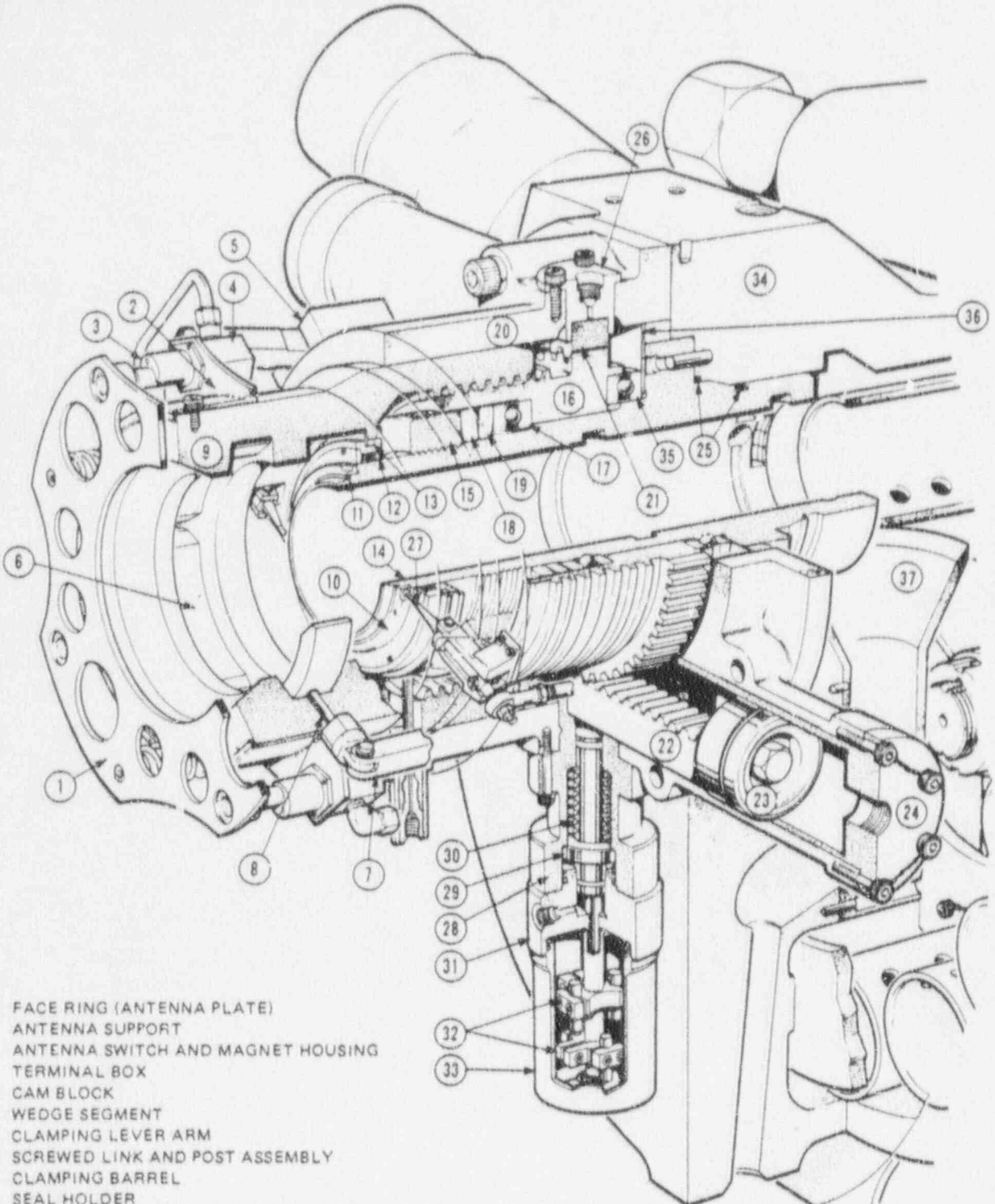


FIGURE 3-21 FUELING MACHINE AT IRRADIATED FUEL PORT



1 FACE RING (ANTENNA PLATE)
2 ANTENNA SUPPORT
3 ANTENNA SWITCH AND MAGNET HOUSING
4 TERMINAL BOX
5 CAM BLOCK
6 WEDGE SEGMENT
7 CLAMPING LEVER ARM
8 SCREWED LINK AND POST ASSEMBLY
9 CLAMPING BARREL
10 SEAL HOLDER
11 HYDRODYNAMIC STATIC SEAL
12 SEALING RING
13 'O' RING
14 CENTRE SUPPORT
15 LOCK RING
16 SCREW AND GEAR
17 FRONT THRUST BEARING
18 BELEVILLE SPRING WASHER
19 SPACER
20 OUTER SUPPORT
21 RACK-UPPER
22 RACK-LOWER
23 PISTON
24 CYLINDER
25 'O' RING
26 GUIDE PLUG
27 SNOUT PROBES
28 EMERGENCY LOCK PISTON HOUSING
29 EMERGENCY LOCK PISTON
30 EMERGENCY LOCK SPRING
31 EMERGENCY LOCK COVER (CYLINDER)
32 REED SWITCHES
33 EMERGENCY LOCK COVER
34 MAGAZINE END COVER
35 REAR THRUST BEARING
36 SPLIT SPACER
37 WEIR

FIGURE 3-22 SNOUT ASSEMBLY

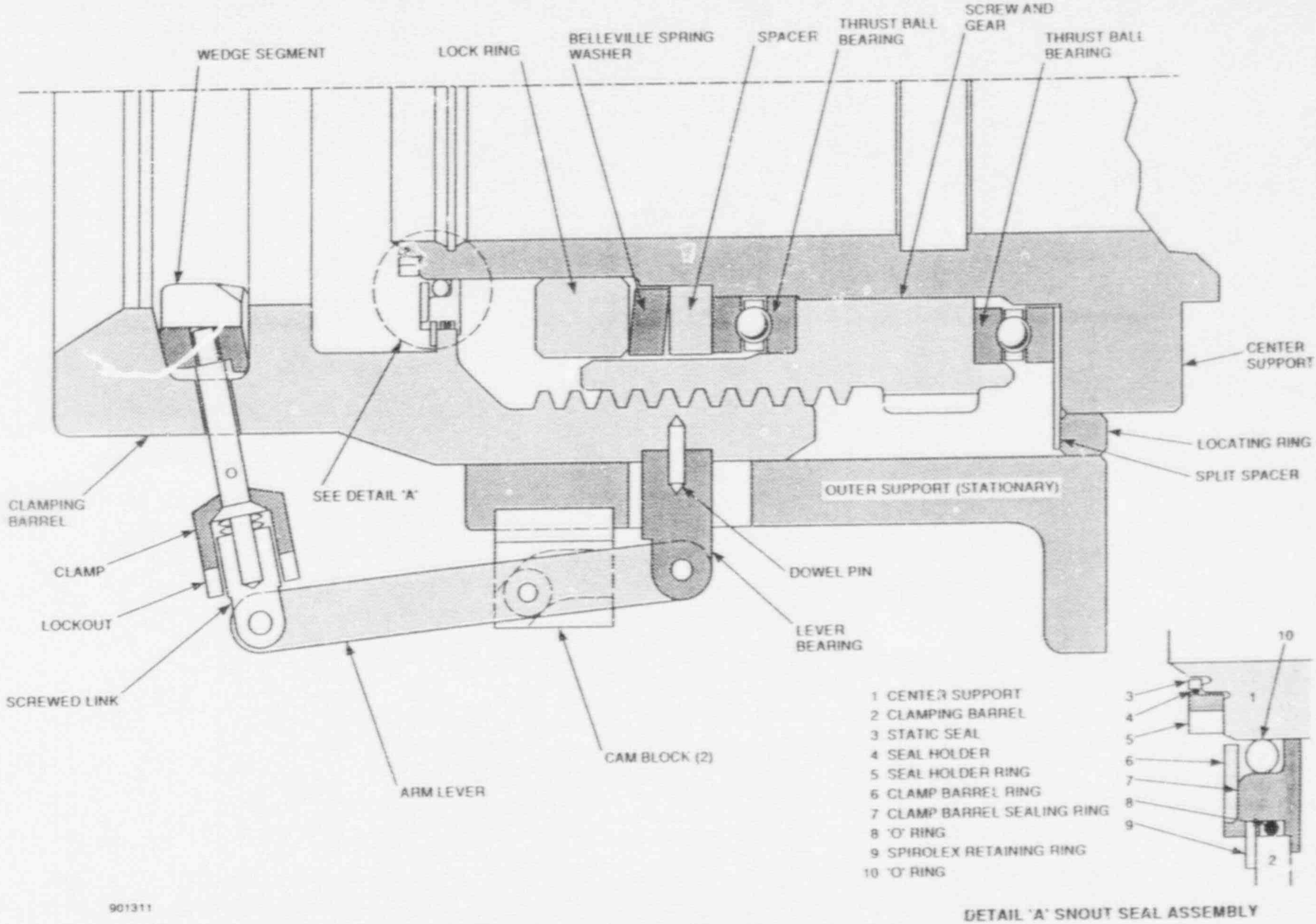
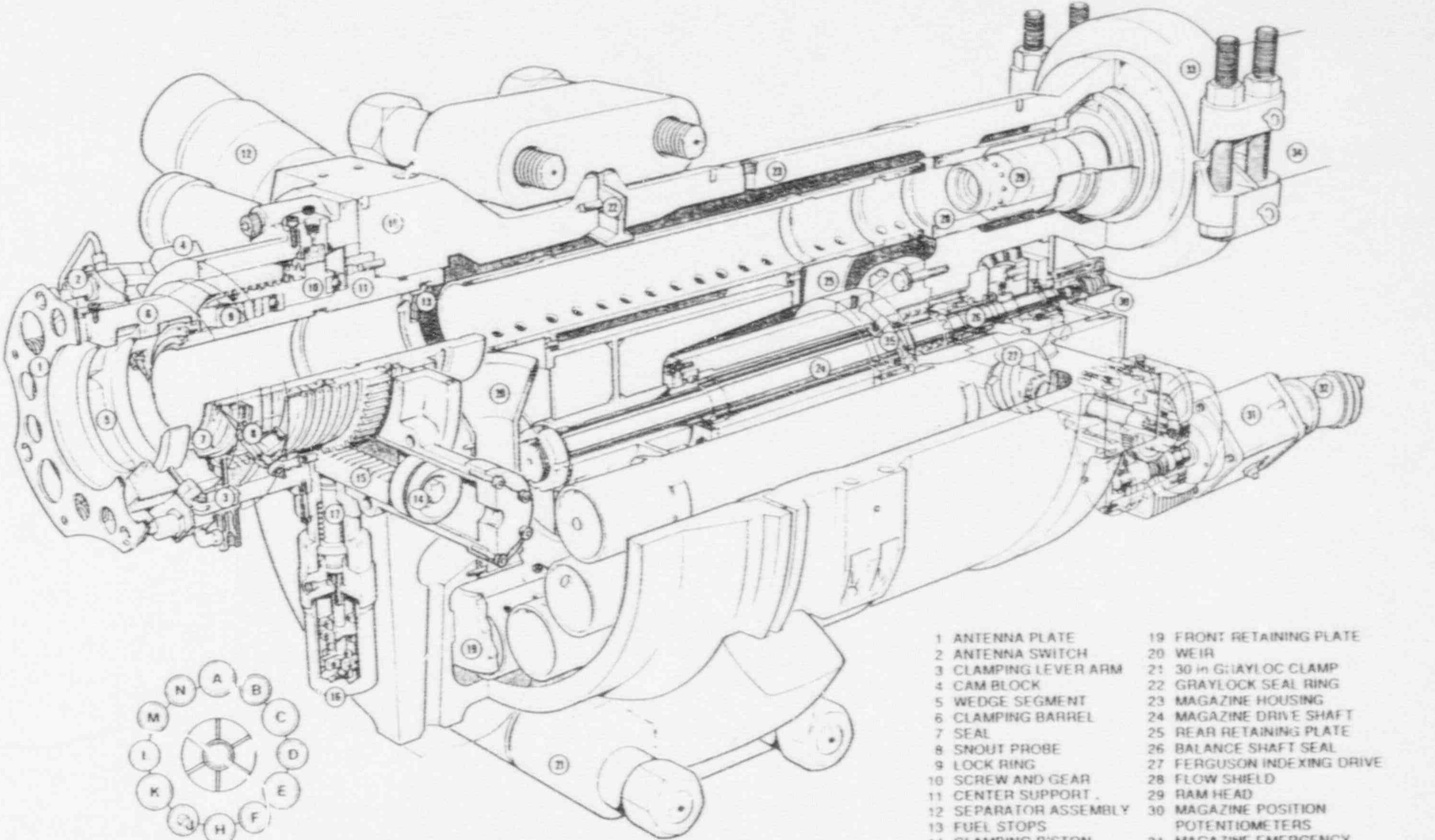


FIGURE 3-23 FUELING MACHINE HEAD SNOUT ASSEMBLY (SECTIONAL VIEW)



A SNOUT PLUG
B FUEL
C CHANNEL CLOSURE
D FUEL
E GUIDE SLEEVE AND INSERTION TOOL
F FUEL
H SHIELD PLUG
J ADAPTER
K CHANNEL CLOSURE (SPARE)
L FUEL
M SHIELD PLUG (SPARE)
N FUEL

VIEW FROM THE REAR

1 ANTENNA PLATE
2 ANTENNA SWITCH
3 CLAMPING LEVER ARM
4 CAM BLOCK
5 WEDGE SEGMENT
6 CLAMPING BARREL
7 SEAL
8 SNOUT PROBE
9 LOCK RING
10 SCREW AND GEAR
11 CENTER SUPPORT
12 SEPARATOR ASSEMBLY
13 FUEL STOPS
14 CLAMPING PISTON
15 RACK
16 SNOUT EMERGENCY LOCK ASSEMBLY
17 LOCK PISTON
18 MAGAZINE END COVER
19 FRONT RETAINING PLATE
20 WEIR
21 30 in GRAYLOC CLAMP
22 GRAYLOCK SEAL RING
23 MAGAZINE HOUSING
24 MAGAZINE DRIVE SHAFT
25 REAR RETAINING PLATE
26 BALANCE SHAFT SEAL
27 FERGUSON INDEXING DRIVE
28 FLOW SHIELD
29 RAM HEAD
30 MAGAZINE POSITION POTENTIOMETERS
31 MAGAZINE EMERGENCY DRIVE GEARBOX
32 MAGAZINE DRIVE MOTOR
33 10 in GRAYLOC CLAMP
34 RAM HOUSING
35 EDUCTOR

FIGURE 3-24 MAGAZINE ASSEMBLY FUELING MACHINE HEAD

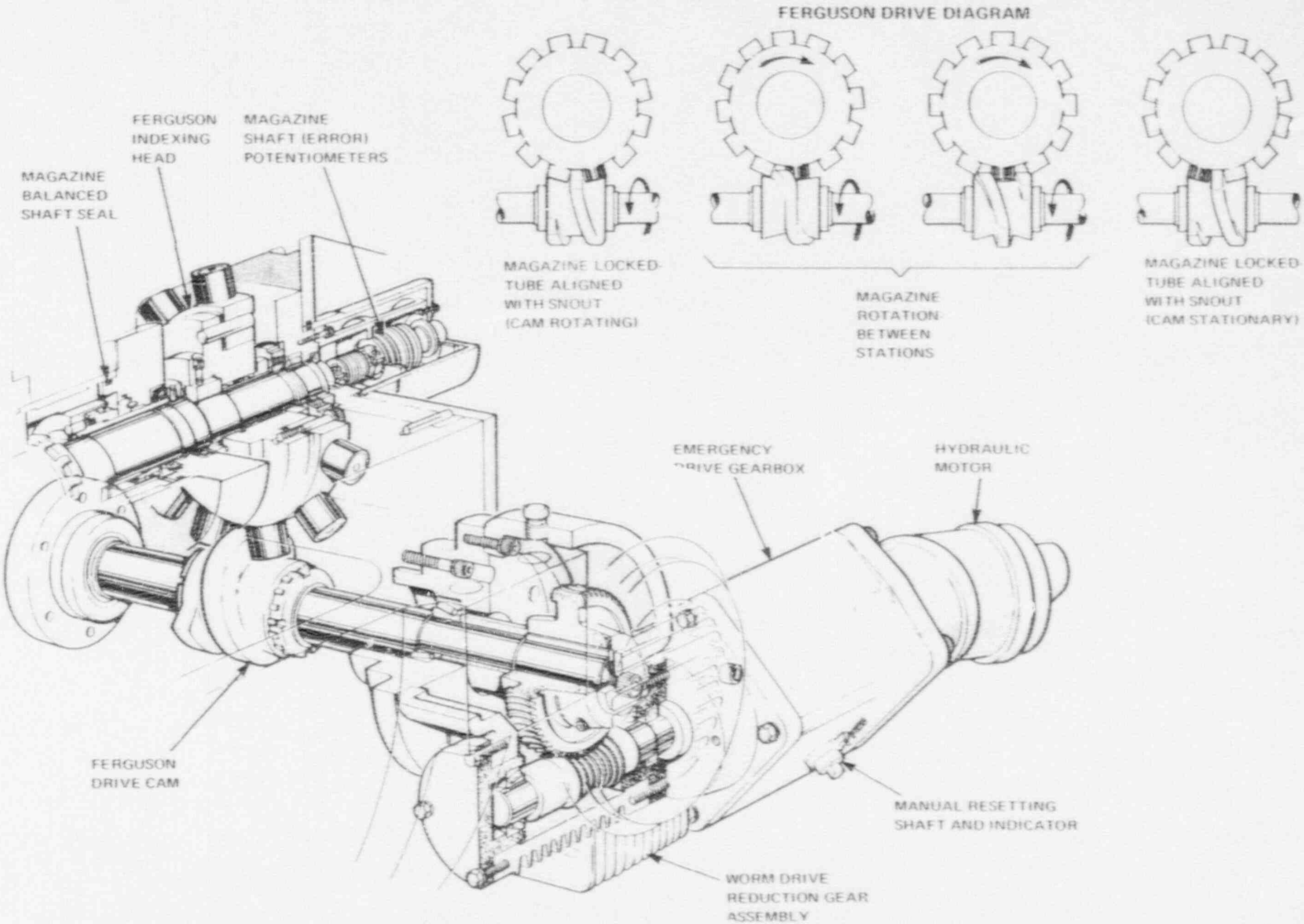


FIGURE 3-25 MAGAZINE DRIVE SYSTEM

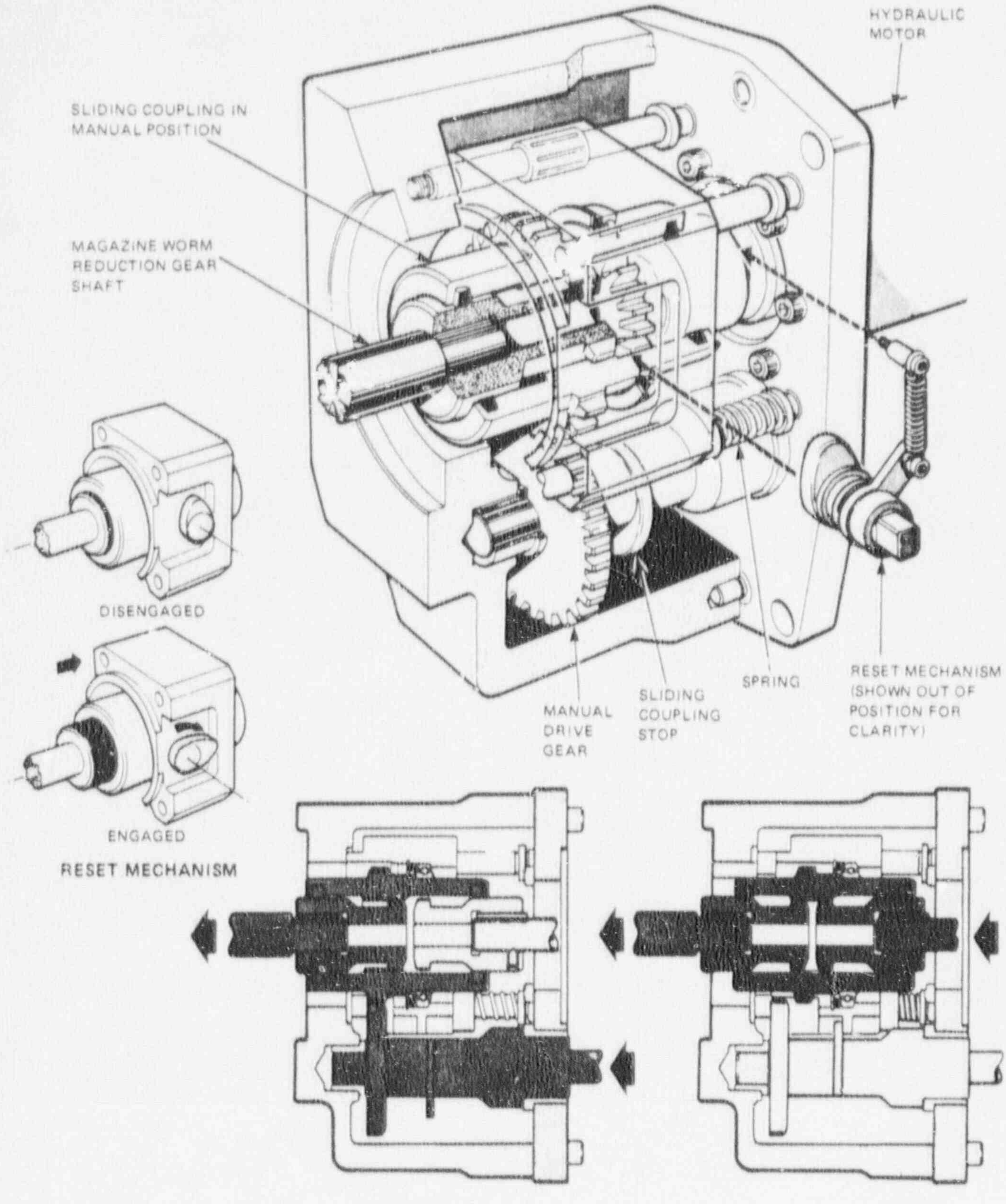
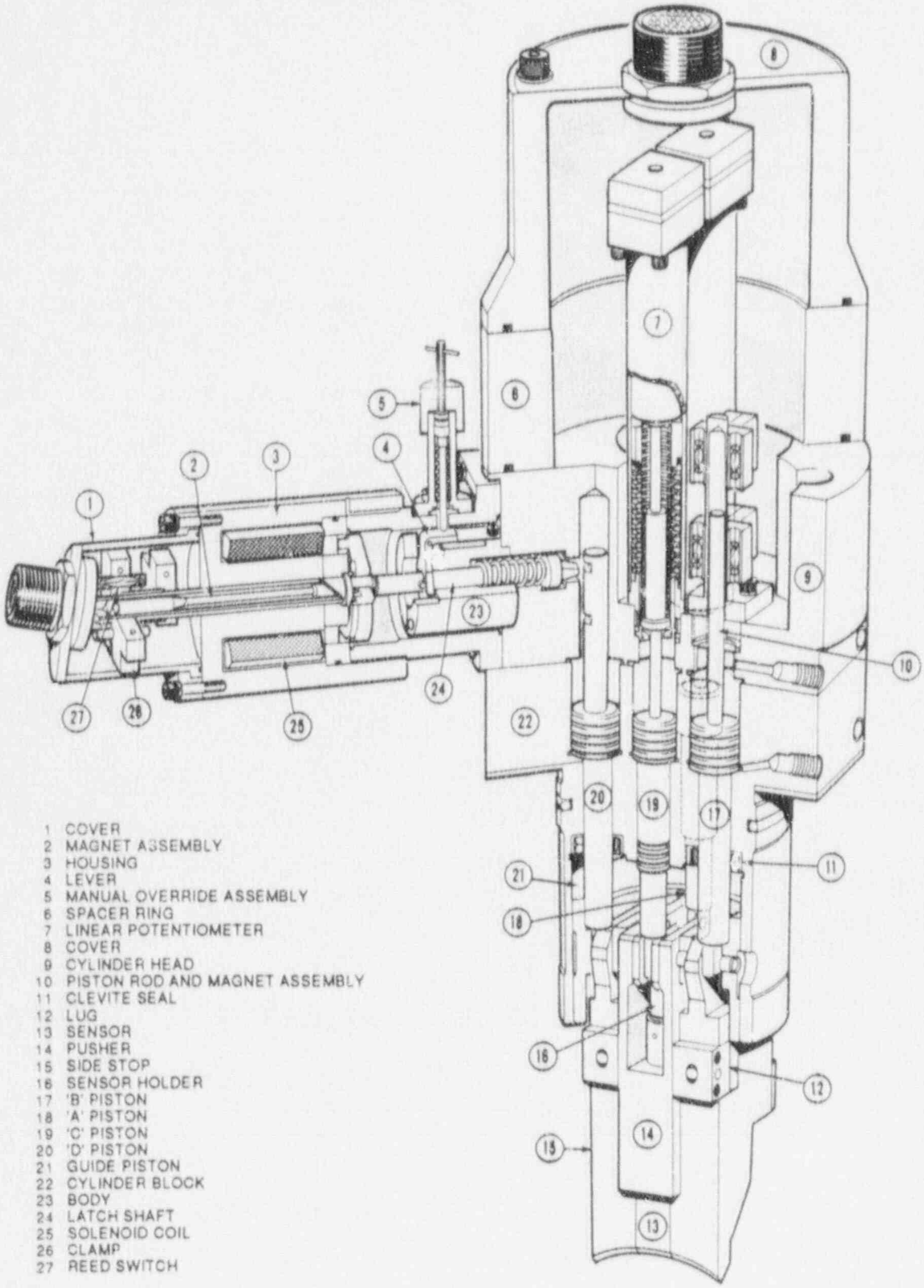


FIGURE 3-26 MAGAZINE EMERGENCY DRIVE GEARBOX



1 COVER
2 MAGNET ASSEMBLY
3 HOUSING
4 LEVER
5 MANUAL OVERRIDE ASSEMBLY
6 SPACER RING
7 LINEAR POTENTIOMETER
8 COVER
9 CYLINDER HEAD
10 PISTON ROD AND MAGNET ASSEMBLY
11 CLEVITE SEAL
12 LUG
13 SENSOR
14 PUSHER
15 SIDE STOP
16 SENSOR HOLDER
17 'B' PISTON
18 'A' PISTON
19 'C' PISTON
20 'D' PISTON
21 GUIDE PISTON
22 CYLINDER BLOCK
23 BODY
24 LATCH SHAFT
25 SOLENOID COIL
26 CLAMP
27 REED SWITCH

FIGURE 3-27 FUELING MACHINE SEPARATOR

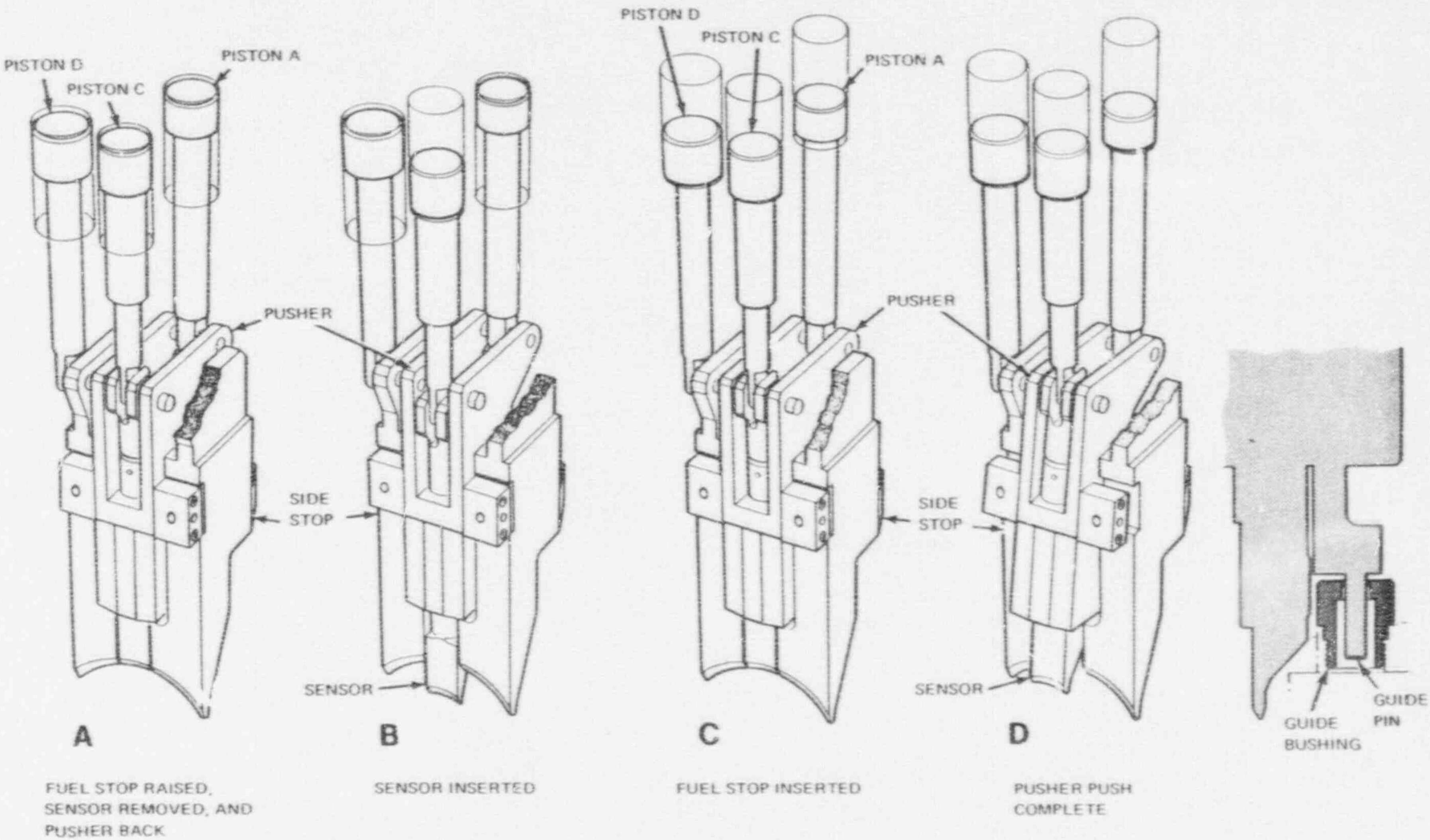


FIGURE 3-28 OPERATION OF SIDE STOP, SENSOR AND PUSHER

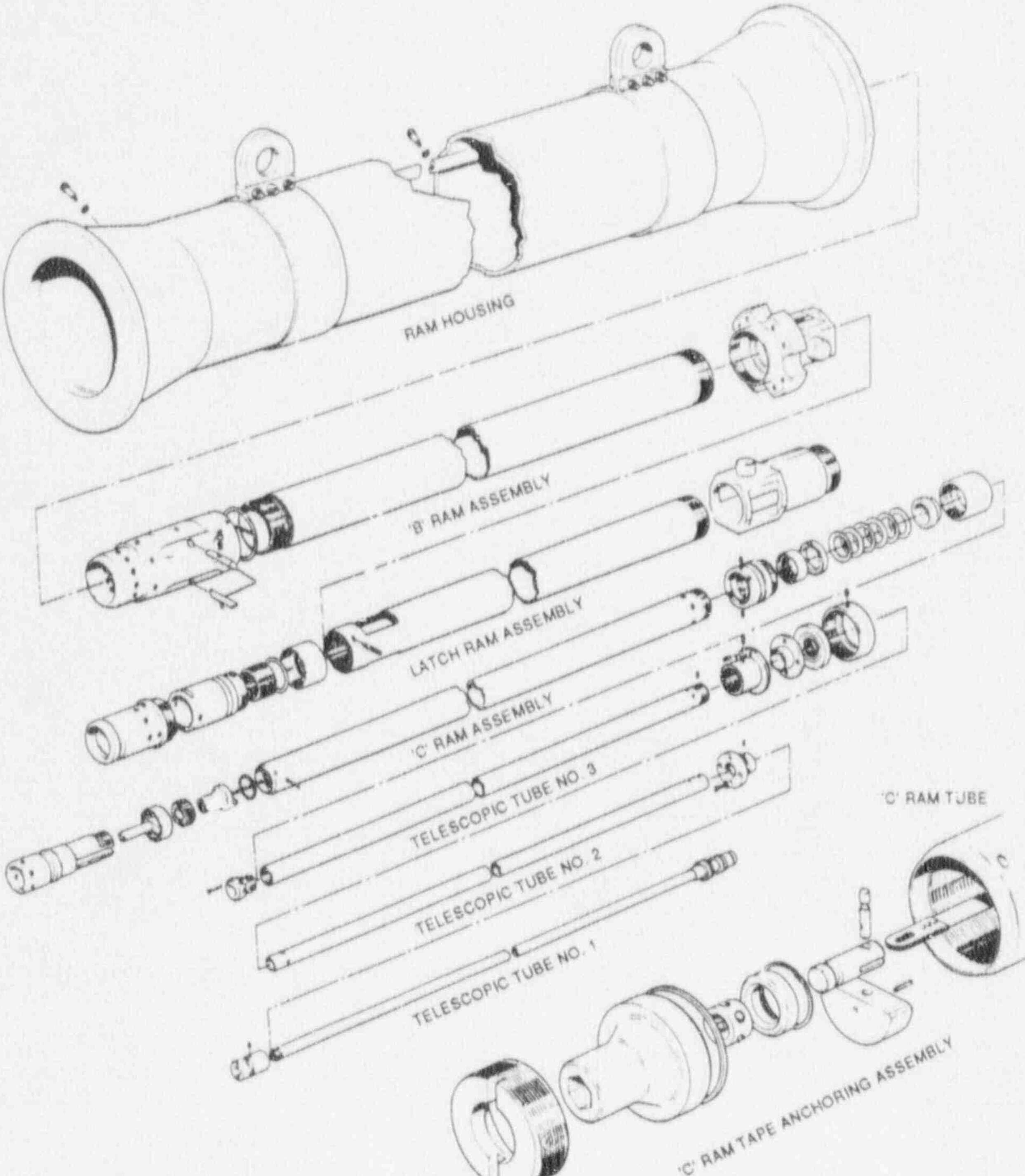
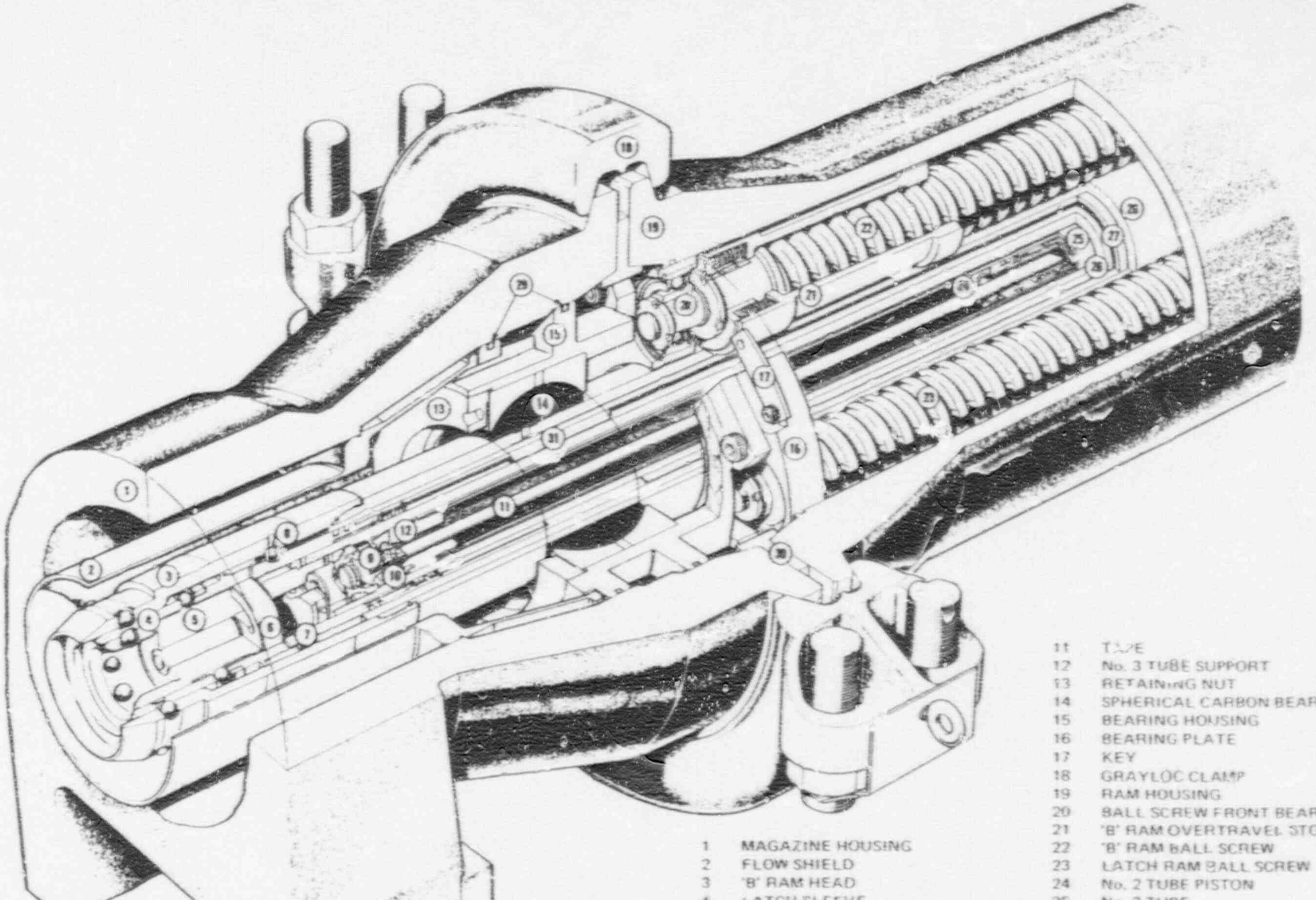
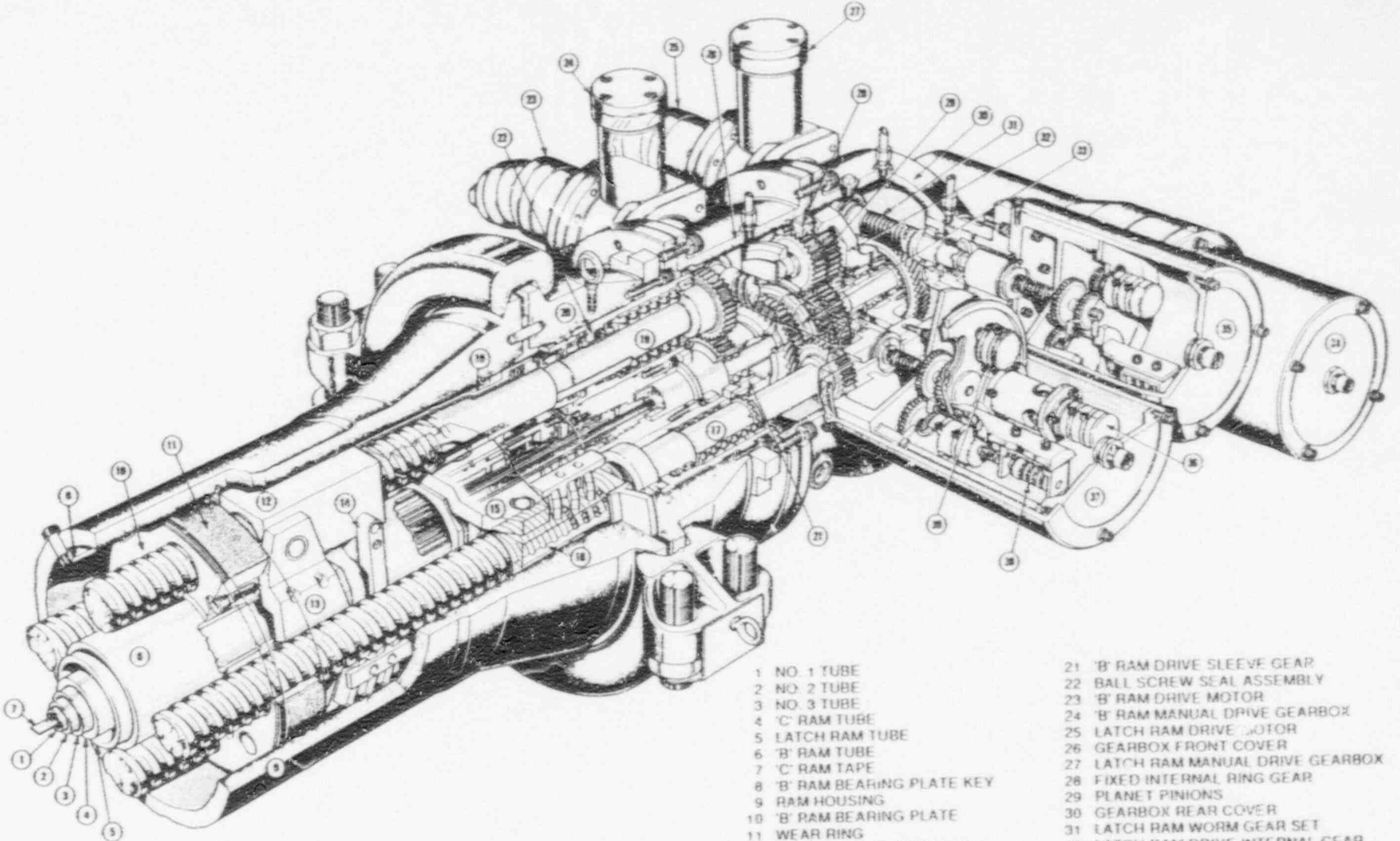


FIGURE 3-29 RAM ASSEMBLY - EXPLODED VIEW



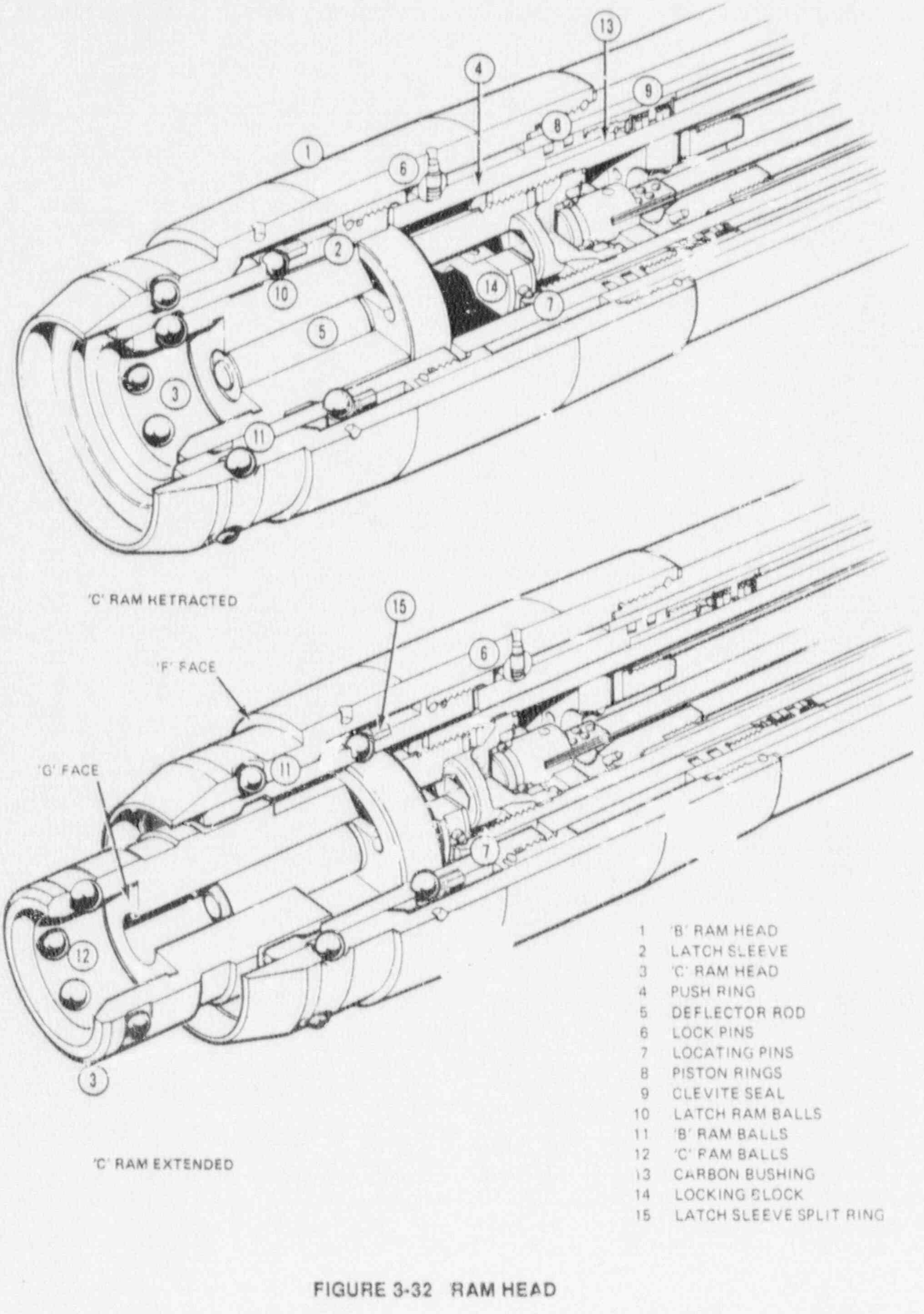
1 MAGAZINE HOUSING
2 FLOW SHIELD
3 'B' RAM HEAD
4 LATCH SLEEVE
5 'C' RAM HEAD
6 DEFLECTOR ROD
7 PUSH RING
8 LOCK PIN
9 TAPE END BEARING
10 TAPE BEARING COUNTERWEIGHT
11 TAPE
12 No. 3 TUBE SUPPORT
13 RETAINING NUT
14 SPHERICAL CARBON BEARING
15 BEARING HOUSING
16 BEARING PLATE
17 KEY
18 GRAYLOC CLAMP
19 RAM HOUSING
20 BALL SCREW FRONT BEARING
21 'B' RAM OVERTRAVEL STOP TUBE
22 'B' RAM BALL SCREW
23 LATCH RAM BALL SCREW
24 No. 2 TUBE PISTON
25 No. 3 TUBE
26 'C' RAM TUBE
27 LATCH RAM TUBE
28 'B' RAM TUBE
29 'O' RINGS
30 SEAL RING
31 'C' RAM MECHANICAL STOP

FIGURE 3-30 RAM ASSEMBLY - FRONT END



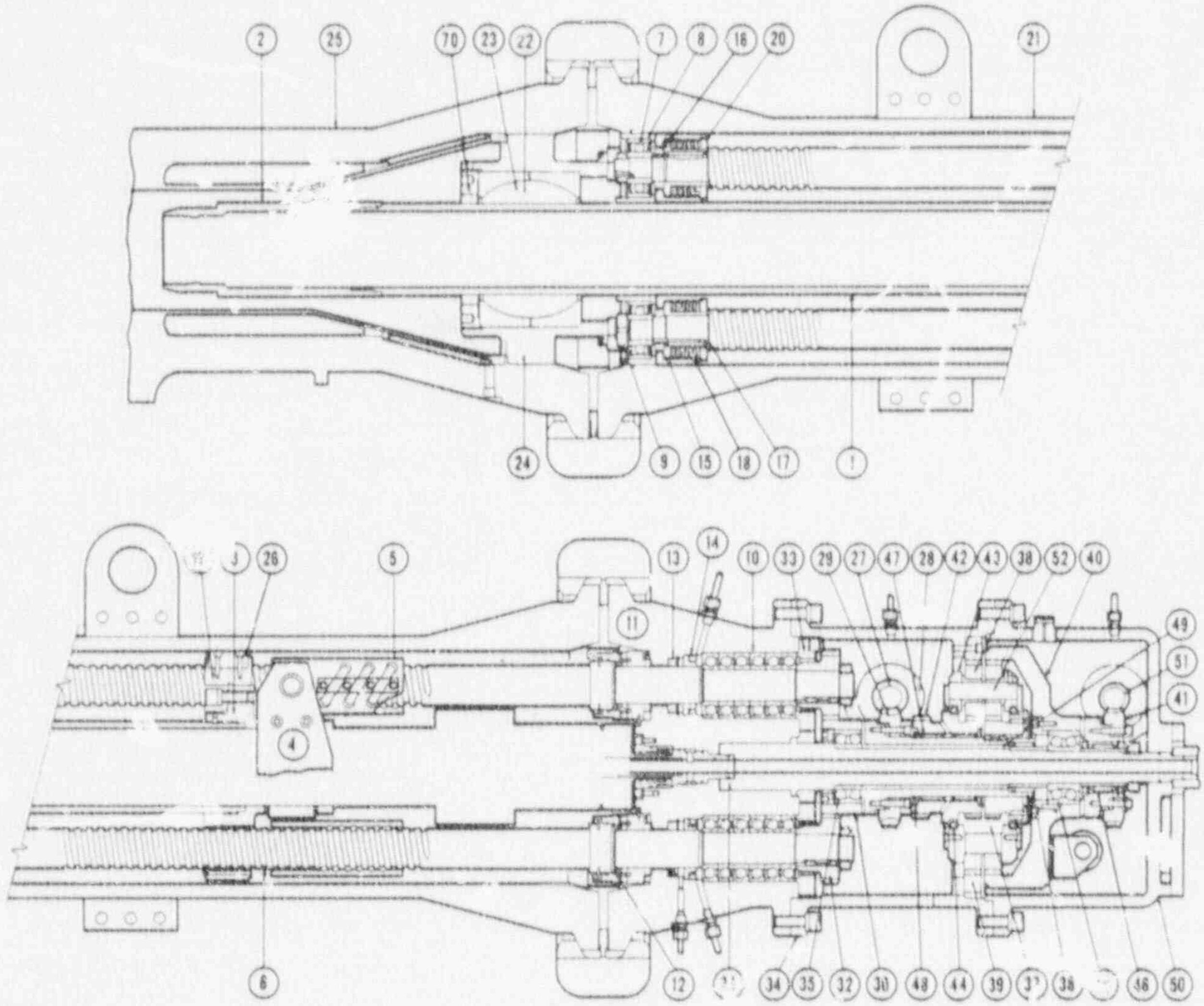
1 NO. 1 TUBE
2 NO. 2 TUBE
3 NO. 3 TUBE
4 'C' RAM TUBE
5 LATCH RAM TUBE
6 'B' RAM TUBE
7 'C' RAM TAPE
8 'B' RAM BEARING PLATE KEY
9 RAM HOUSING
10 'B' RAM BEARING PLATE
11 WEAR RING
12 'B' RAM UPPER BALL NUT
13 'B' RAM TRUNNION PLATE
14 'B' RAM BALL NUT SUPPORT LINKS
15 LATCH RAM TRUNNION PLATE
16 LATCH RAM BALL NUT
17 LATCH RAM BALL SCREW
18 'B' RAM RETRACT STOP
19 'B' RAM BALL SCREW
20 RAM REAR FORGING
21 'B' RAM DRIVE SLEEVE GEAR
22 BALL SCREW SEAL ASSEMBLY
23 'B' RAM DRIVE MOTOR
24 'B' RAM MANUAL DRIVE GEARBOX
25 LATCH RAM DRIVE MOTOR
26 GEARBOX FRONT COVER
27 LATCH RAM MANUAL DRIVE GEARBOX
28 FIXED INTERNAL RING GEAR
29 PLANET PINIONS
30 GEARBOX REAR COVER
31 LATCH RAM WORM GEAR SET
32 LATCH RAM DRIVE INTERNAL GEAR
33 DOUBLE ENDED CENTER GEAR
34 'C' RAM TAPE DRIVE ASSEMBLY
35 LATCH RAM POTENTIOMETER ASSEMBLY
36 COARSE POTENTIOMETERS
37 'B' RAM POTENTIOMETER ASSEMBLY
38 COUNTER
39 FINE POTENTIOMETER

FIGURE 3-31 RAM ASSEMBLY - REAR END



1 'B' RAM HEAD
2 LATCH SLEEVE
3 'C' RAM HEAD
4 PUSH RING
5 DEFLECTOR ROD
6 LOCK PINS
7 LOCATING PINS
8 PISTON RINGS
9 CLEVITE SEAL
10 LATCH RAM BALLS
11 'B' RAM BALLS
12 'C' RAM BALLS
13 CARBON BUSHING
14 LOCKING BLOCK
15 LATCH SLEEVE SPLIT RING

FIGURE 3-32 RAM HEAD



1 'B' RAM TUBE
2 'B' RAM HEAD
3 'B' RAM TRUNNION
4 TRUNNION PLATE
5 BALL SCREW NUT
6 'B' RAM BALL SCREW
7 BALL BEARING
8 BEARING PLATE
9 LOCK NUT
10 ANGULAR CONTACT BEARINGS
11 RAM REAR FORGING
12 BALL SCREW FACE SEAL
13 SEAL
14 OIL SEAL
15 OVERTRAVEL SLEEVE
16 LOCKNUT
17 OVERTRAVEL SPACER
18 BELLEVILLE WASHER SPRING
19 BEARING PLATE
20 OVERTRAVEL RING
21 RAM HOUSING
22 CARBON BEARING
23 CARBON BEARING RETAINER
24 BEARING HOUSING
25 MAGAZINE HOUSING
26 CARBON RING
27 WORM SHAFT
28 ROLLER BEARING
29 WORM GEAR
30 SLEEVE GEAR
31 GEAR BOX MAIN SHAFT
32 'B' RAM PINION
33 BEARING CAP
34 GEAR BOX FRONT COVER
35 DOUBLE ROW A/C BEARINGS
36 ROLLER BEARING
37 LATCH CENTRE GEAR
38 PLANET PINION GEARS
39 INTERNAL RING GEAR
40 INTERNAL GEAR
41 LATCH WORM GEAR
42 CENTRE DOUBLE GEAR
43 PLANET GEAR CARRIER
44 BALL BEARING
45 DOUBLE ROW A/C BEARINGS
46 ROLLER BEARINGS
47 NEEDLE BEARING
48 THRUST BEARING
49 SPACER RING
50 GEAR BOX REAR COVER
51 LATCH WORM SHAFT
52 PLANET PINIONS SHAFT
70 BEARING RETAINER PLATE

FIGURE 3-33 'B' RAM AND MECHANICAL DRIVE

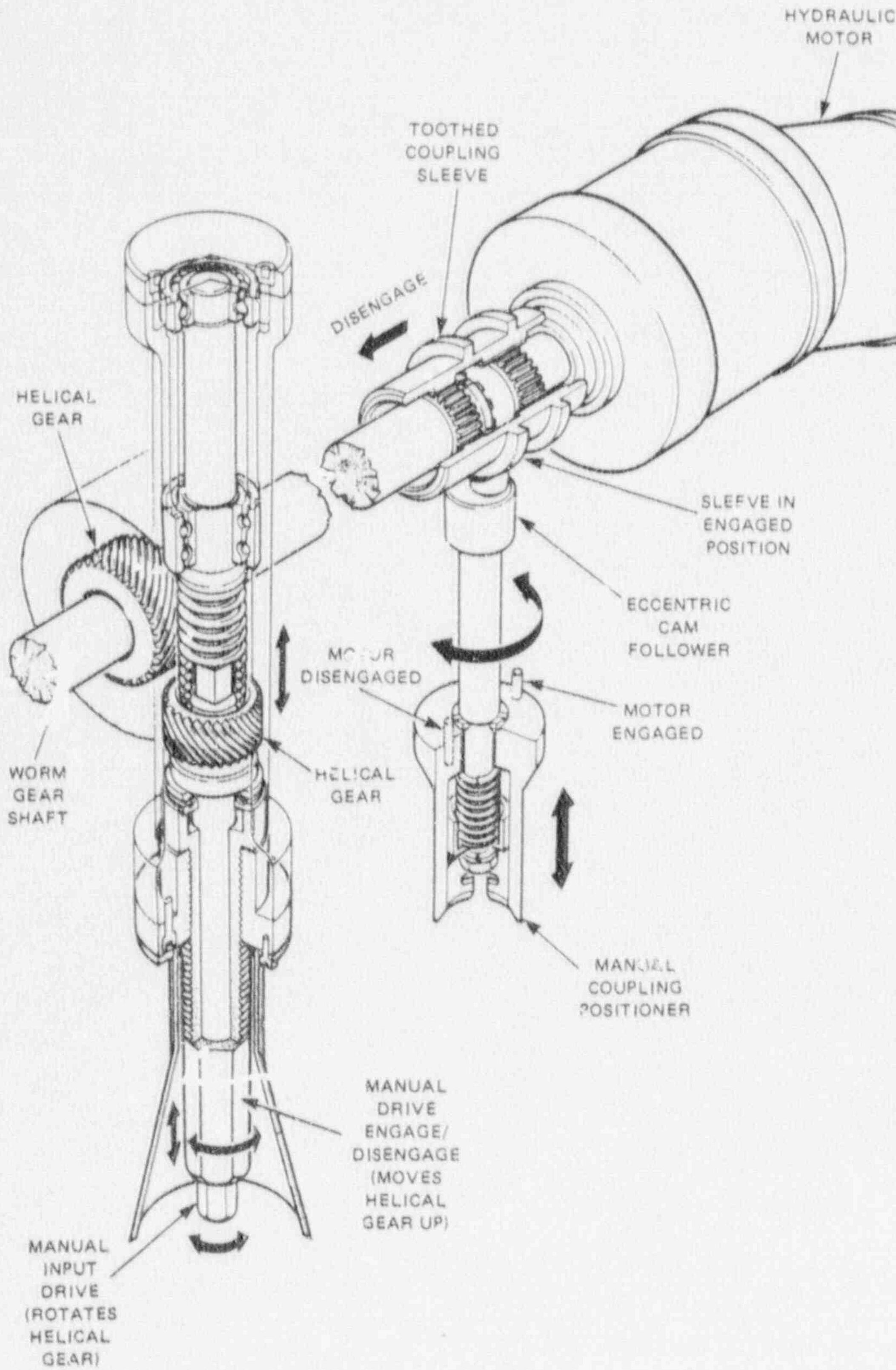


FIGURE 3-34 'B' RAM/LATCH RAM MANUAL DRIVE ASSEMBLY

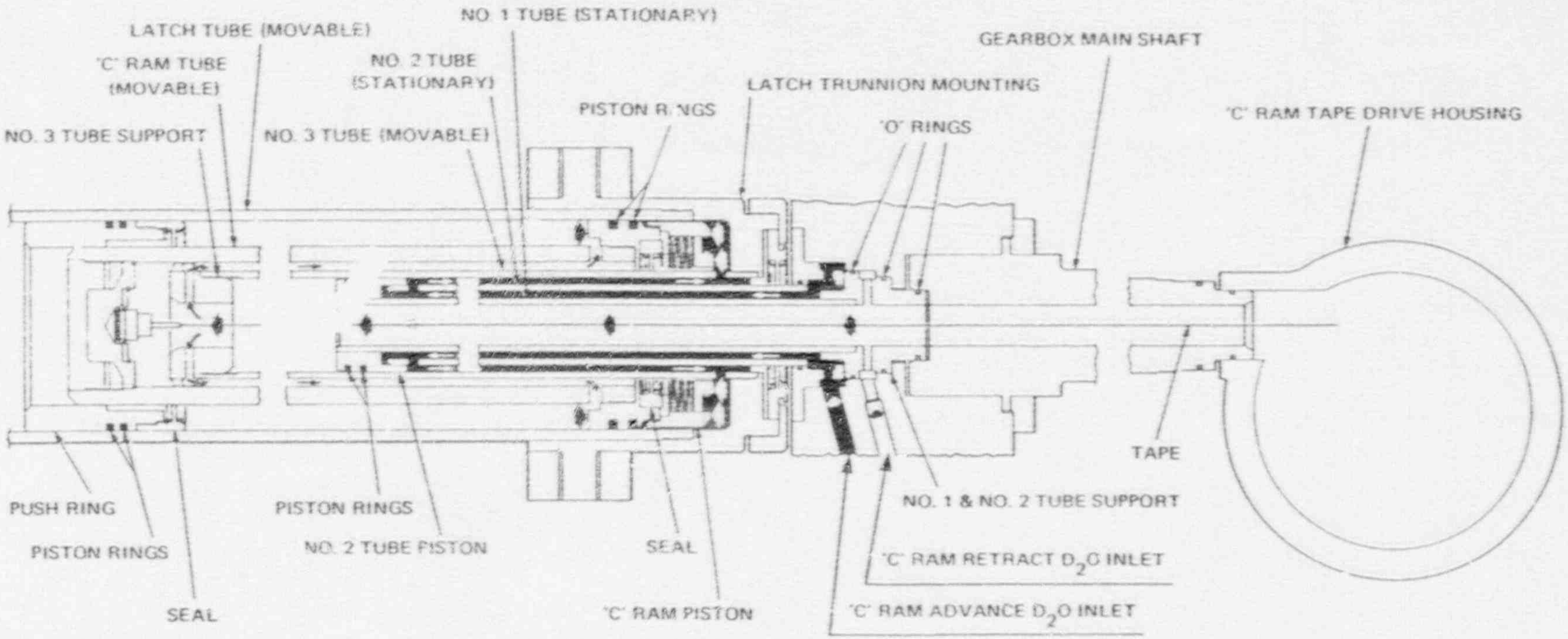


FIGURE 3-35 HYDRAULIC 'C' RAM AND DRIVE (SCHEMATIC)

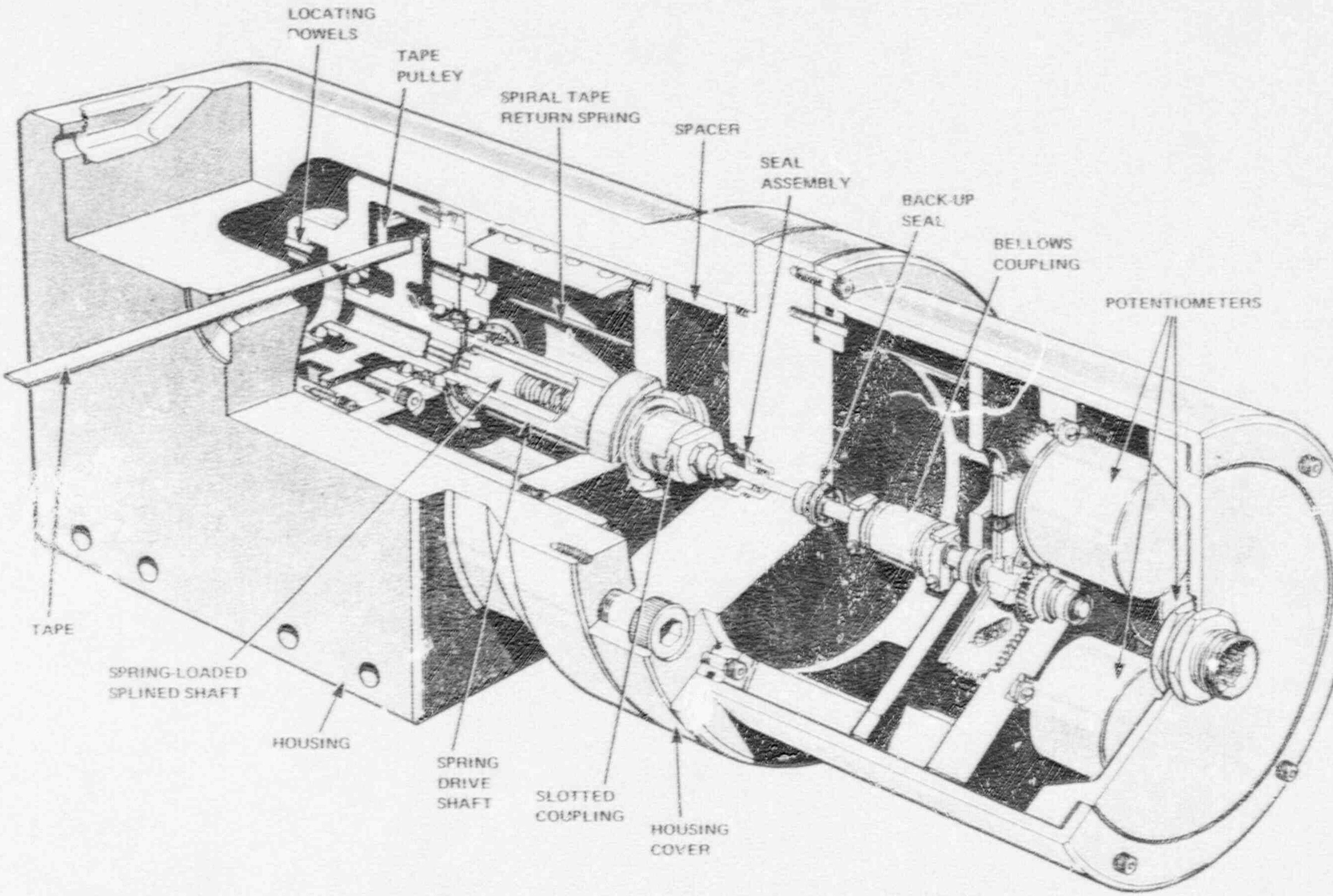


FIGURE 3-36 FUELING MACHINE 'C' RAM TAPE DRIVE ASSEMBLY

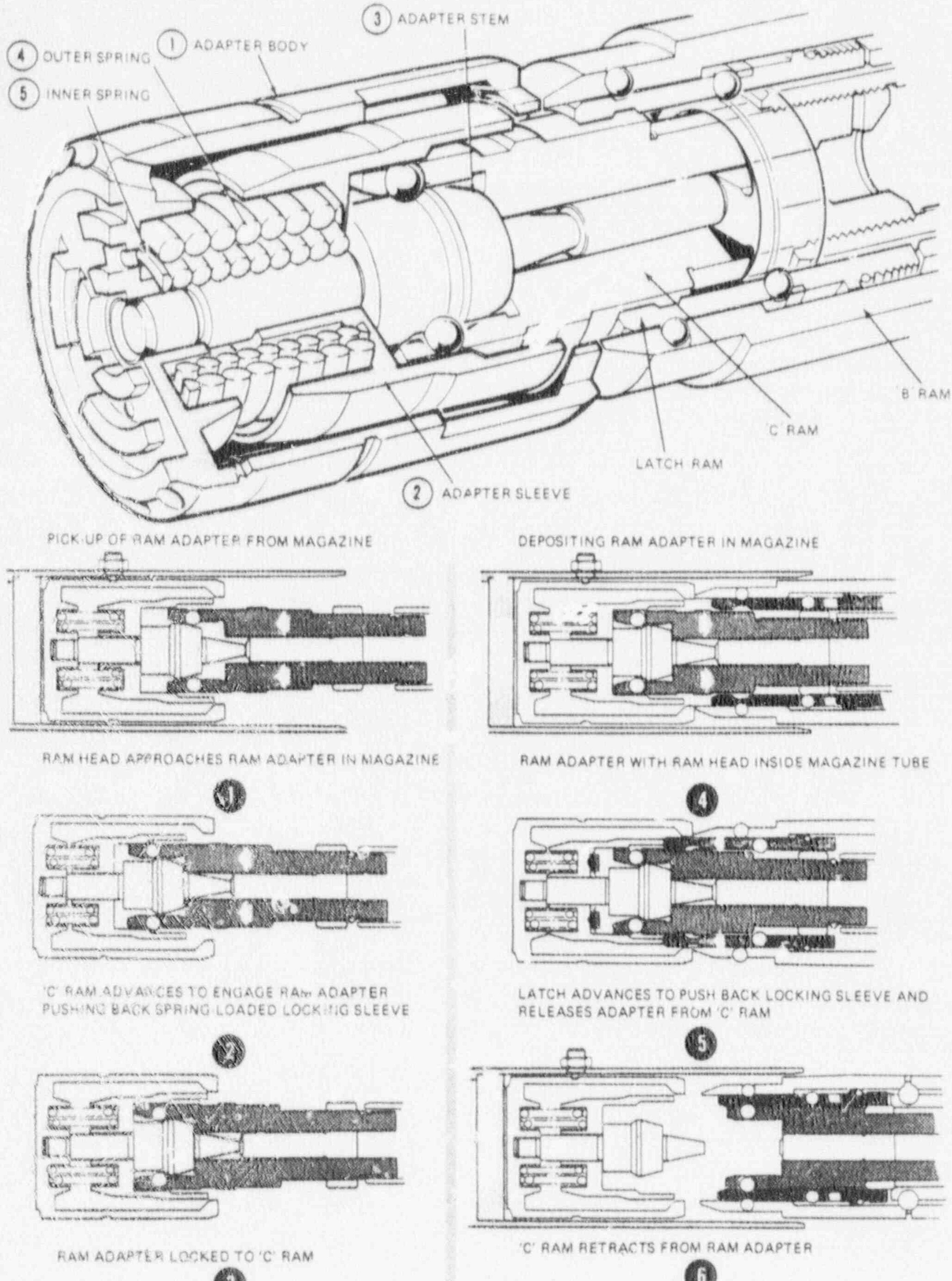


FIGURE 3-37 RAM ADAPTER AND OPERATION

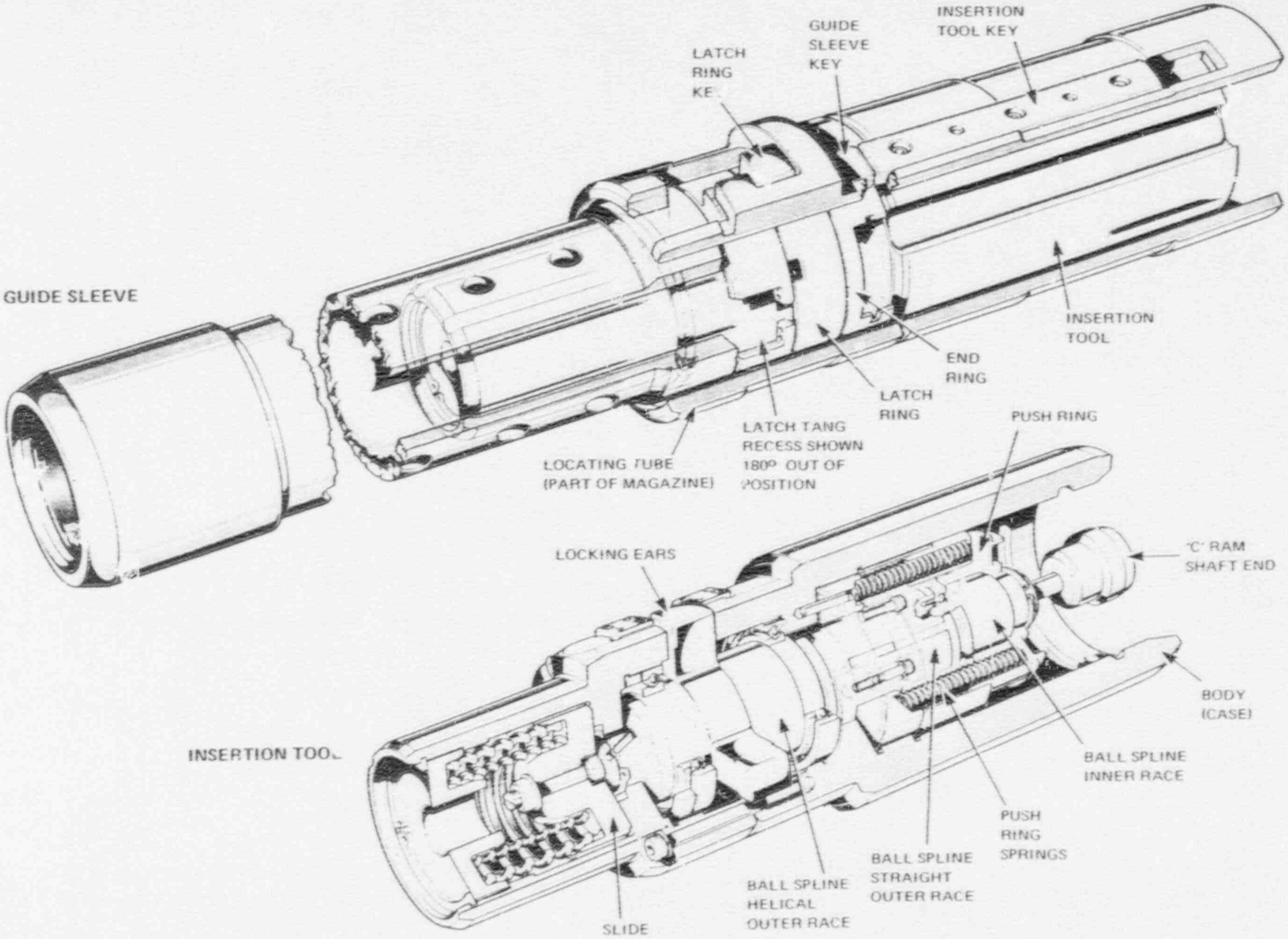


FIGURE 3-38 GUIDE SLEEVE AND INSERTION TOOL

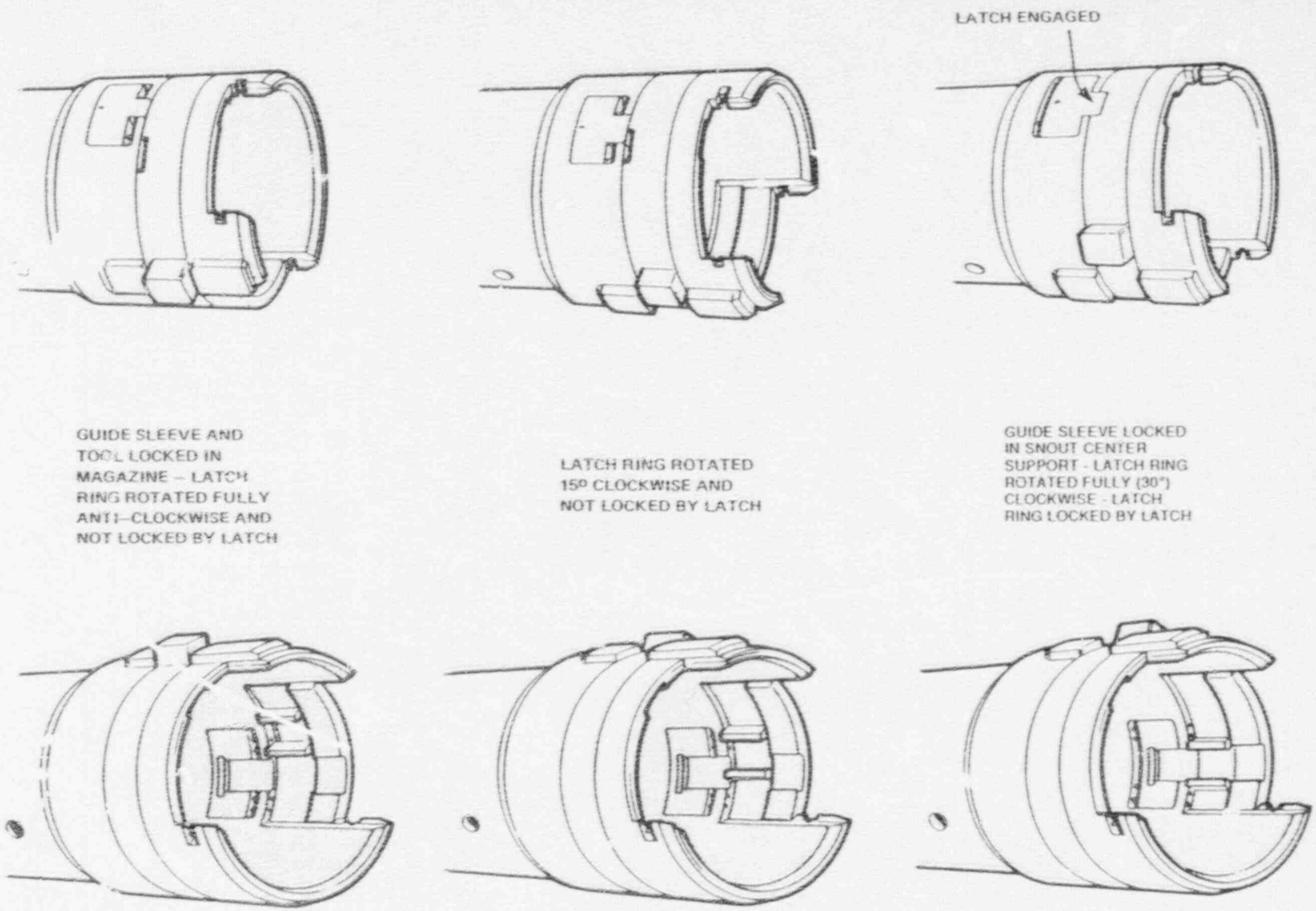
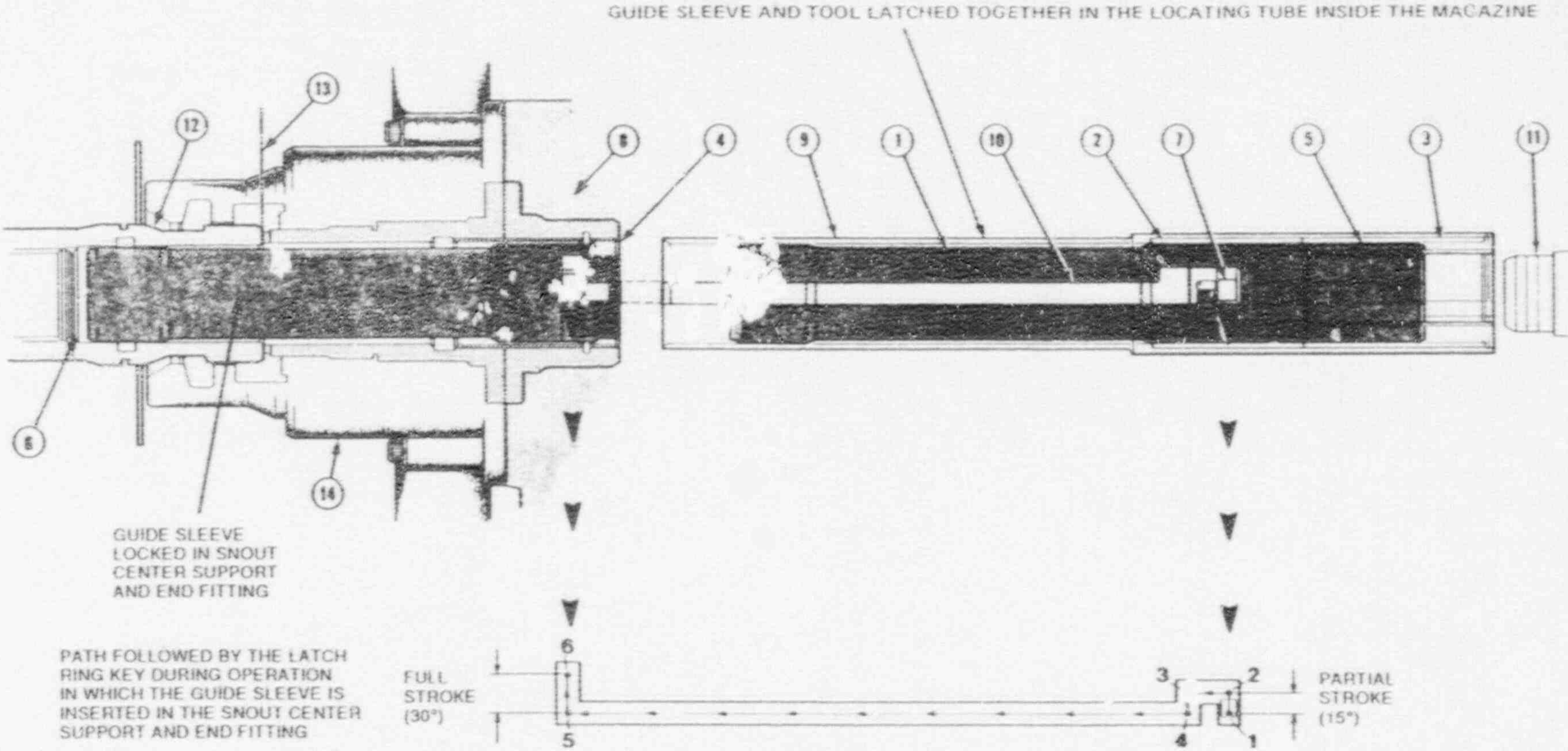


FIGURE 3-39 GUIDE SLEEVE LATCH RING OPERATION



1 GUIDE SLEEVE
2 GUIDE SLEEVE LOCATING TUBE
3 LOCATING TUBE SPACER
4 SNOUT CENTER SUPPORT
5 GUIDE SLEEVE INSERTION TOOL
6 SEAL FACE
7 LATCH RING KEY
8 MAGAZINE END COVER
9 MAGAZINE TUBE
10 MAGAZINE TUBE SLOT
11 'B' RAM HEAD
12 END FITTING
13 END FITTING DATUM FACE
14 SNOUT

(FRONT PORTION OF TOOL IS POSITIONED INSIDE THE GUIDE SLEEVE)

FIGURE 3-40 GUIDE SLEEVE AND TOOL POSITIONS

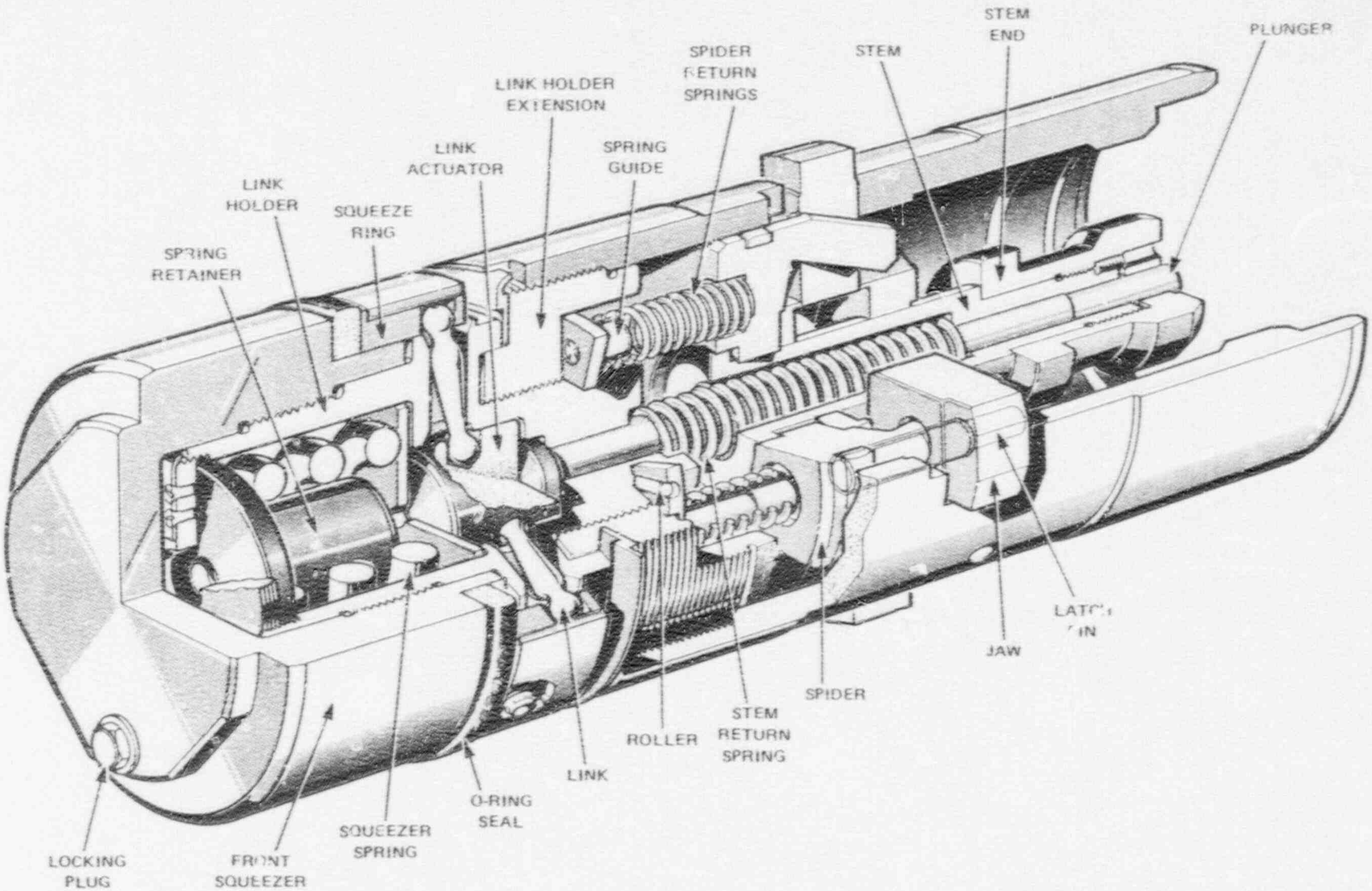
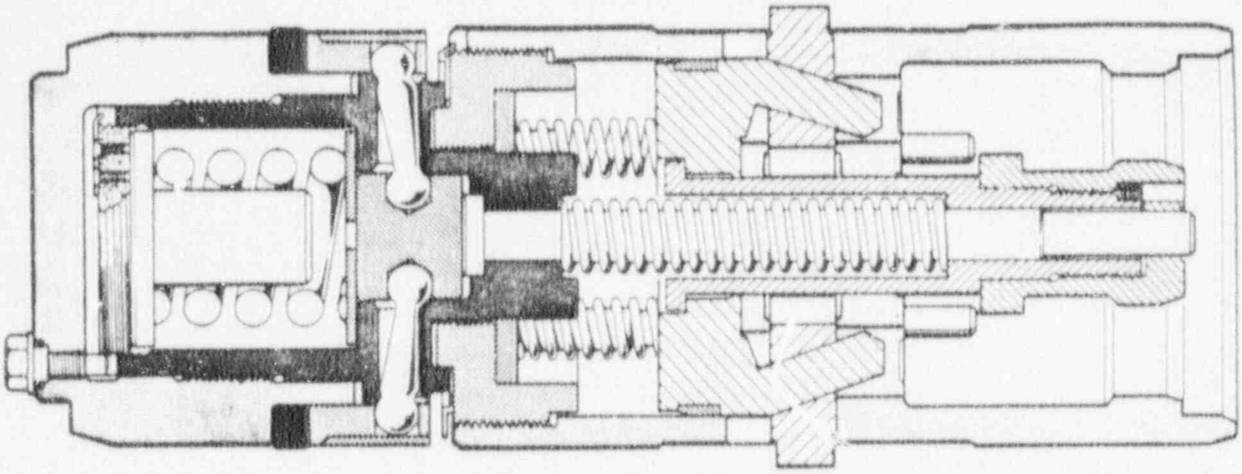
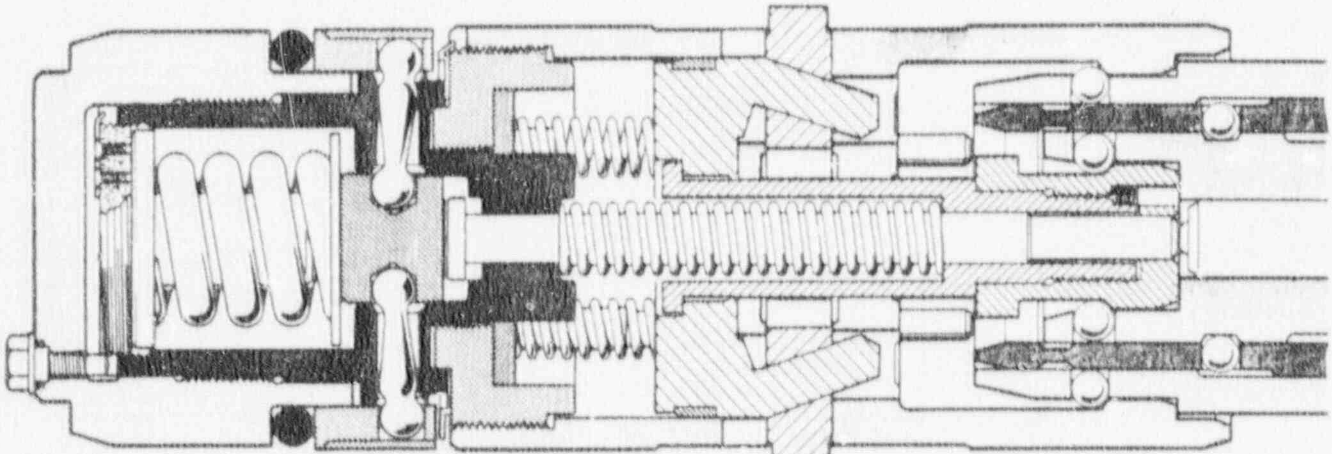


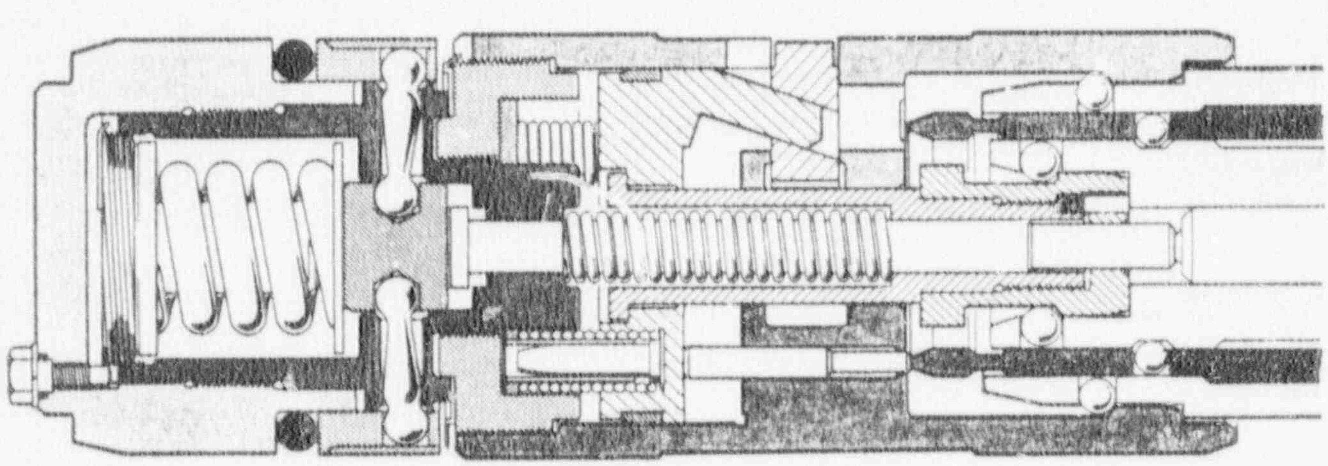
FIGURE 3-41 SNOUT PLUG



SNOUT PLUG WITH JAWS EXTENDED AND O-RING SEAL COMPRESSED

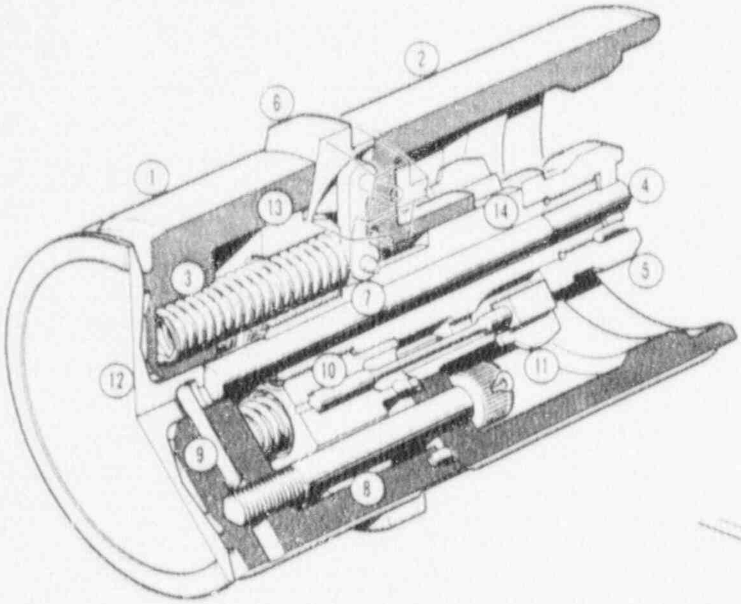


SNOUT PLUG WITH JAWS EXTENDED AND PLUNGER DEPRESSED TO RELAX THE O-RING

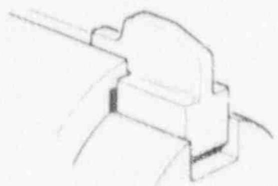


SNOUT PLUG ON THE FUELING MACHINE RAM, WITH THE LATCH RAM ADVANCED 3.38 cm (1.33 in) TO DEPRESS THE SPIDER, VIA THE LATCH PINS, AND RETRACT THE JAWS. THE O-RING SEAL IS RELAXED BY THE ACTION OF THE DEFLECTOR ROD ON THE PLUNGER

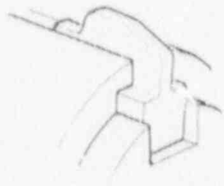
FIGURE 3-42 OPERATION OF SNOUT PLUG



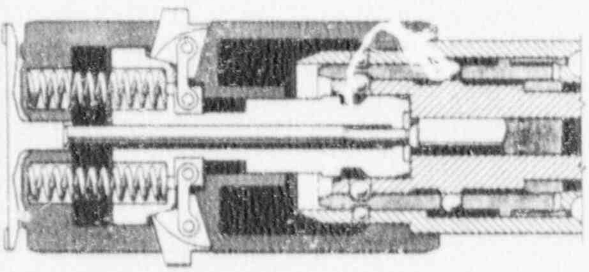
1 FRONT HOUSING
2 REAR HOUSING
3 SPRING
4 PLUNGER
5 STEM END
6 JAW
7 TOGGLE
8 CAP SCREW
9 SEAL DISC PIN
10 SAFETY LATCH SPRING
11 SAFETY LATCH
12 SEAL DISC
13 SPIDER
14 STEM



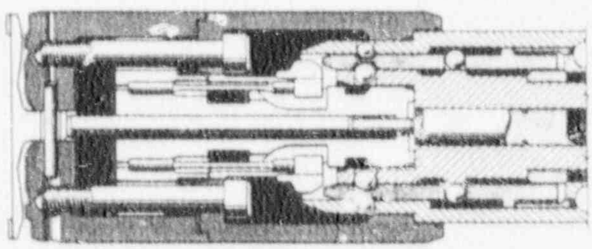
SAFETY LATCH LOCKED
VIEW 2



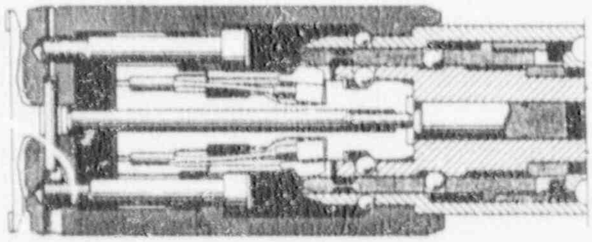
SAFETY LATCH UNLOCKED
VIEW 3



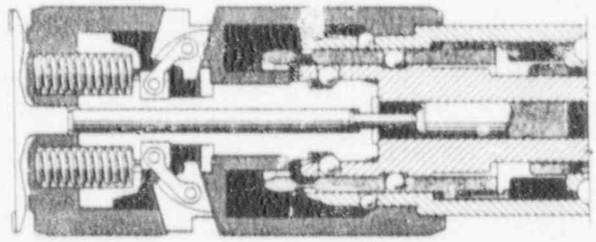
1 SECTION SHOWING THE JAWS AND SPIDER SPRINGS. THE RAM ASSEMBLY HAS JUST CONTACTED THE REAR HOUSING, ADVANCING THE SEAL DISC 0.89 mm (0.035 in)



2 SECTION SHOWING THE SAFETY MECHANISM AND THE CAP SCREWS. THE SAFETY LATCHES ARE IN THIER LOCKED POSITION PREVENTING THE ACCIDENTAL DEPRESSION OF THE STEM

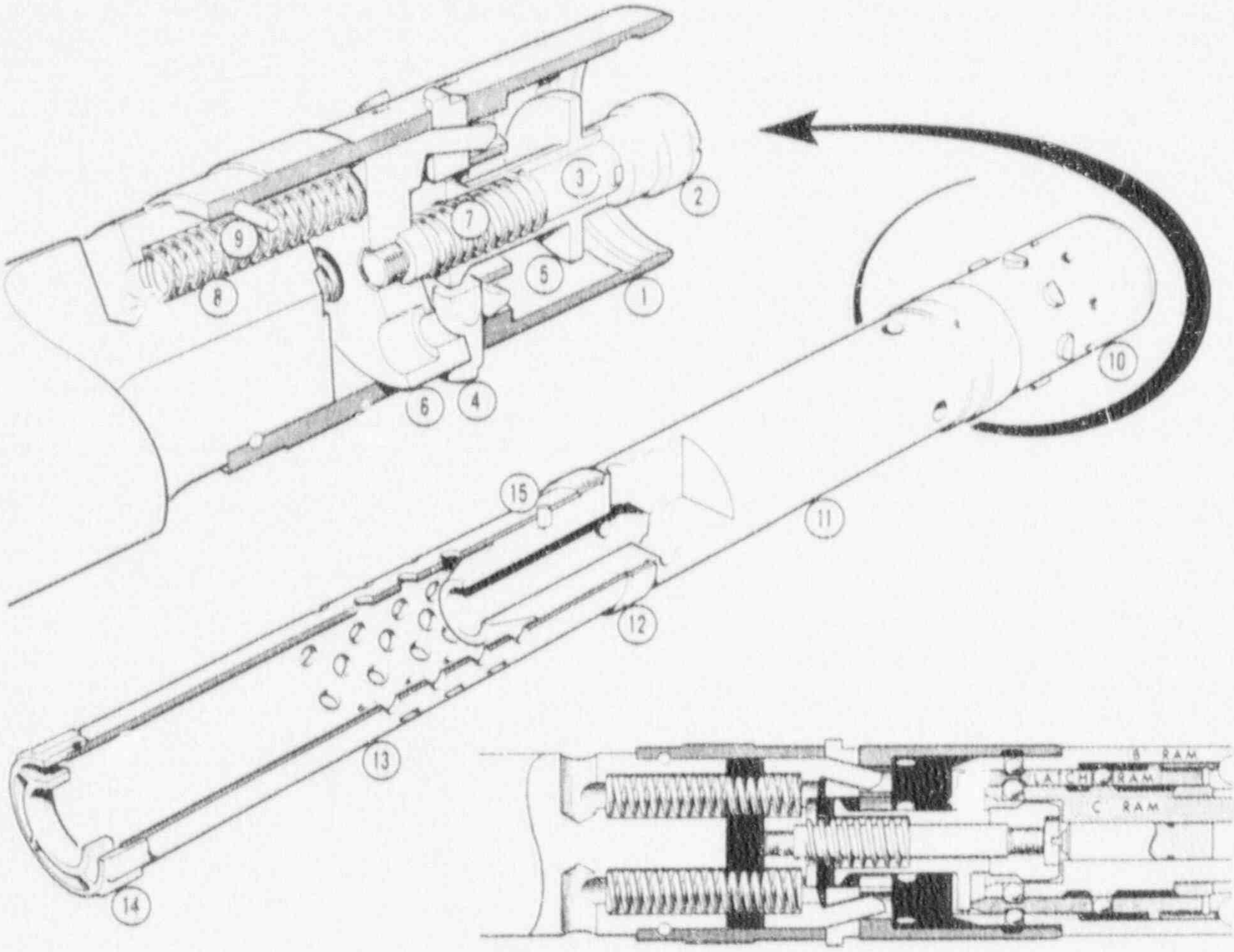


3 HERE THE LATCH RAM HAS ADVANCED 12.7 mm (0.500 in) TO UNLOCK THE SAFETY MECHANISM BY PUSHING THE TWO SAFETY LATCHES INWARD



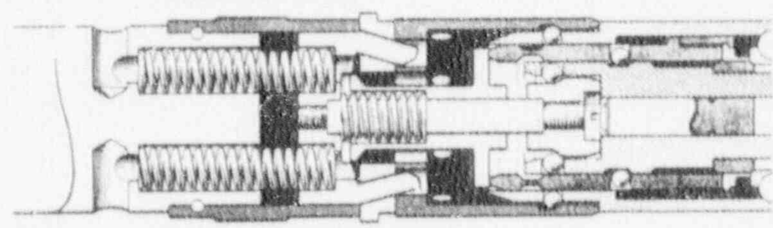
4 THE LATCH RAM AND 'C' RAM HAVE BOTH MOVED A FURTHER 21 mm (0.830 in) TO COMPLETELY RETRACT THE FOUR JAWS

FIGURE 3-43 COOLANT CHANNEL CLOSURE

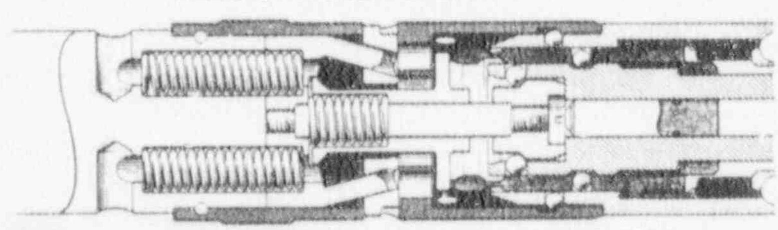


1 CASING
2 STEM END
3 SPIDER STEM
4 JAW
5 SAFETY LATCH
6 SPIDER
7 SAFETY SPRING
8 SPIDER SPRING
9 ROLL PIN
10 LATCH ASSEMBLY
11 SHIELD BODY
12 WEAR RING
13 FLOW TUBE
14 FUEL ADAPTER
15 GROOVE PIN

1 THE RAM HEAD ENTERS THE PLUG AND THE 'B' RAM PROCEEDS UNTIL THE JAWS BEAR AGAINST THE SHOULDER OF THE ANNULAR GROOVE IN THE LINER TUBE



2 THE LATCH RAM ADVANCES 12.7 mm (.50 in) TO LOCK THE 'B' RAM TO THE PLUG CASING AND THE 'C' RAM TO THE STEM END. THIS 12.7 mm (.50 in) MOVEMENT ALSO UNLOCKS THE SAFETY LATCH



3 THE LATCH RAM AND 'C' RAM ADVANCE A FURTHER 21 mm (.83 in) TO RETRACT THE JAWS. THE PLUG CAN NOW BE REMOVED FROM THE COOLANT CHANNEL

FIGURE 3-44 COOLANT CHANNEL SHIELD PLUG

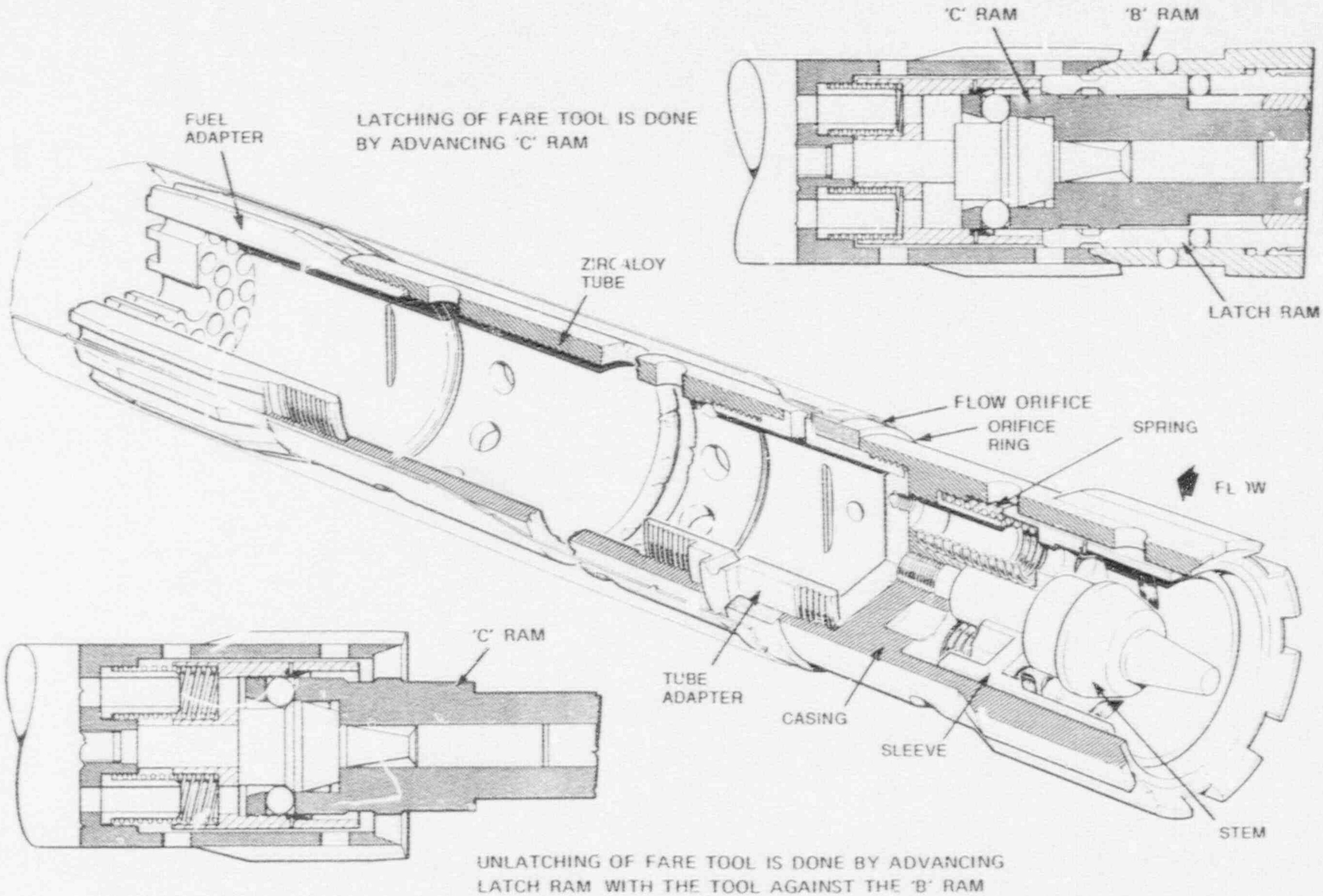


FIGURE 3-45 FARE TOOL ASSEMBLY

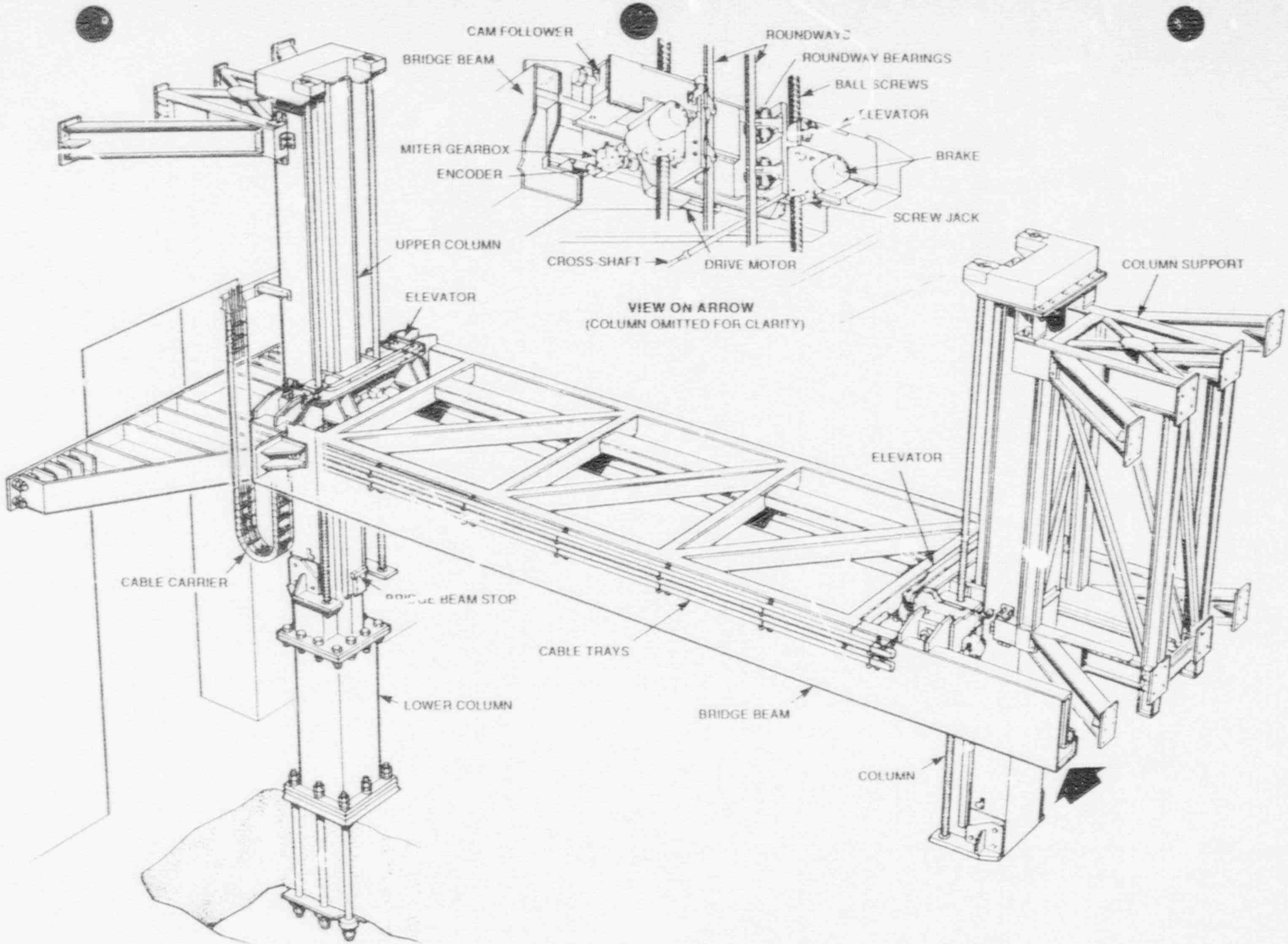


FIGURE 3-46 FUELING MACHINE BRIDGE ASSEMBLY

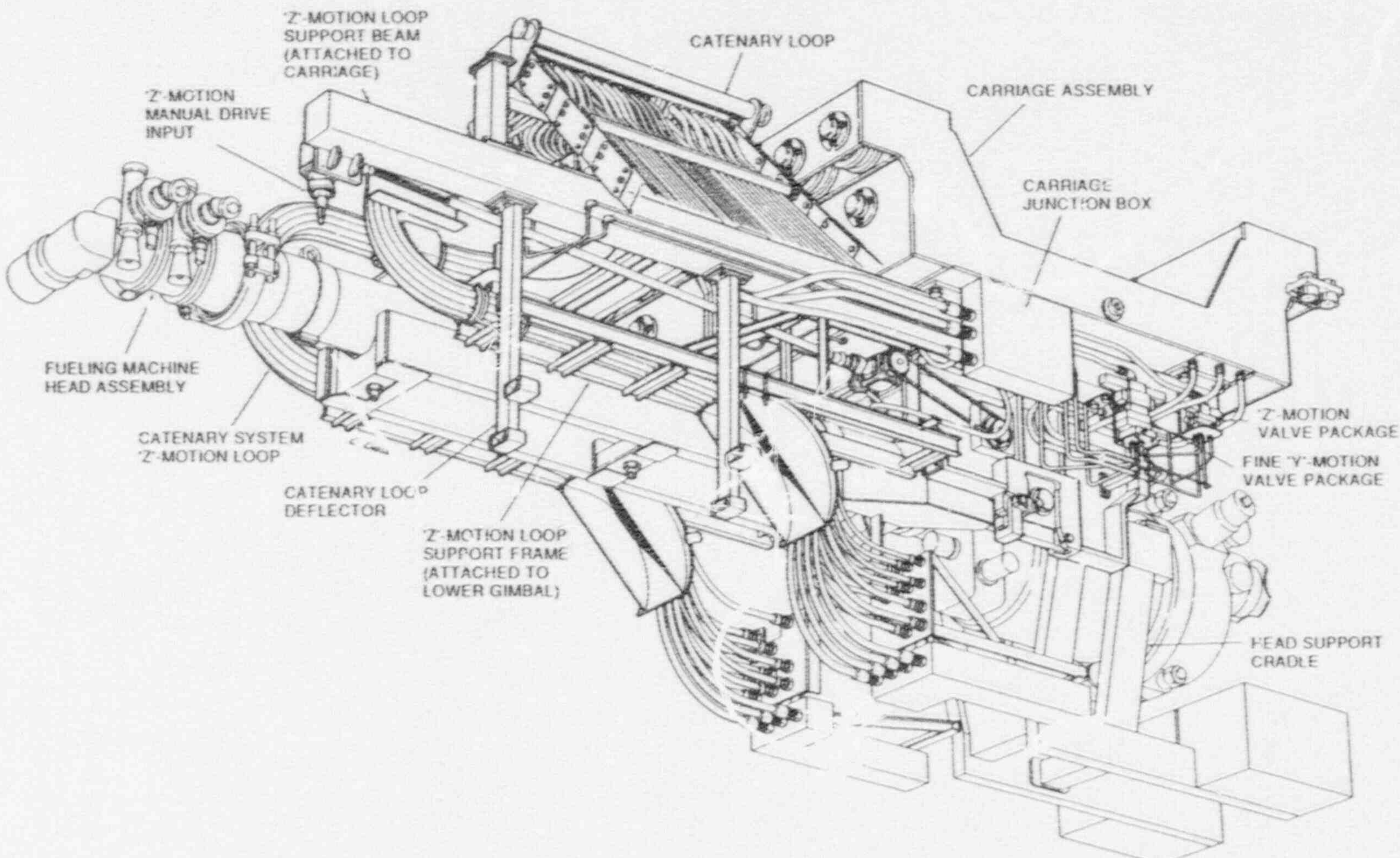


FIGURE 3-47 CARRIAGE/FUELING MACHINE ASSEMBLY

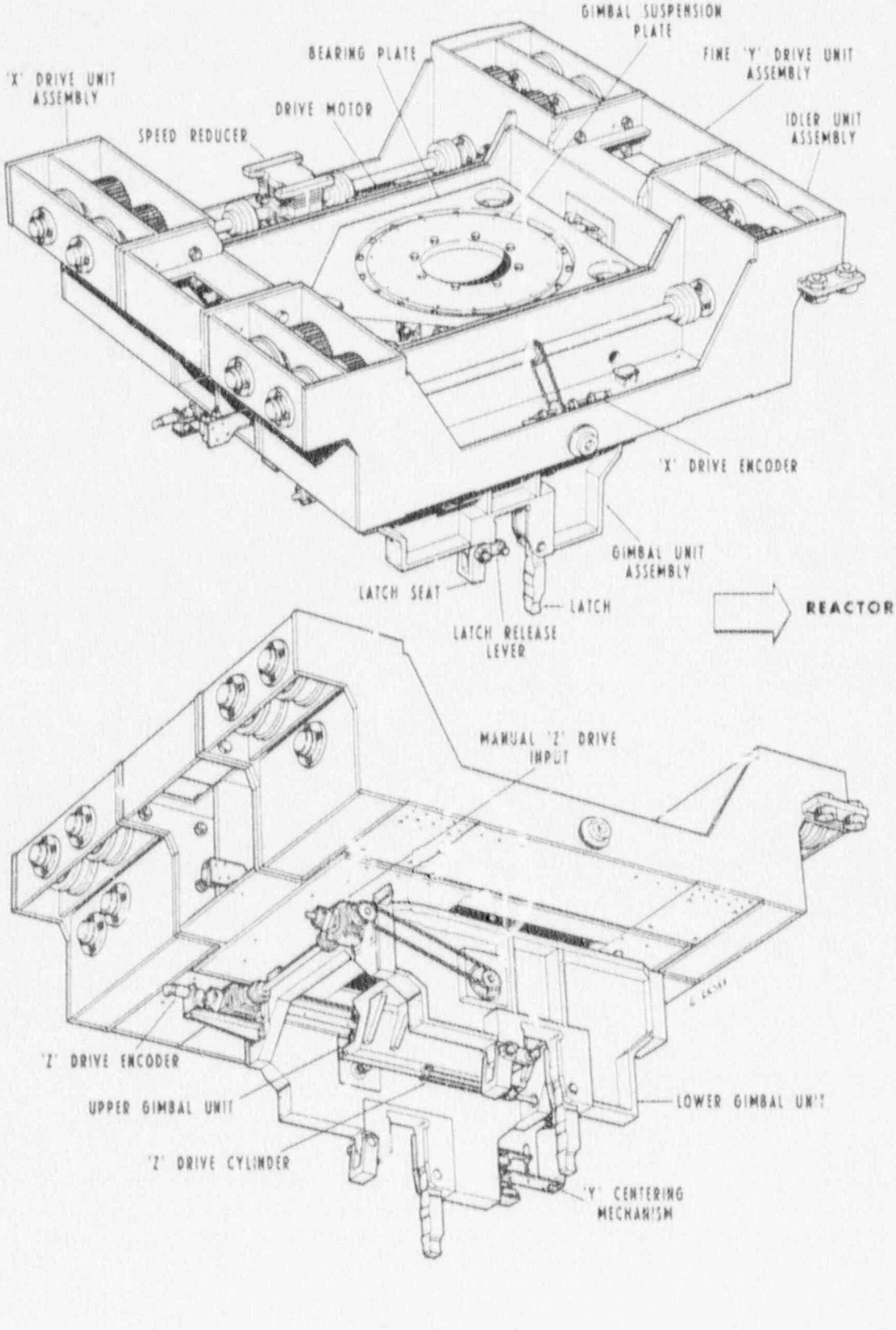


FIGURE 3-48 FUELING MACHINE CARRIAGE ASSEMBLY

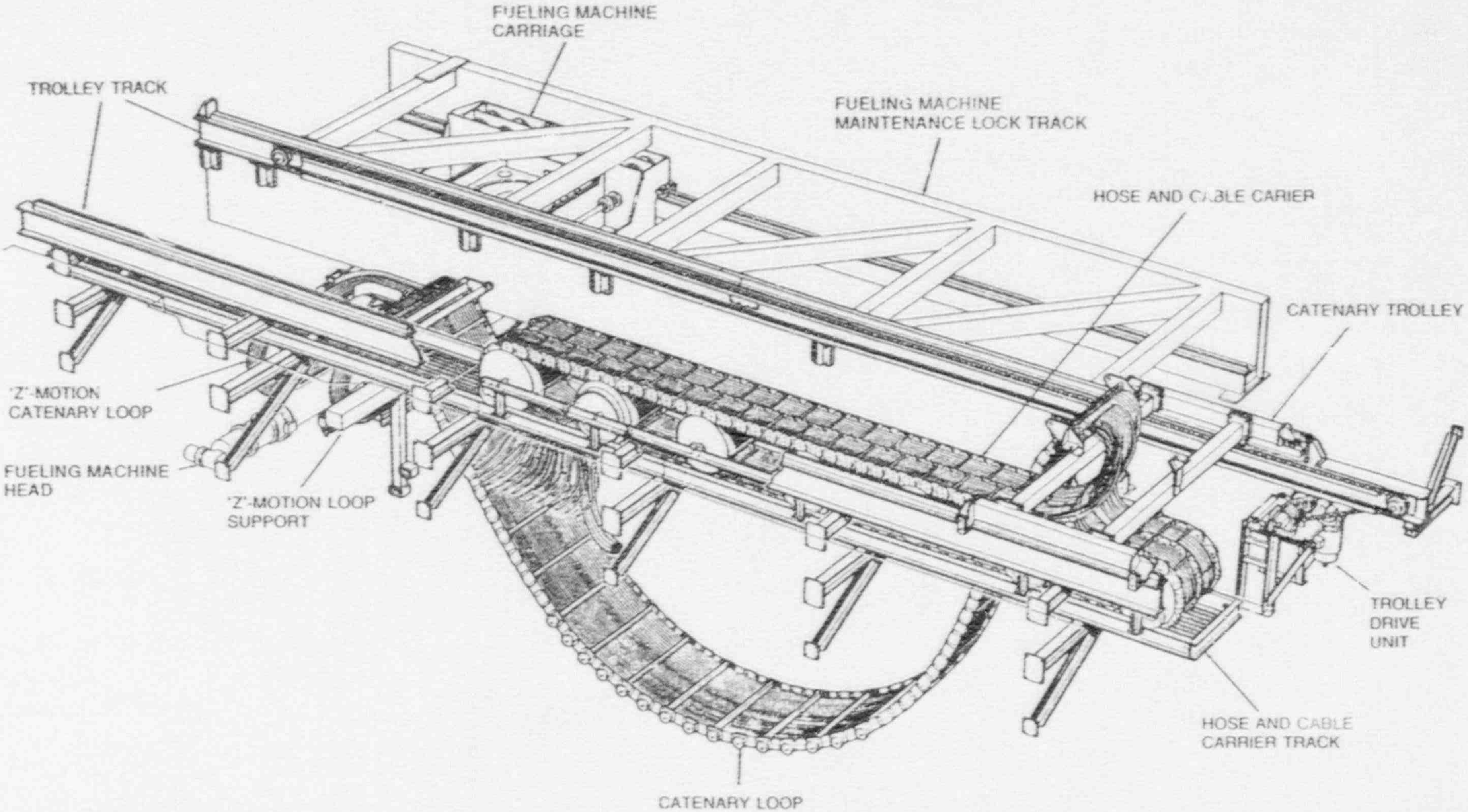


FIGURE 3-49 CATENARY SYSTEM ASSEMBLY

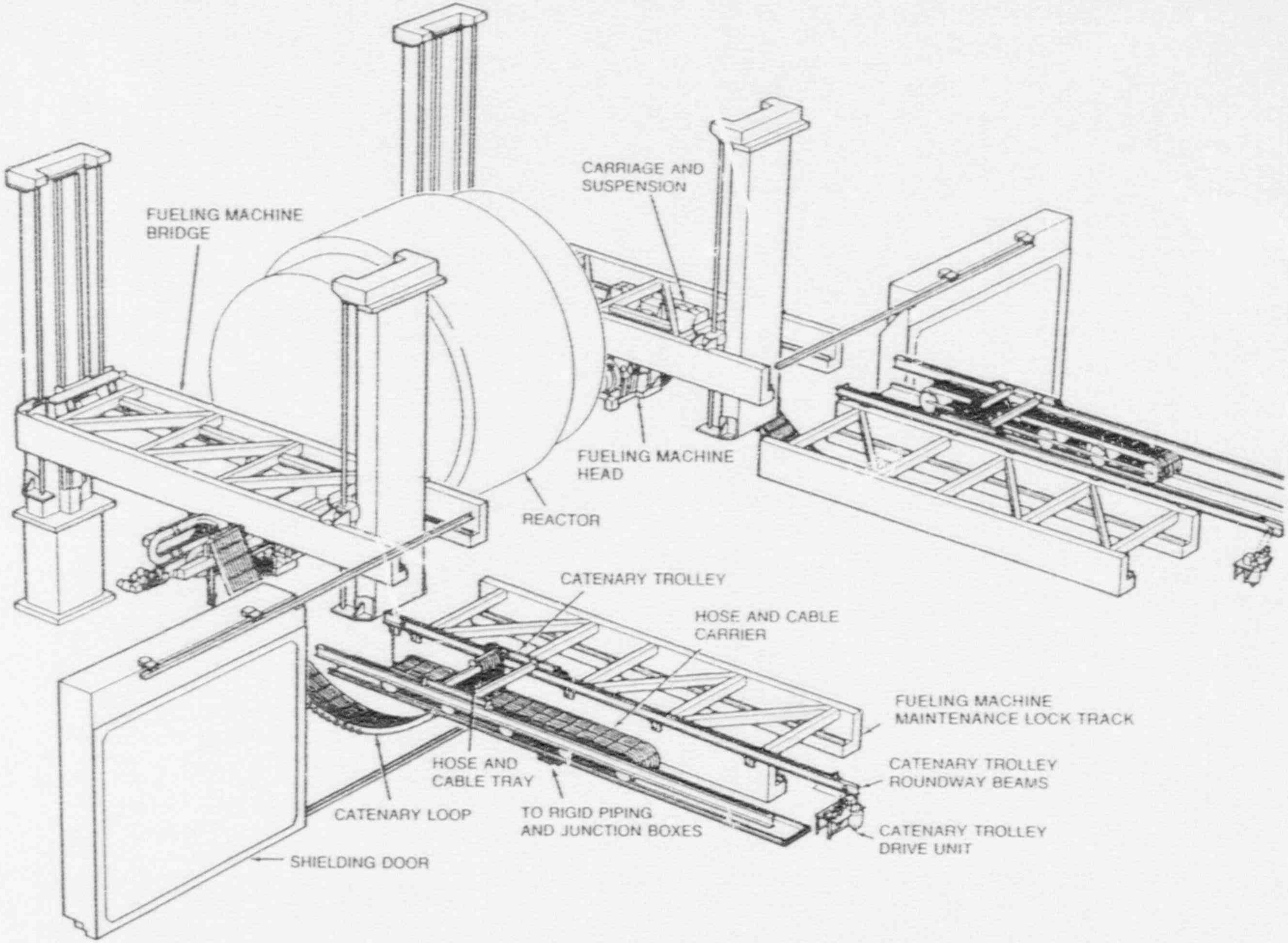


FIGURE 3-50 GENERAL ARRANGEMENT OF FUELING MACHINE BRIDGE, CARRIAGE AND CATENARY

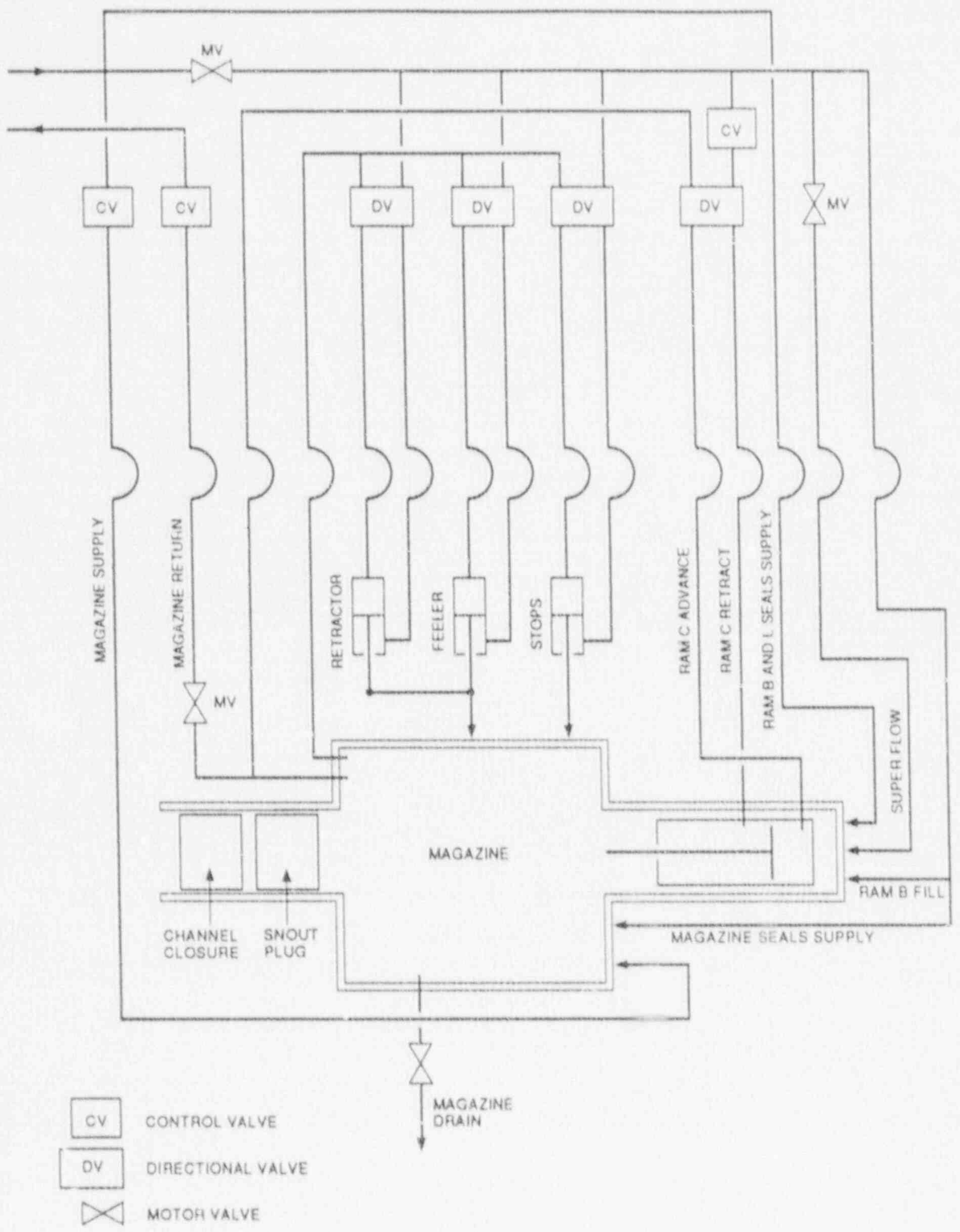


FIGURE 3-51 FUELING MACHINE D_2O SYSTEM BASIC FLOW

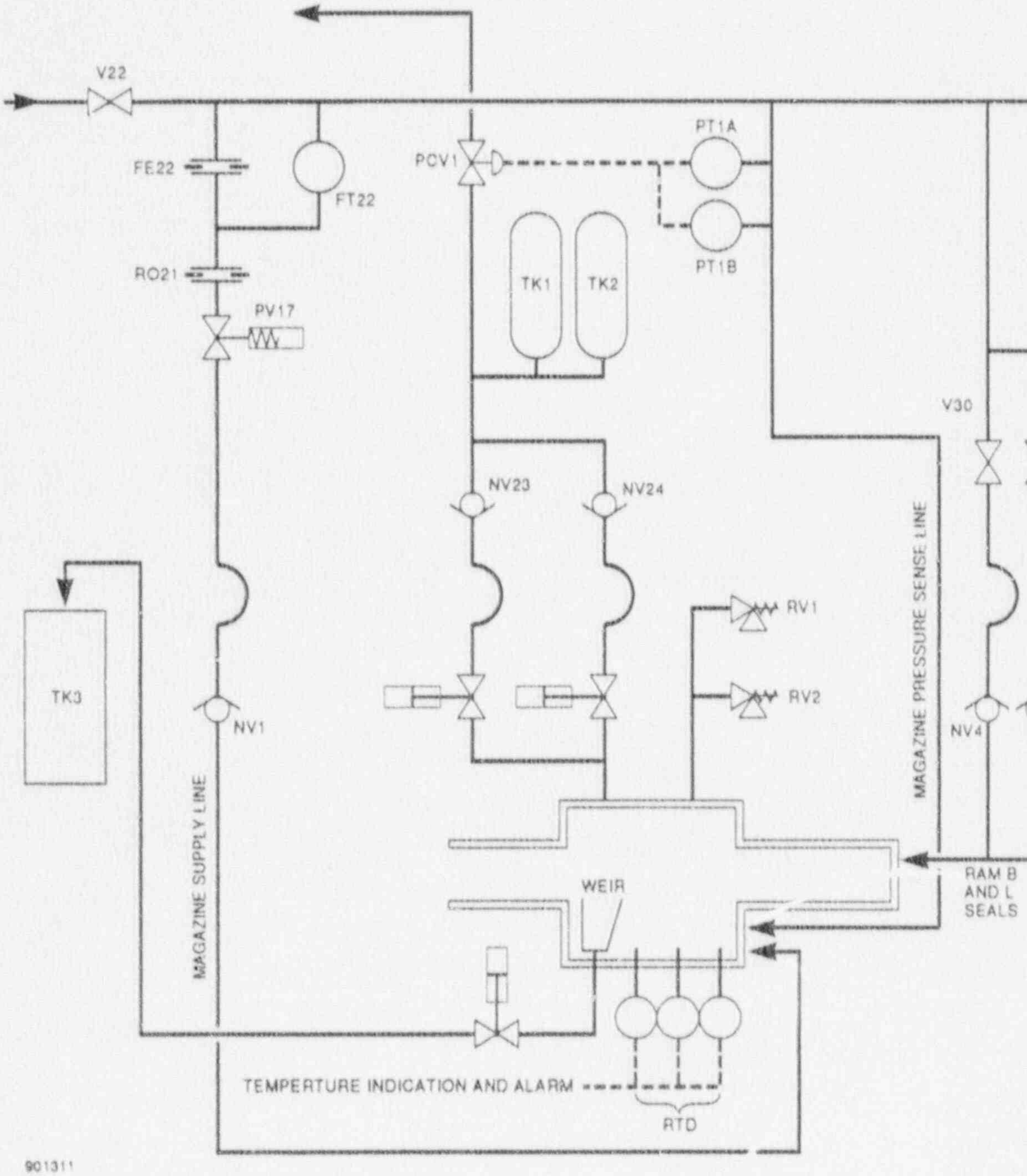


FIGURE 3-52 FUELING MACHINE MAGAZINE SUPPLY LINE

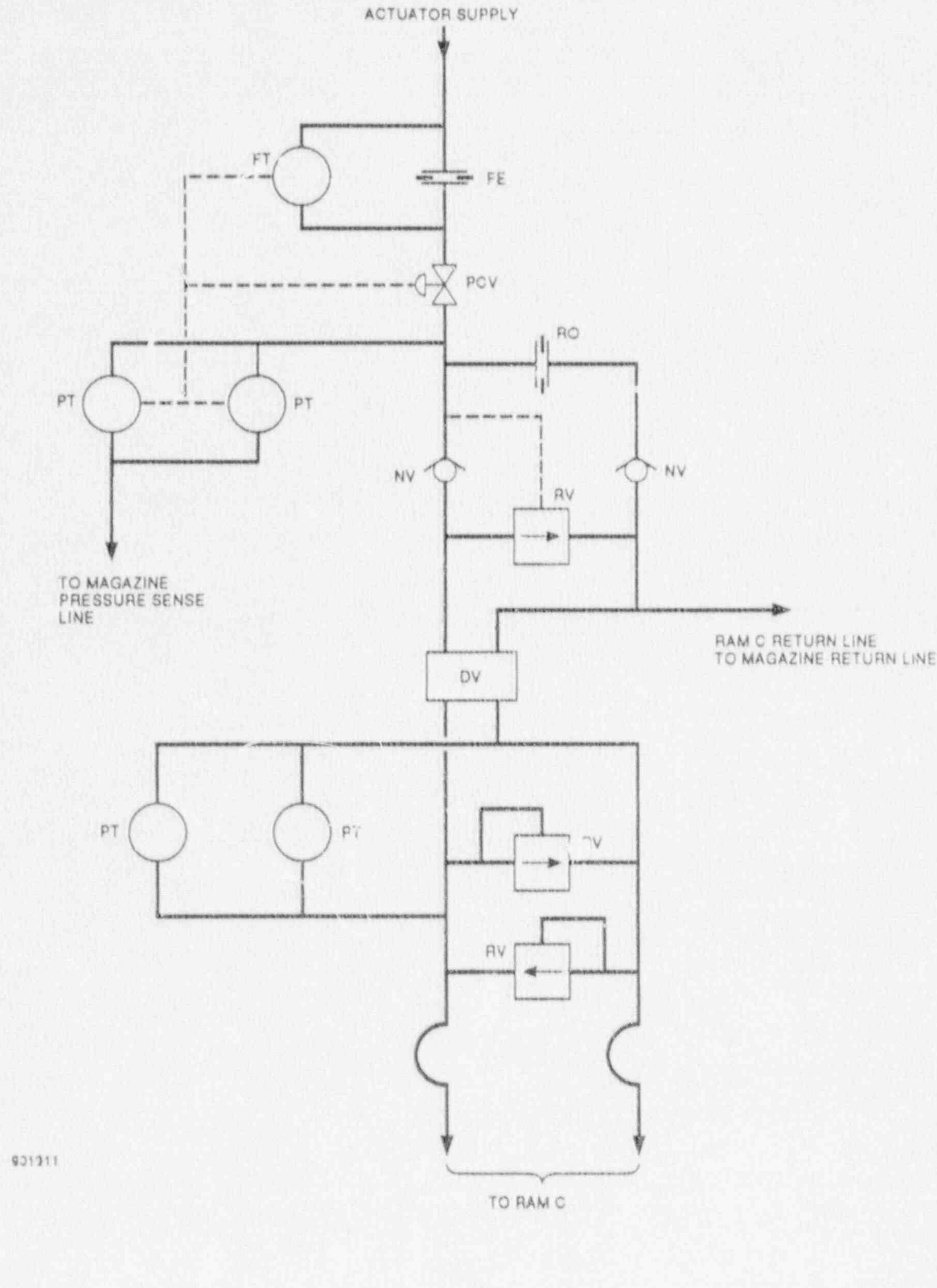


FIGURE 3-53 FUELING MACHINE RAM C HYDRAULIC CONTROL CIRCUIT

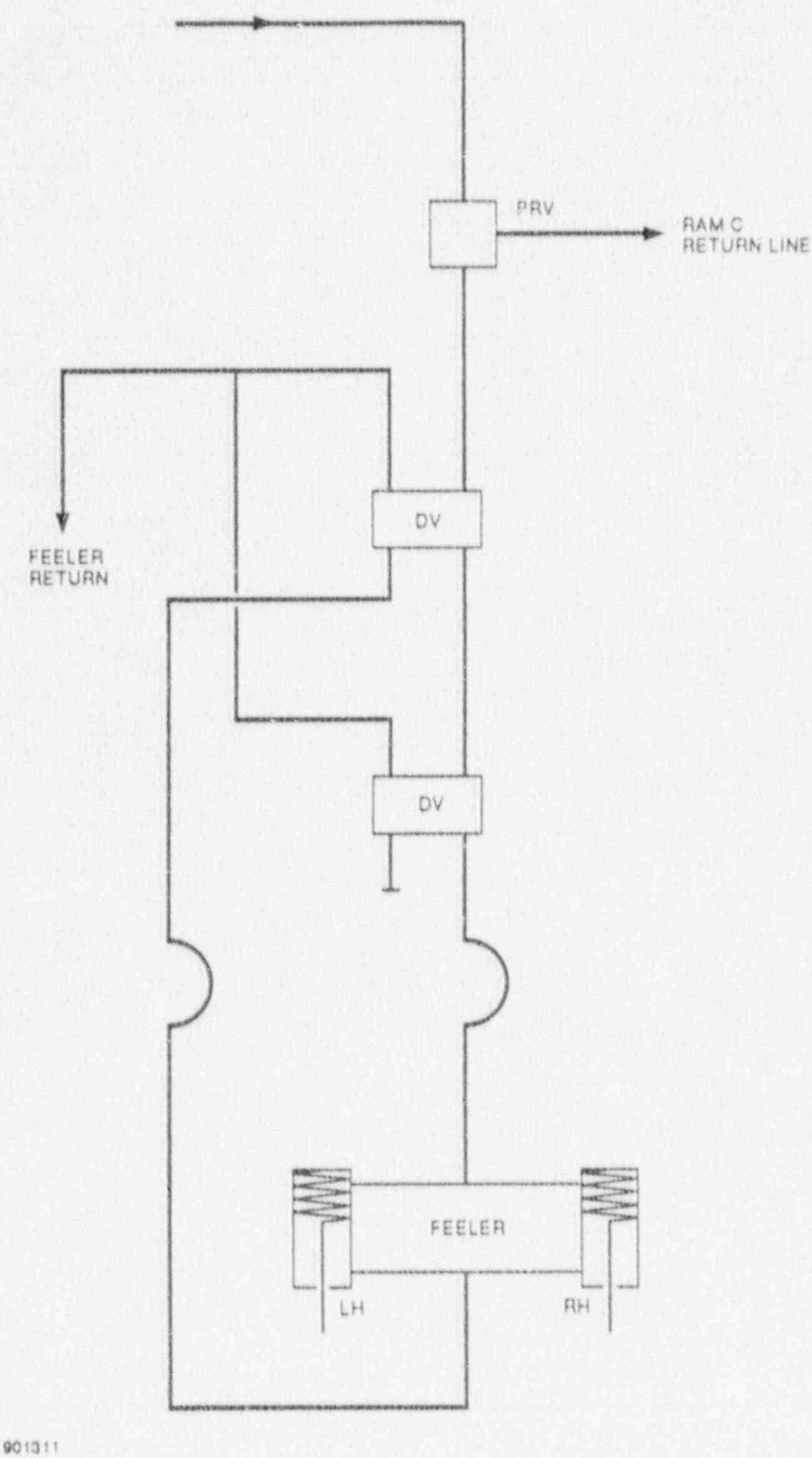


FIGURE 3-54 FUELING MACHINE SEPARATORS CONTROL CIRCUIT

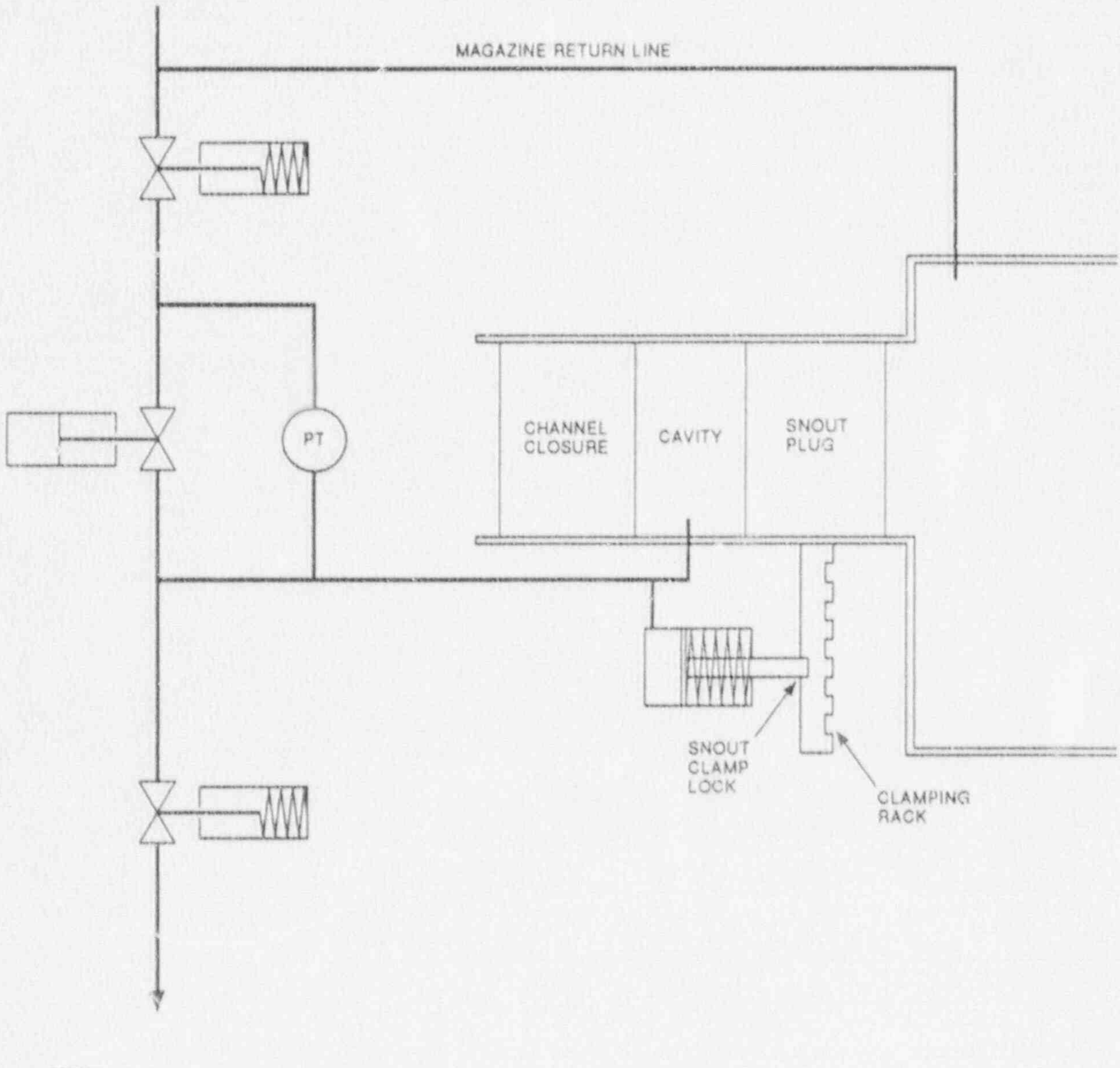


FIGURE 3-55 FUELING MACHINE SNOUT CAVITY LEAK DETECTION CIRCUIT

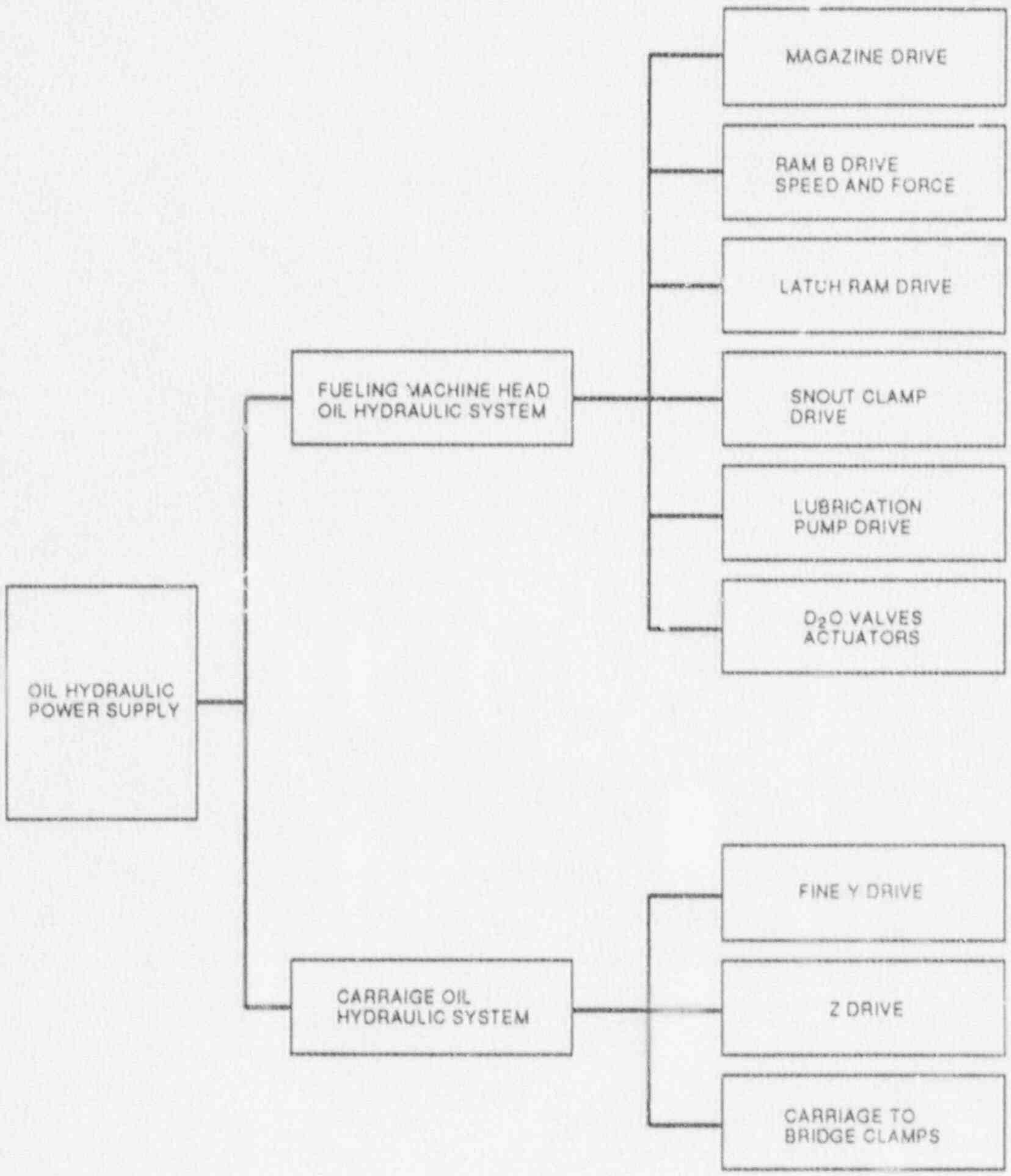


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FIGURE 3-56 FUELING MACHINE OIL HYDRAULIC SYSTEM BLOCK DIAGRAM

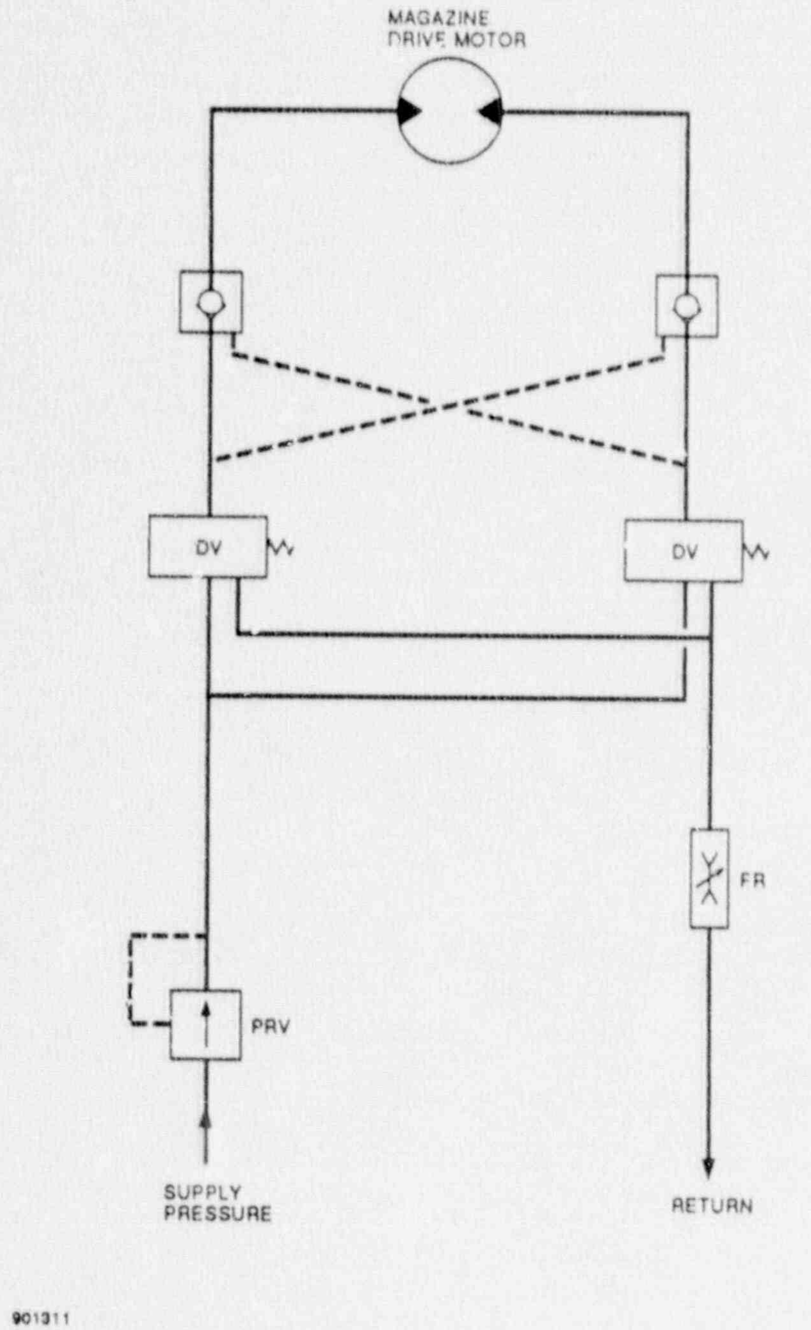


FIGURE 3-57 FUELING MACHINE MAGAZINE DRIVE

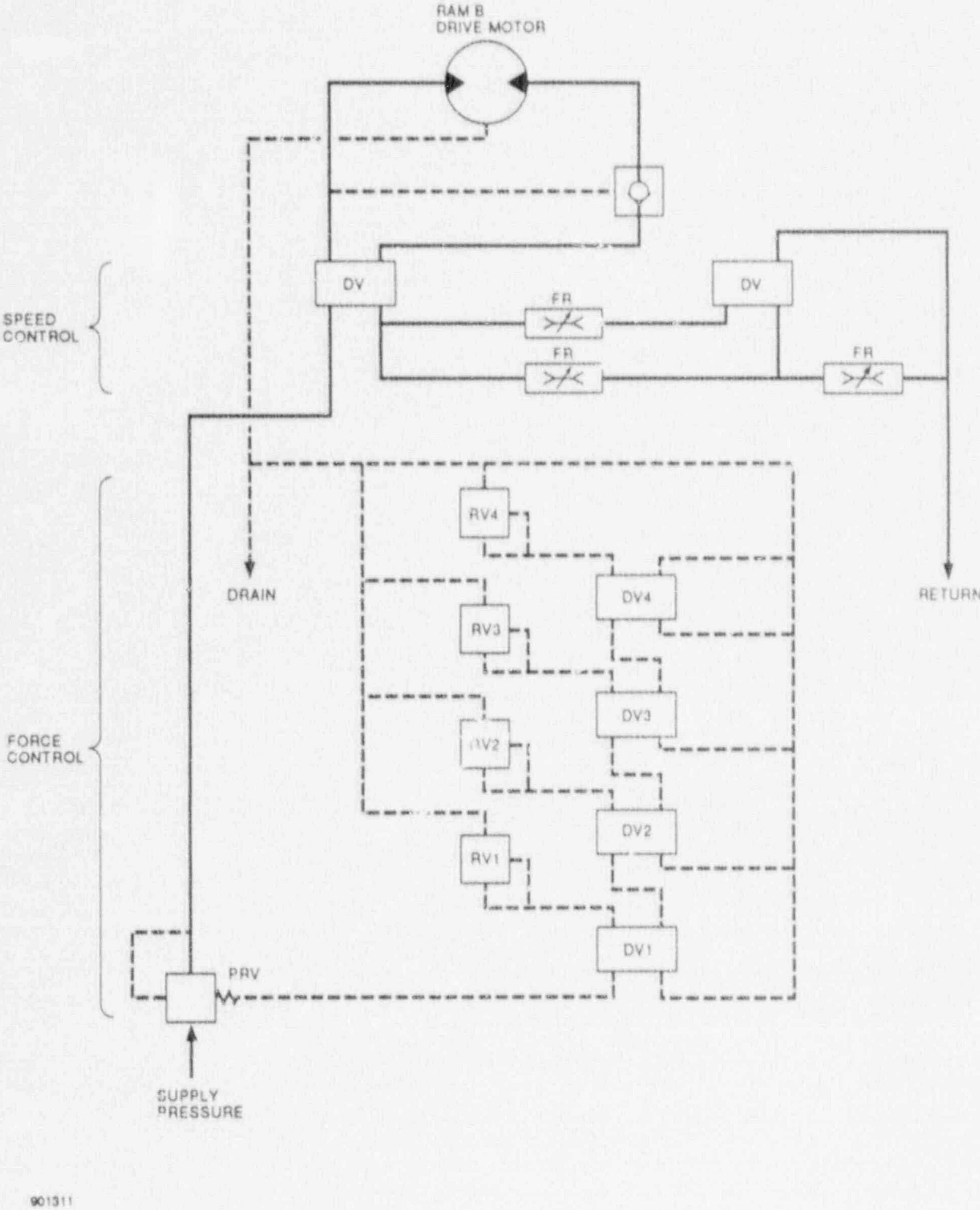


FIGURE 3-58 FUELING MACHINE RAM B DRIVE SPEED AND FORCE CONTROL

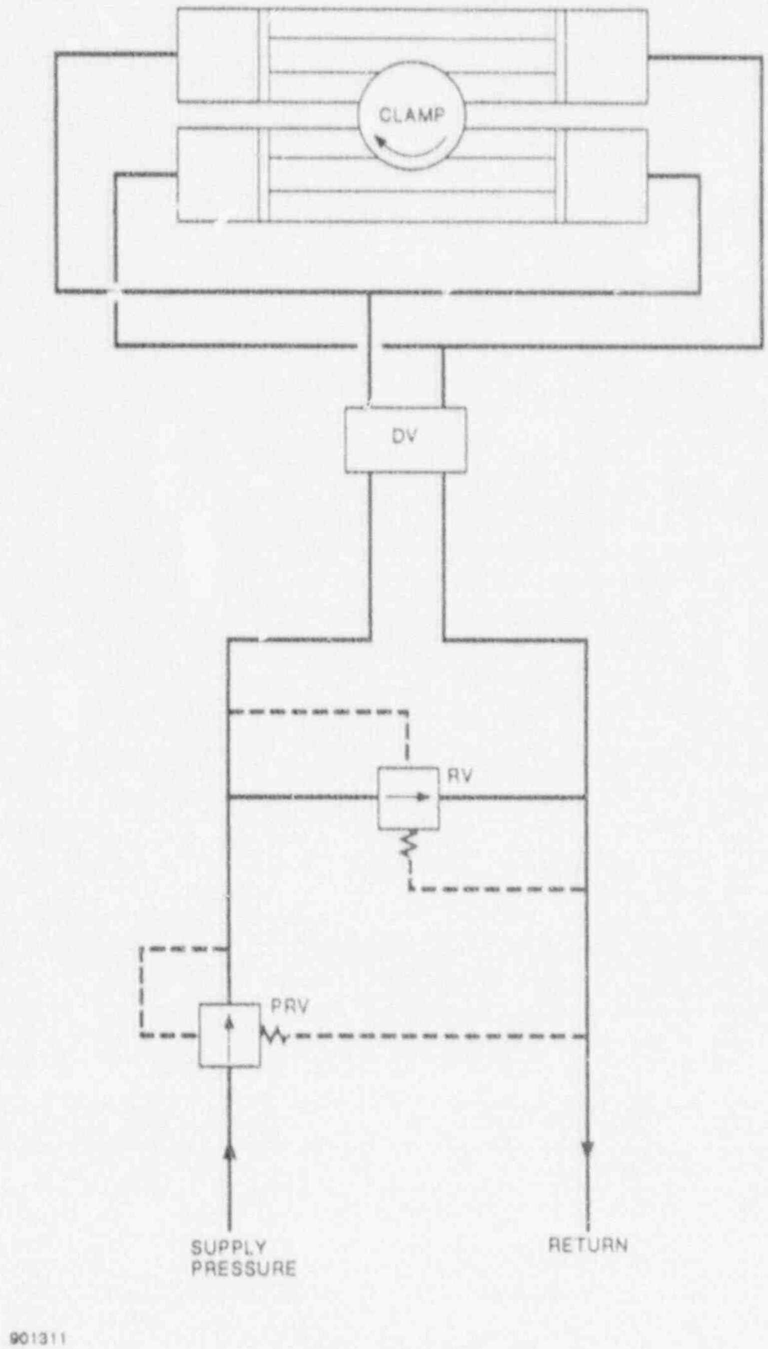


FIGURE 3-59 FUELING MACHINE SNOUT CLAMP

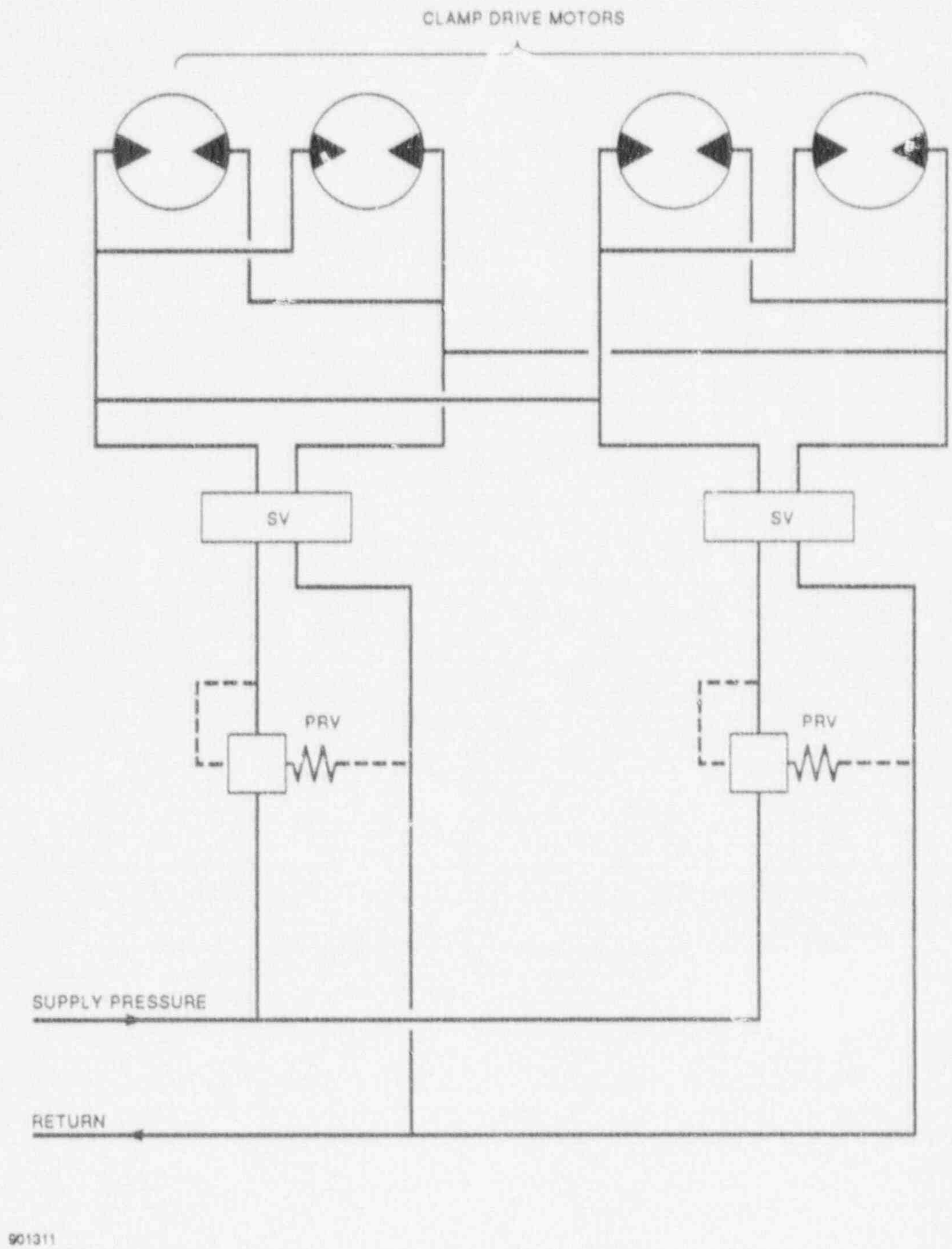
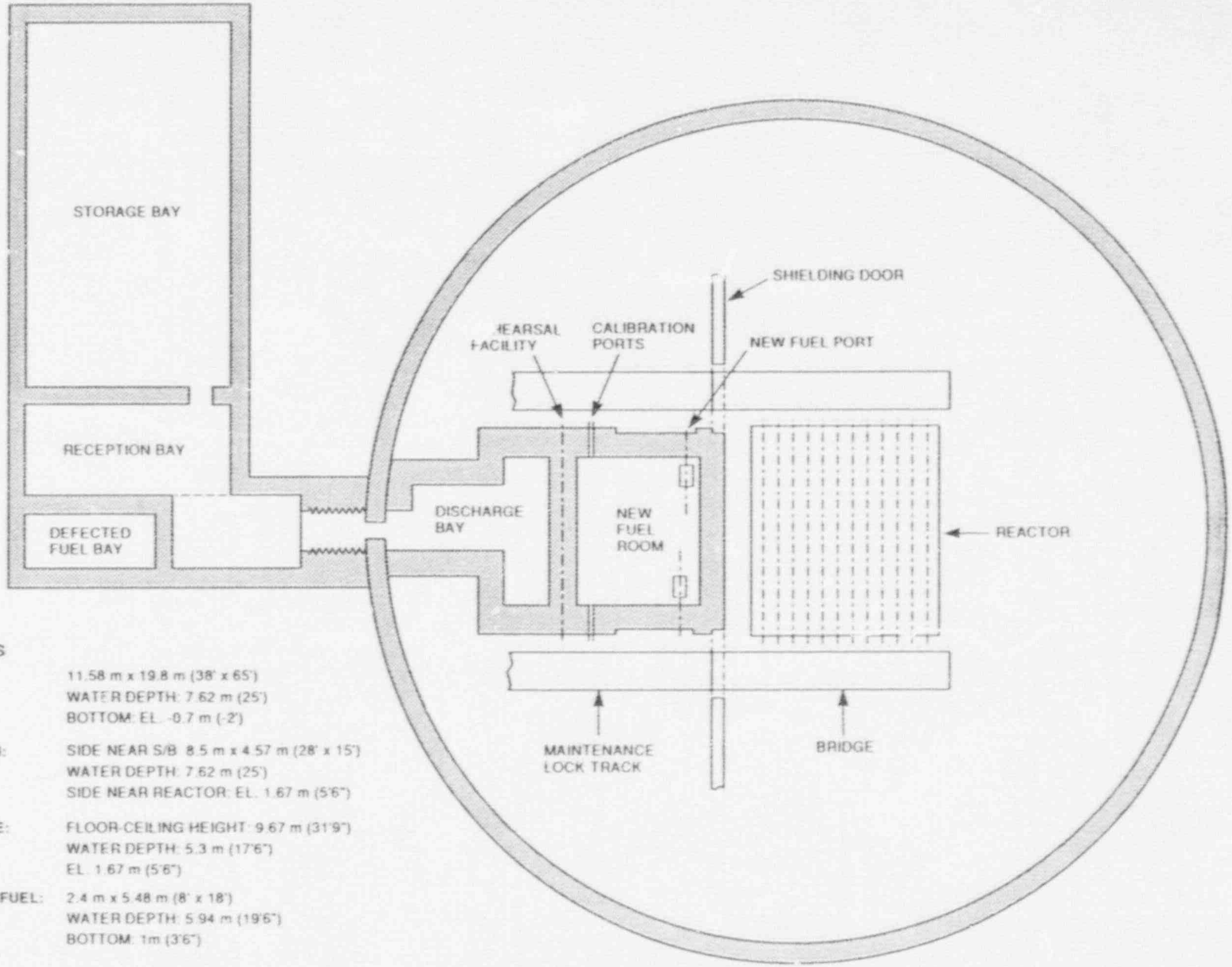


FIGURE 3-60 FUELING MACHINE CARRIAGE-TO-BRIDGE CLAMPS



DIMENSIONS

STORAGE:	11.58 m x 19.8 m (38' x 65') WATER DEPTH: 7.62 m (25') BOTTOM: EL. -0.7 m (-2')
RECEPTION:	SIDE NEAR S/B 8.5 m x 4.57 m (28' x 15') WATER DEPTH: 7.62 m (25') SIDE NEAR REACTOR: EL. 1.67 m (5'6")
DISCHARGE:	FLOOR-CEILING HEIGHT: 9.67 m (31'9") WATER DEPTH: 5.3 m (17'6") EL. 1.67 m (5'6")
DEFECTED FUEL:	2.4 m x 5.48 m (8' x 18') WATER DEPTH: 5.94 m (19'6") BOTTOM: 1m (3'6")

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FIGURE 3-61 REACTOR AND IRRADIATED FUEL BAYS

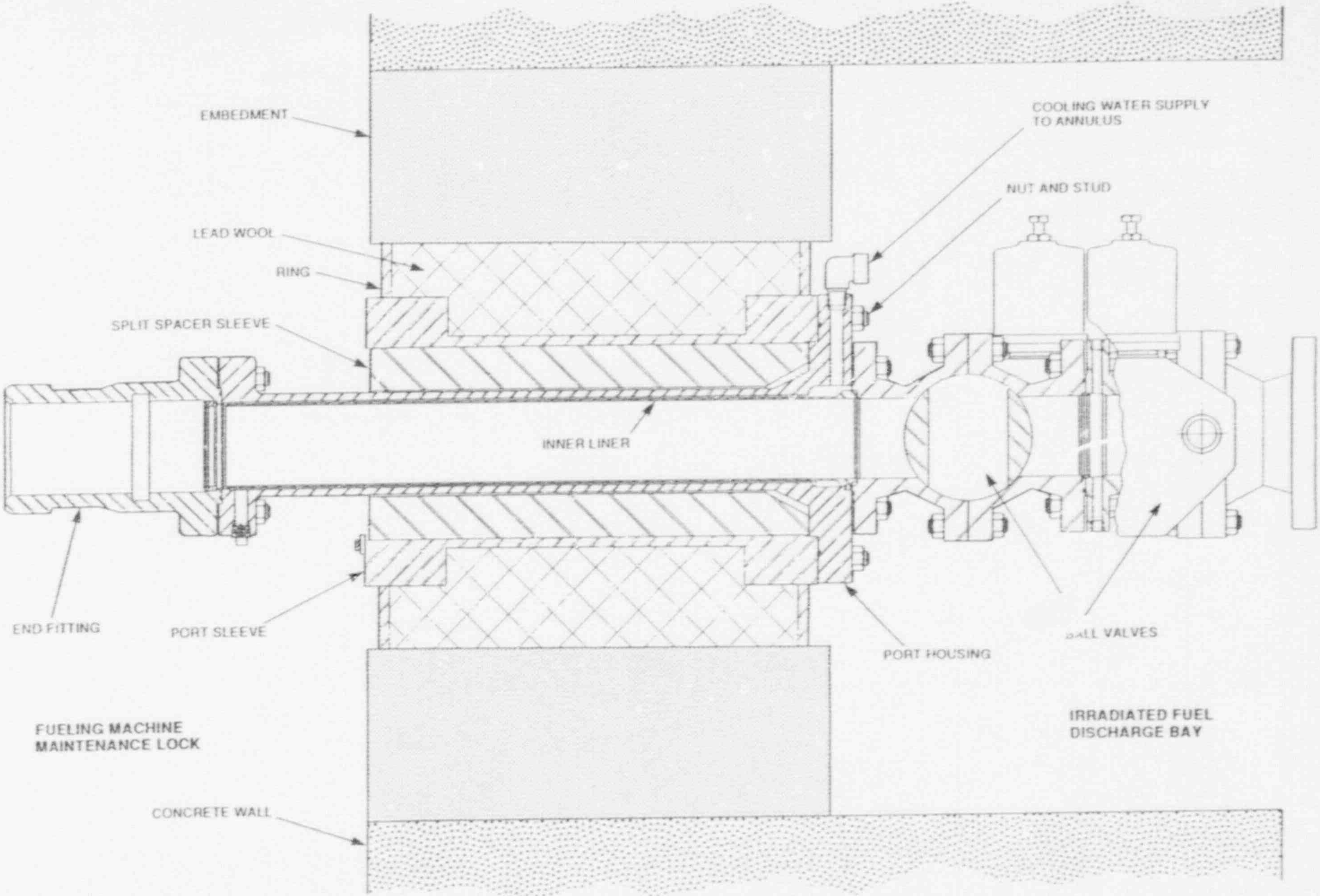
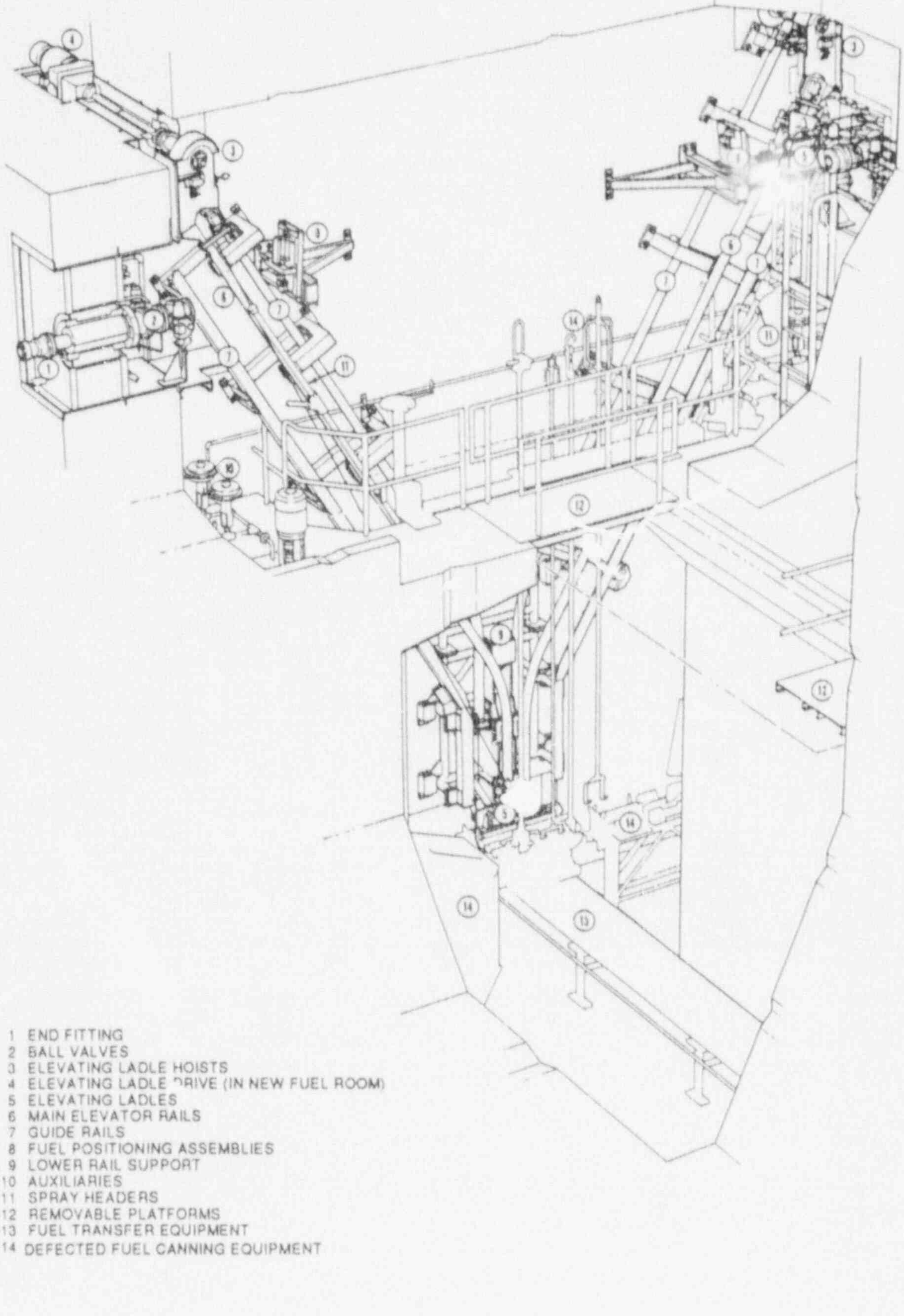


FIGURE 3-62 IRRADIATED FUEL PORT



1 END FITTING
2 BALL VALVES
3 ELEVATING LADLE HOISTS
4 ELEVATING LADLE DRIVE (IN NEW FUEL ROOM)
5 ELEVATING LADLES
6 MAIN ELEVATOR RAILS
7 GUIDE RAILS
8 FUEL POSITIONING ASSEMBLIES
9 LOWER RAIL SUPPORT
10 AUXILIARIES
11 SPRAY HEADERS
12 REMOVABLE PLATFORMS
13 FUEL TRANSFER EQUIPMENT
14 DEFECTED FUEL CANNING EQUIPMENT

FIGURE 3-63 IRRADIATED FUEL DISCHARGE EQUIPMENT

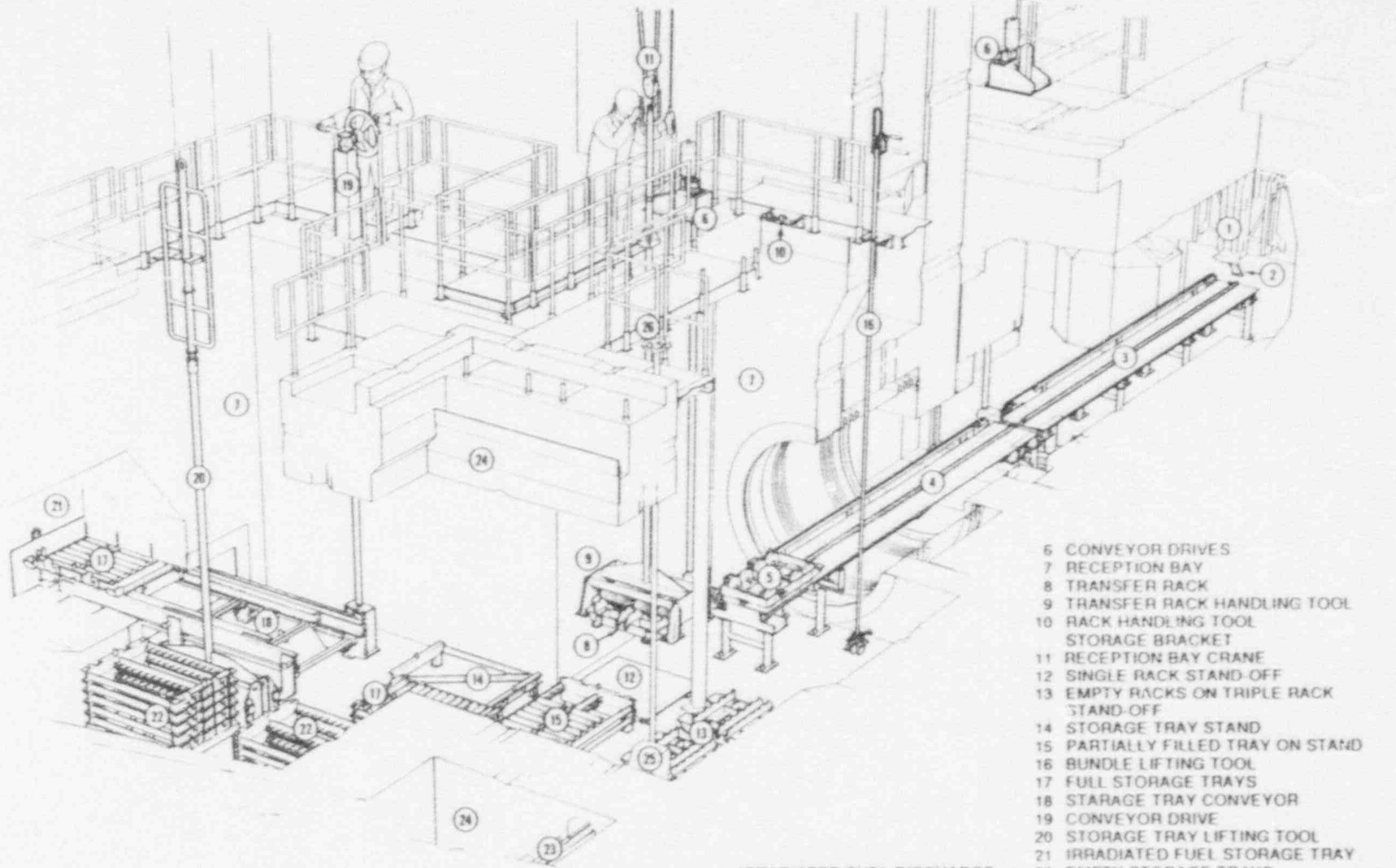


FIGURE 3-64 IRRADIATED FUEL TRANSFER EQUIPMENT

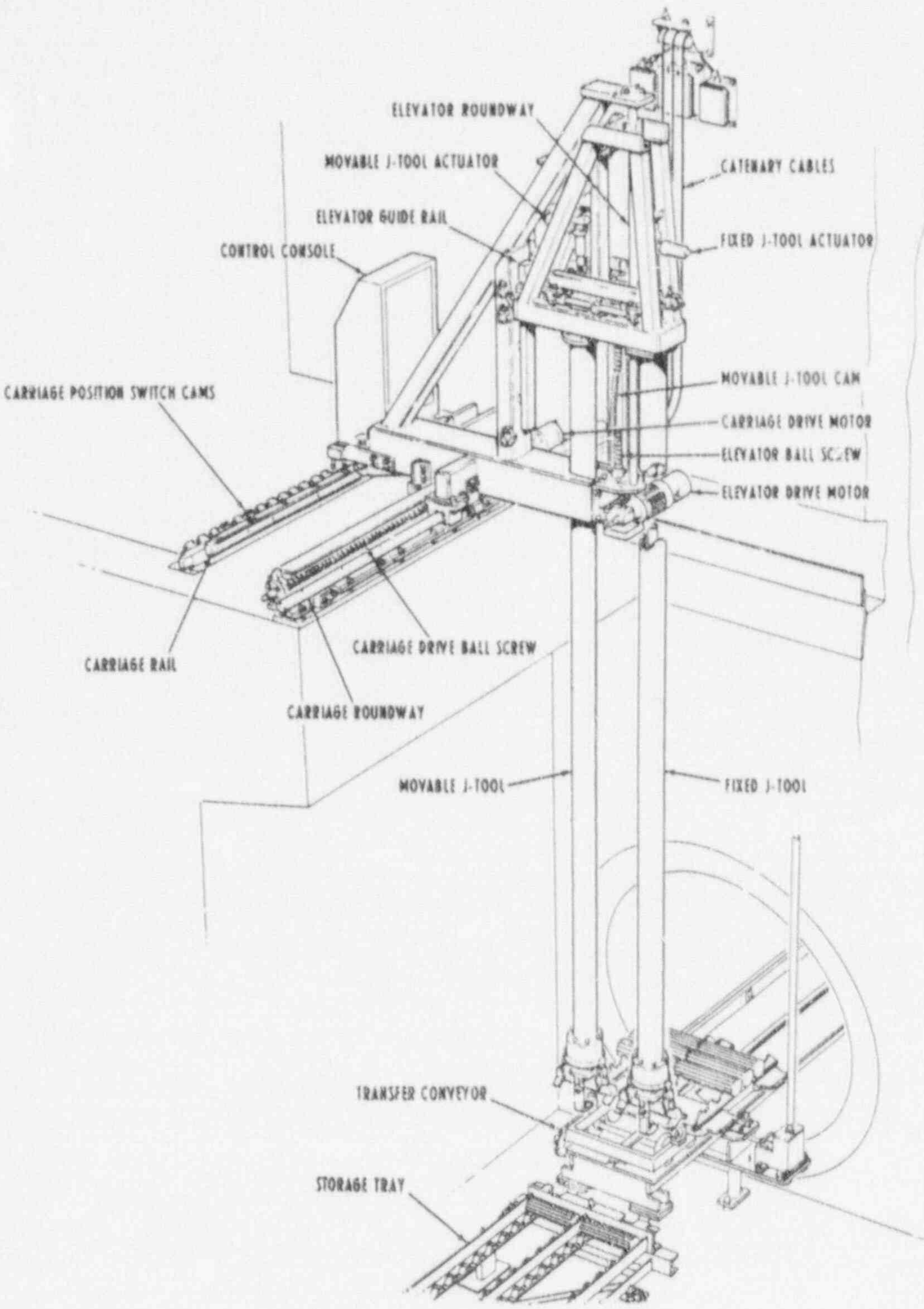


FIGURE 3-65 SEMI-AUTOMATED FUEL HANDLING SYSTEM

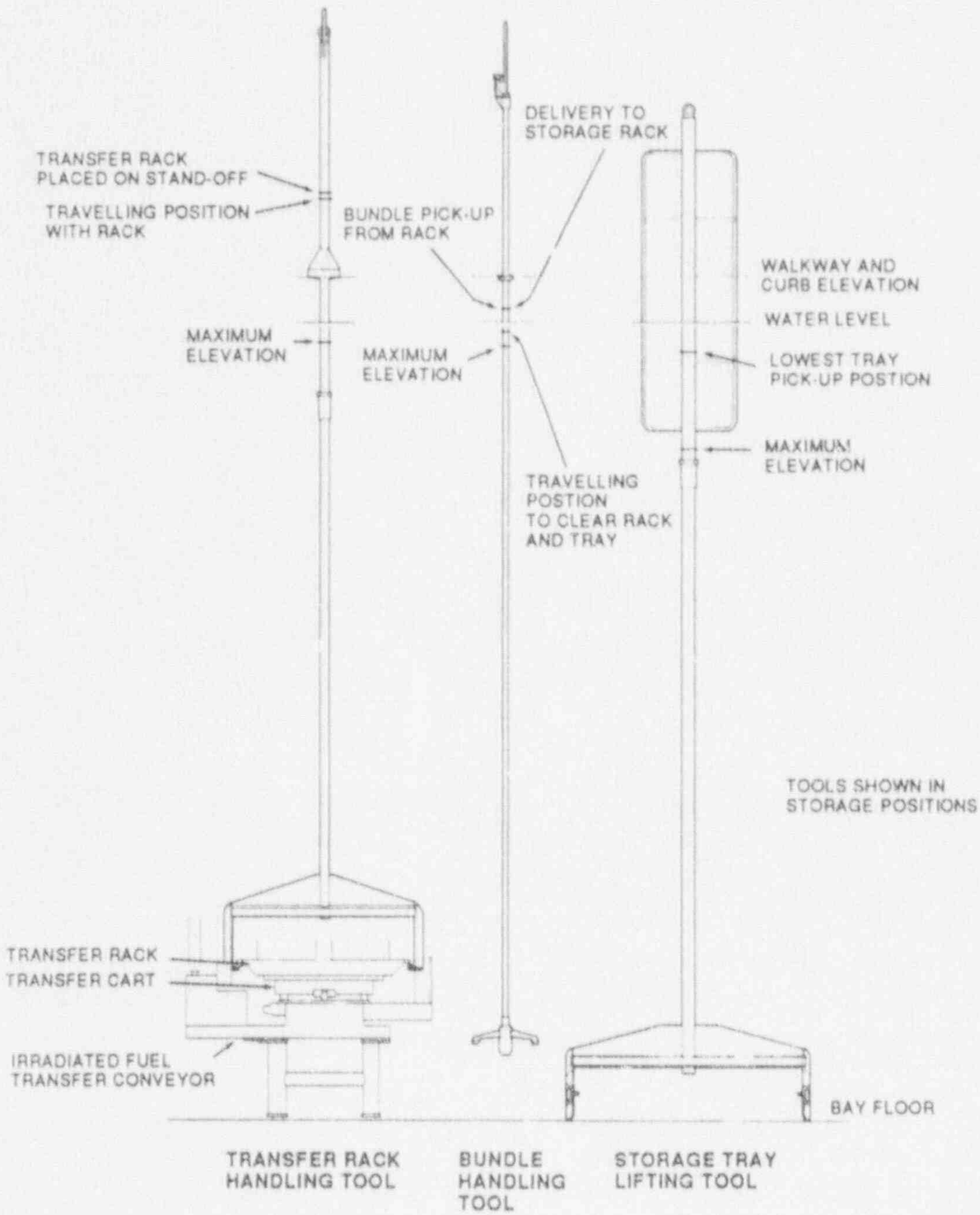
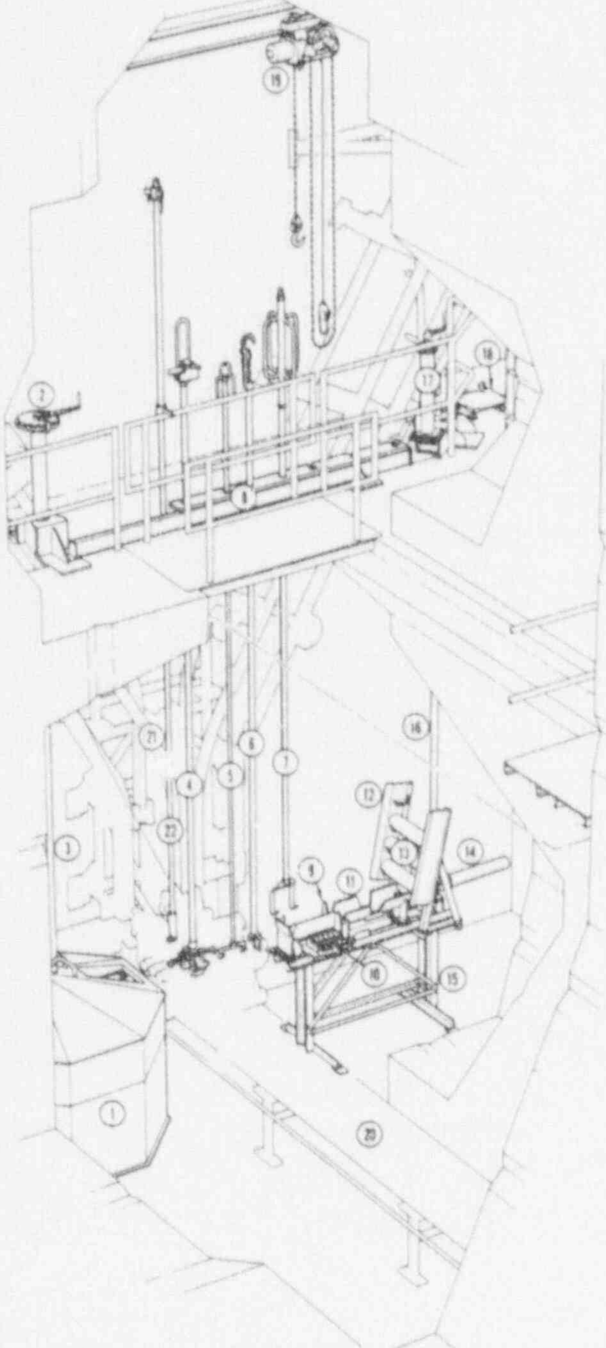


FIGURE 3-66 IRRADIATED FUEL HANDLING TOOLS IN RECEPTION BAY



1 DEFECTED FUEL TEMPORARY STORAGE CAROUSEL
2 CAROUSEL INDEXING DRIVE
3 DRIVE SHAFT
4 FUEL HANDLING TOOL
5 LID STORAGE RACK HANDLING TOOL
6 LID HANDLING TOOL
7 CAN HANDLING TOOL
8 TOOL STORAGE RACK
9 CAN STAND
10 LID STORAGE RACK
11 FUEL TROUGH
12 CAN STORAGE RACK
13 STORAGE CANS
14 LOADING RAM
15 SUPPORT STRUCTURE
16 RAM DRIVE SHAFT
17 RAM DRIVE MECHANISM
18 LID STORAGE RACK ELEVATING TABLE
19 MONORAIL
20 FUEL TRANSFER EQUIPMENT
21 IRRADIATED FUEL DISCHARGE EQUIPMENT

FIGURE 3-67 DEFECTED FUEL TEMPORARY STORAGE AND CANNING EQUIPMENT

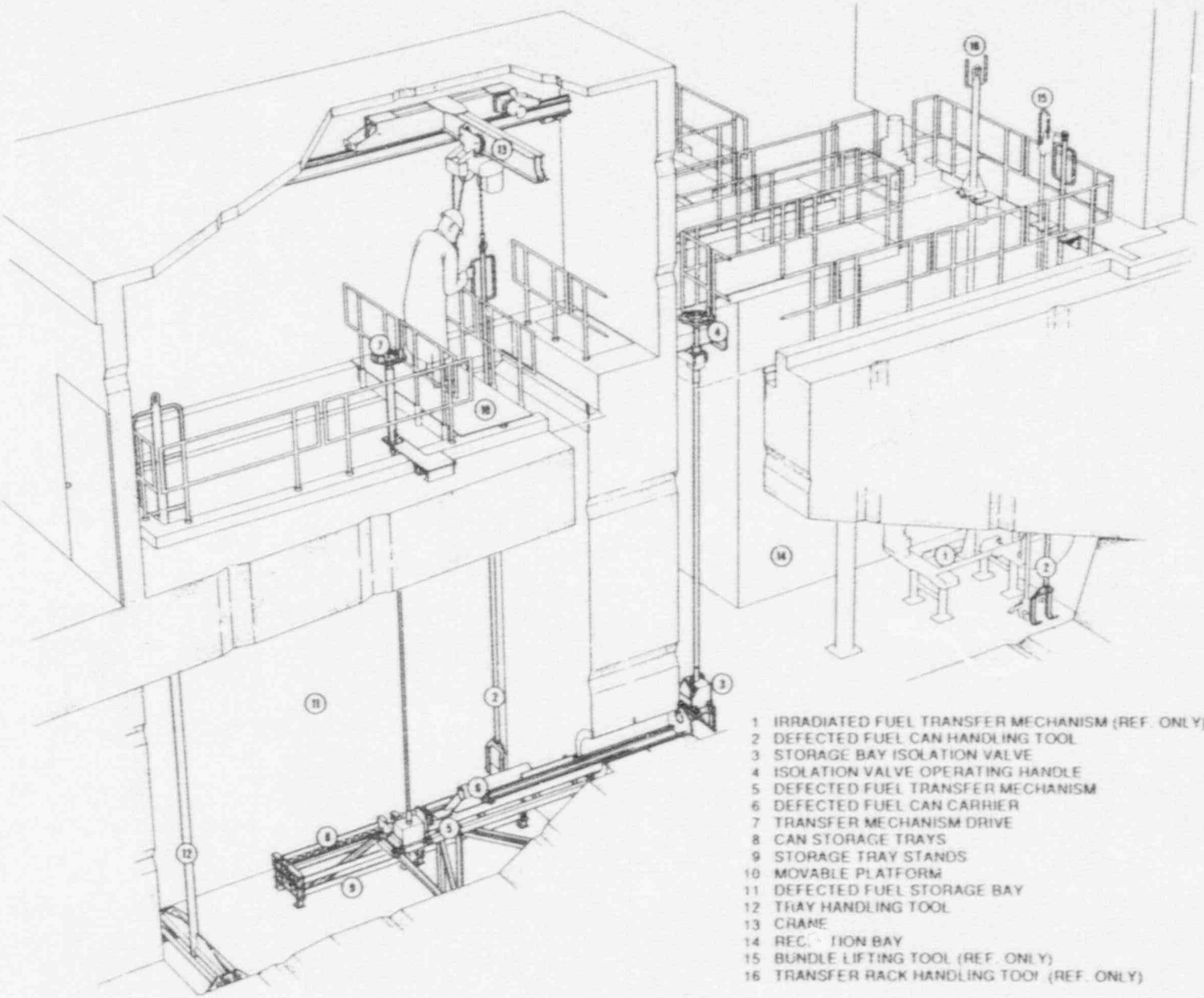


FIGURE 3-68 DEFECTED FUEL HANDLING EQUIPMENT

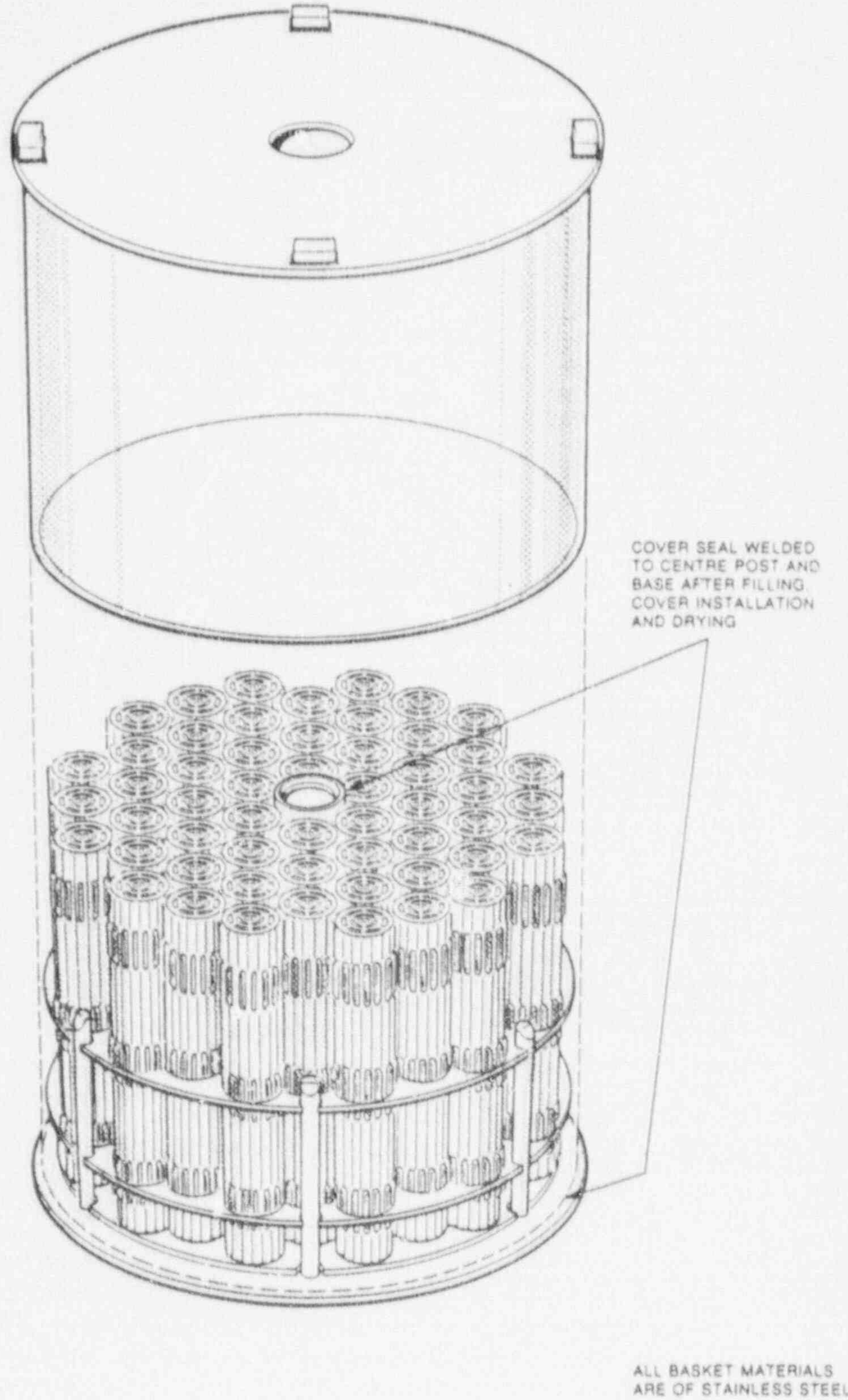


FIGURE 3-69 STORAGE BASKET

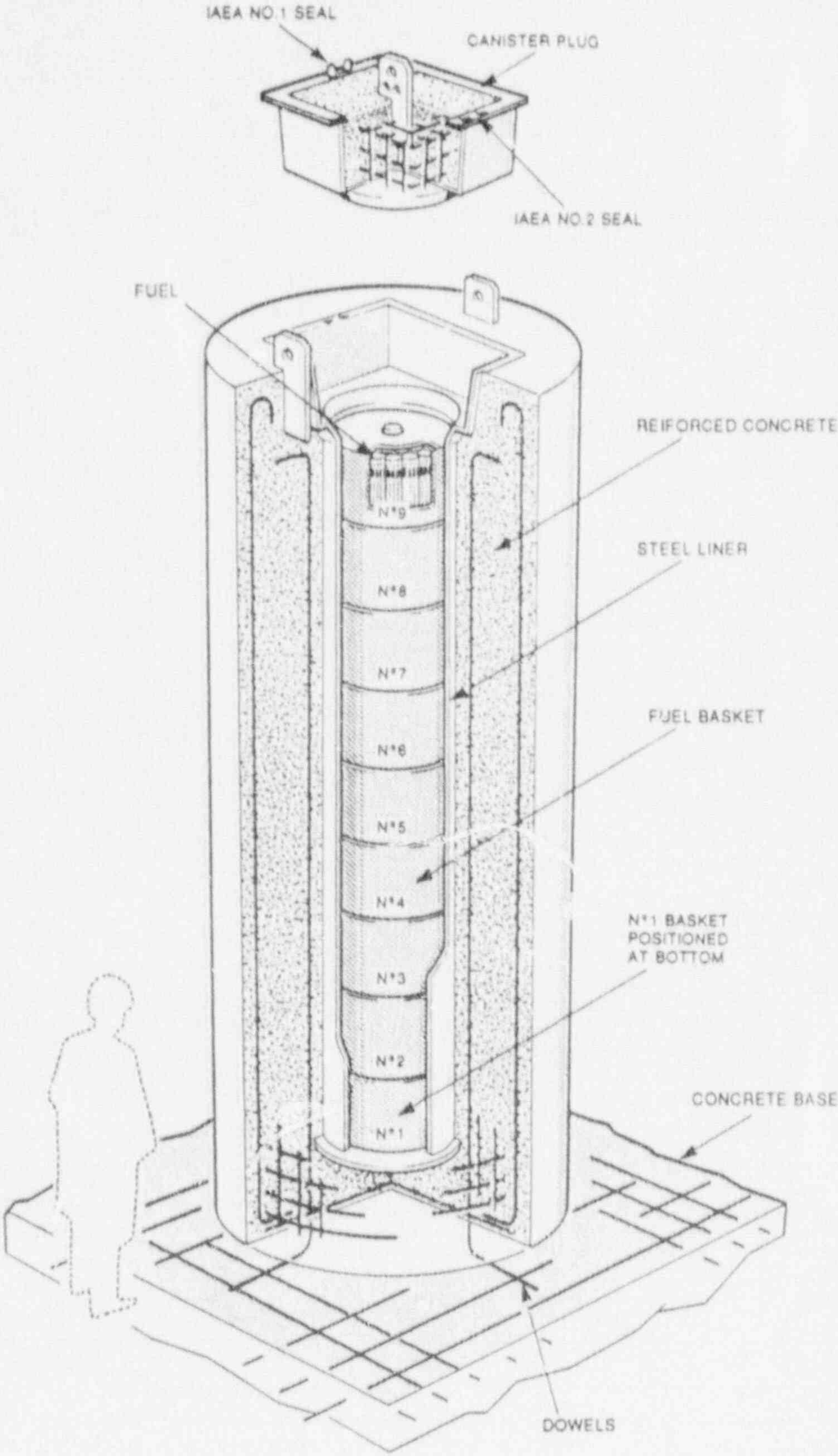


FIGURE 3-70 INTERIM DRY STORAGE CONCRETE CANISTER

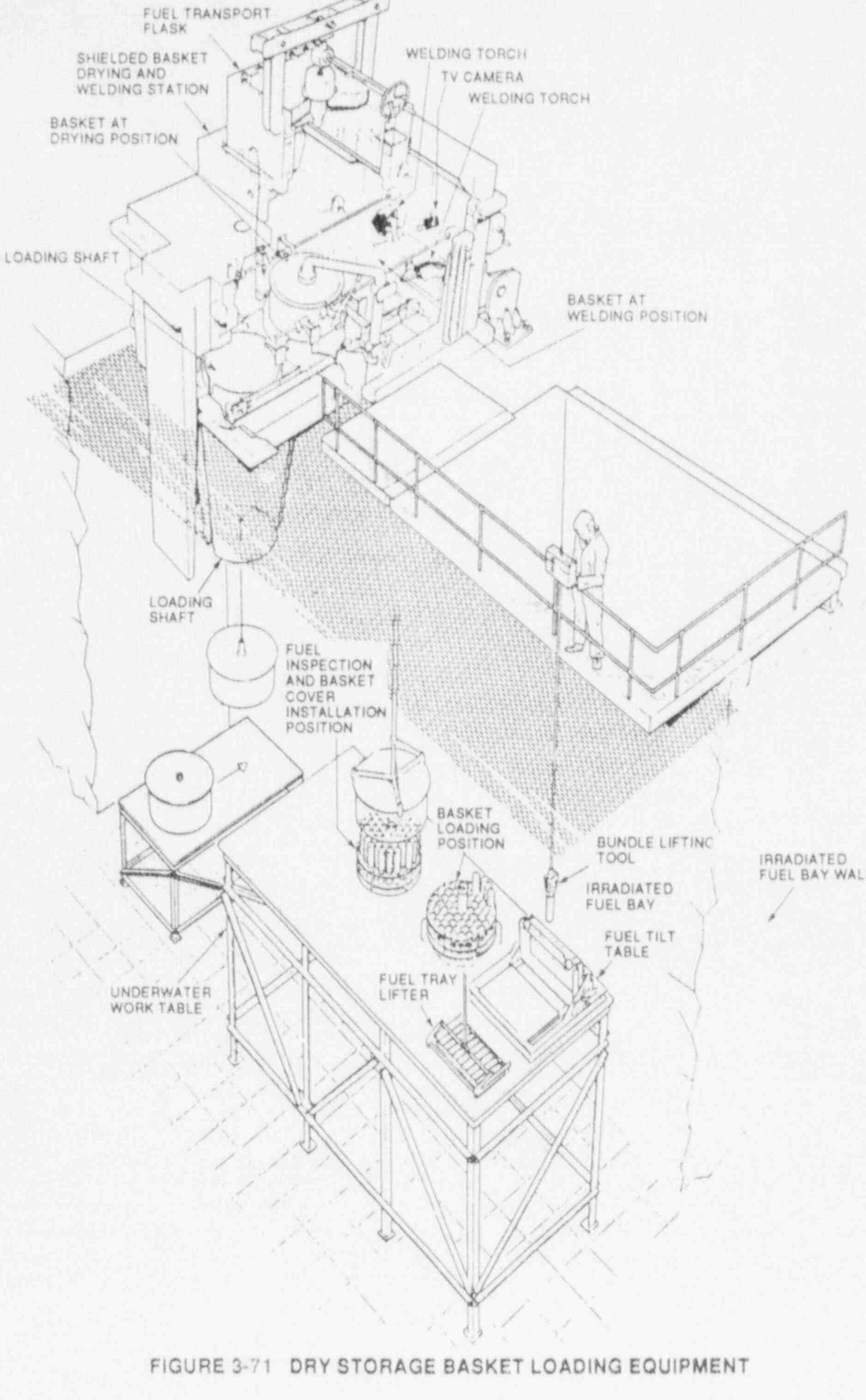


FIGURE 3-71 DRY STORAGE BASKET LOADING EQUIPMENT

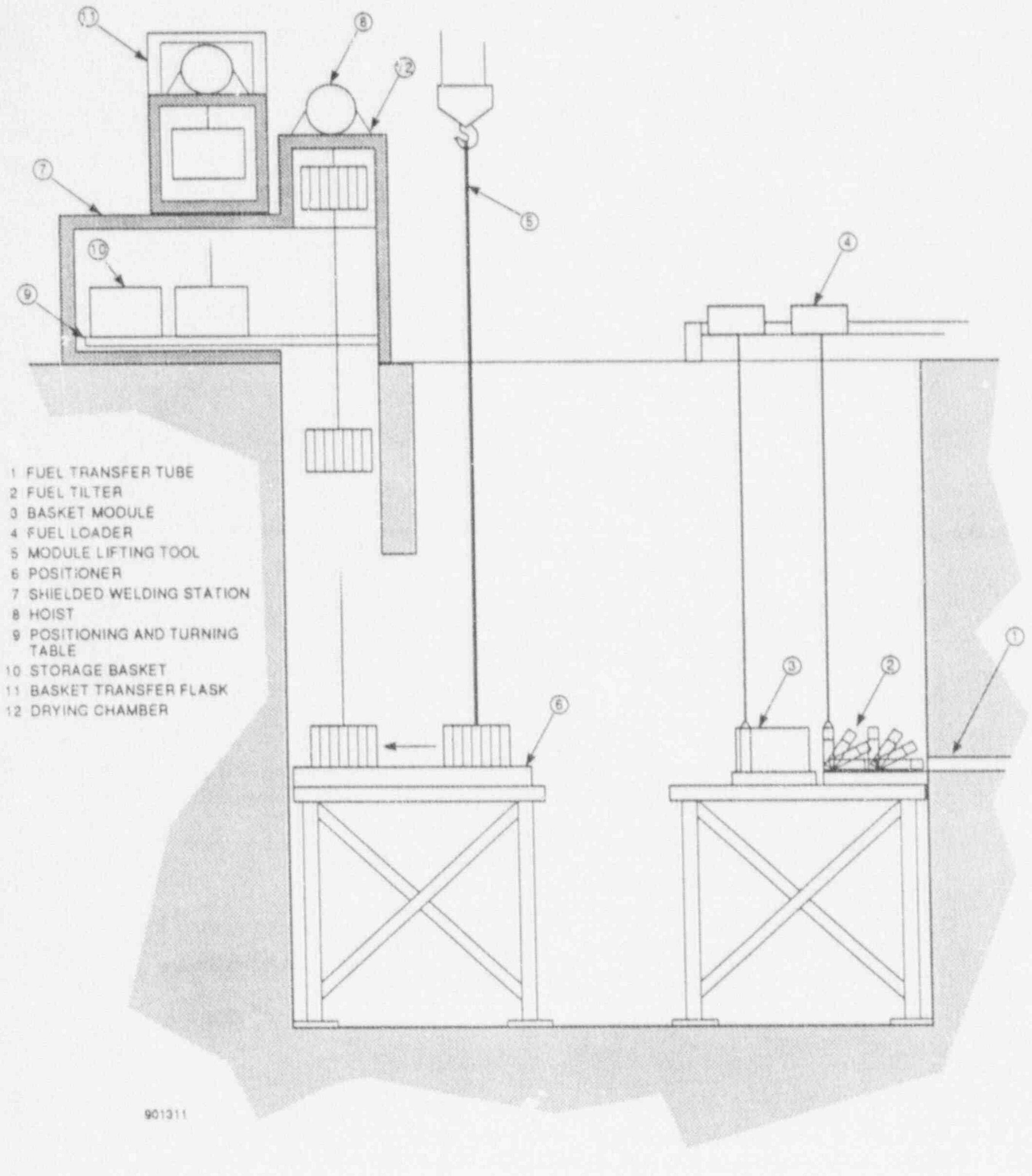


FIGURE 3-72 FUEL HANDLING AND STORAGE OPERATIONS

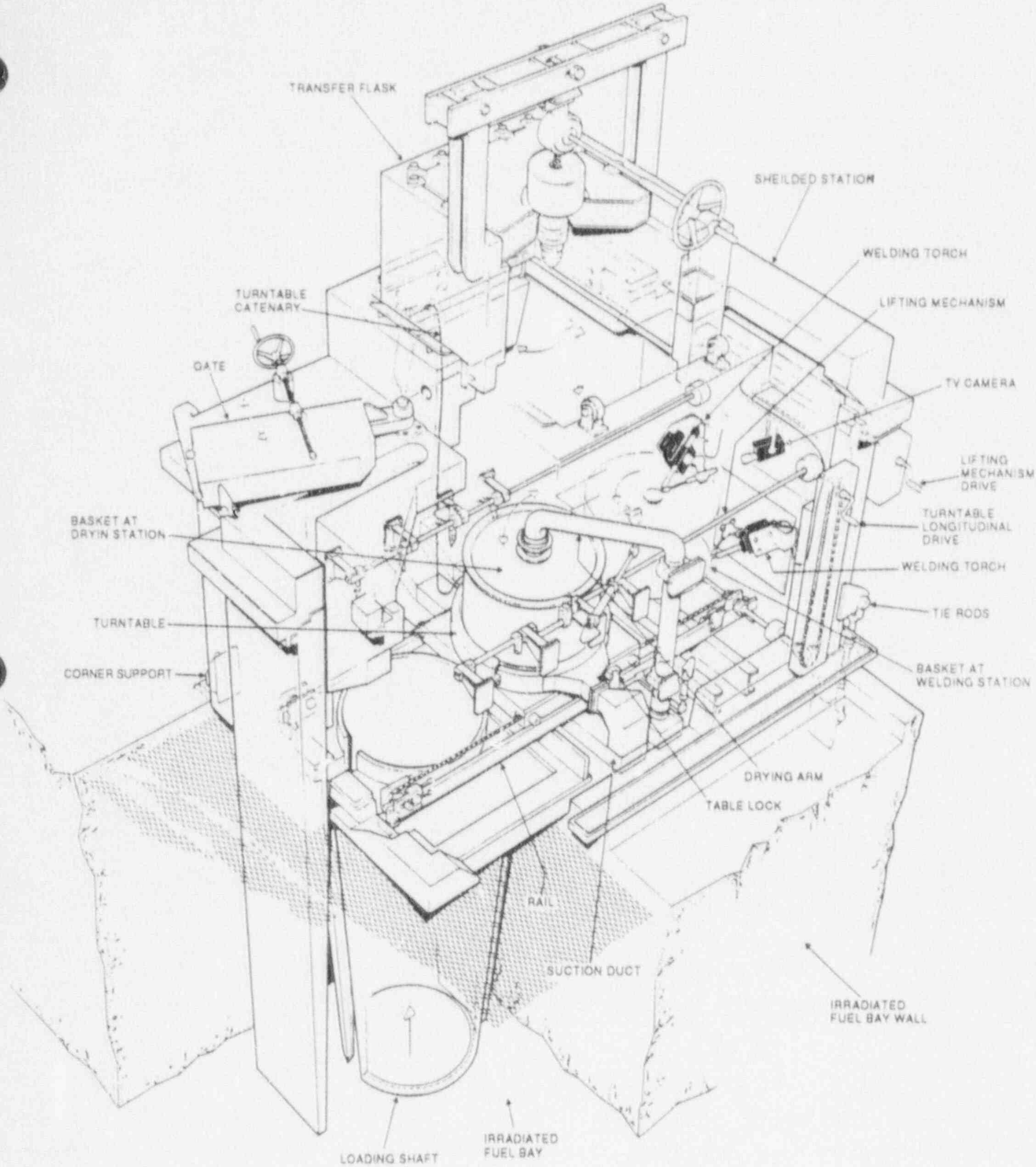


FIGURE 3-73 SHEILDED WORK STATION INSTALLATION

Atomic Energy
of Canada Limited
CANDU Operations

Énergie atomique
du Canada limitée
Opérations CANDU

TTR-305
Rev. 0

CHAPTER 4

ON-POWER FUELING HISTORY

1991 January

AECL CANDU
Sheridan Park Research Community
Mississauga, Ontario, Canada
L5K 1B2

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91/01/24

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ON-POWER FUELING HISTORY
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ON-POWER FUELING HISTORY

INTRODUCTION

The CANDU Owners Group (COG) is an international organization that was formed in 1984 by the Canadian CANDU owning utilities and AECL CANDU. The purpose of COG is to provide a framework that will promote closer co-operation among the utilities owning and operating CANDU stations in matters relating to plant operation and maintenance, and to foster co-operative development programs leading to improved plant performance.

The organization was expanded internationally in 1986 to include the Korea Electric Power Corporation (KEPCO) and the Comision Nacional de Energia Atomica (CNEA) and to include the Pakistan Atomic Energy Commission (PAEC) and Nuclear Power Corporation of India Limited (NPC) in 1989 in the Information Exchange Program.

Reports relating to fueling machine (F/M) and fuel handling have been published by COG and are available to the member organizations.

Continuing development programs serve to further advance the technology of the CANDU fuel handling system. This chapter reviews the operating history, including problem areas, station incapability due to fuel handling and improvements that were made to increase fueling capability.

Technology for the CANDU program that involves the design of water lubricated mechanisms and high pressure shaft seals has been highly developed at AECL CANDU. In conjunction with this technology, substantial test data on galling and wear resistance between different mating materials in water have been accumulated over a number of years. Successful performance of components such as gears, anti-friction ball bearings and ballscrews in a water environment is achieved partially by the proper choice of materials. This basic proven technology that has been developed over the past 25 to 30 years is applied to the operating F/M as well as those under development.

The CANDU 6 F/M is a derivative of the Pickering machine and much of the modular components are nearly identical. Hence, a common development program embraces the two systems. Although the Bruce/Darlington F/Ms are different, there is commonalty in the basic technology. This also applies to the different fuel transfer and storage systems that are tailored to meet the different station requirements. CANDU 6 is a single unit station, whereas Pickering and Bruce/Darlington are multi-unit stations.

In mature operating stations, fueling capability may be affected due to pressure tube In-Service Inspection Programs. Such programs often require the use of some of the fuel handling equipment.

2. MATERIALS

Selection of materials was found to be particularly important in the successful design of the F/Ms. Pressure boundary material must be such that it can be readily qualified to meet the jurisdictional requirements. Mechanisms within the pressure boundary must operate in moving contact without galling and with low friction and wear characteristics, while immersed in water.

Much of the CANDU F/M head pressure boundary components are constructed from martensitic stainless steel because of its relatively high strength. However, with this material, qualification to meet the jurisdictional requirements of the heat affected zone of any welded joint was found to be very difficult. As a result, welding has been eliminated from housing components specifying this material.

Similarly, it was found that weld qualification of precipitation hardening material was difficult and Inco 600 has been used instead on some F/Ms. Inco 600 is similar to austenitic stainless steel in that it does not exhibit a nil ductility temperature, hence weld qualification is relatively simple. Where stress requirements justify its use, austenitic stainless steels have been used on the pressure boundary. Precipitation hardening stainless steels have been used only where welding was not necessary.

Strength, wear characteristics and economy are some of the factors which dictate materials used in sliding contact in water.

Nitriding of stainless steels has been used extensively to provide good wear resistant, low friction surfaces. However, nitriding reduces the corrosion resistance property of the stainless steel, such that when components are immersed in cold water for any length of time, severe corrosion takes place. When the nitrided components were continuously immersed in hot water, they were found to give satisfactory service. Where hard wear resistance surfaces are required, chromium plating provides an excellent surface.

Successful development of water lubricated gears, anti-friction bearings and ballscrews were results of satisfactory material combinations. Otherwise, their basic designs are nearly identical to their standard grease or oil lubricated applications.

3. BALLSCREW ASSEMBLIES

A ballscrew assembly is a device comprising a screw and a mating nut with a complement of bearing balls for translating rotary motion to linear motion or vice versa. Its mechanical efficiency is more than 90% when converting torque to thrust.

Ballscrews have been used on CANDU F/M ram assemblies in water lubricated applications, as well as in a more conventional application for vertical motion of the F/M using grease or oil lubrication. This report will deal with ballscrew applications in a water environment.

3.1 APPLICATION

The F/M ram is a severe application for a ballscrew assembly in that the device must operate unlubricated, in water. In some applications, the ballscrew acts as the ram itself and penetrates the reactor fuel channel end fitting environment. On other applications, the ram only needs to reach the channel closure, hence it is only exposed to the lower temperature of the F/M magazine housing. For some of these applications, the rotation of the ballnut has resulted in linear actuation of the ballscrew.

The operating temperature of the ballscrew assembly in the CANDU 6 ram is kept at the F/M temperature. The operating temperature is a significant factor in the selection of materials.

3.2 DESIGN

The ballscrew assemblies which are specified for CANDU F/M generally incorporate deflectors that are separate from the return tubes. A ballnut may have one, two, three or more circuits of balls in an assembly; this usually depends on the proprietary design being considered.

Ballscrews without separate deflectors, but incorporating pick-up fingers on the return tubes have been used on some applications with relatively small ball sizes. With this design, jamming of the balls could occur, should the pick-up fingers fail.

Development testing of cross–over ballnuts was also carried out with limited success. Cross-over ballnuts incorporate transfer inserts to form a cross-over path, which guide the balls internally from the end of the circuit to the start of the same circuit. The contour of the cross-over path is critical to ensure smooth ball transfer. It was concluded that some development testing was required for each new application to optimize the cross-over path. The advantage of this design is that return tubes and deflectors are eliminated.

A variation of the cross-over design featuring an internal axial ball return path in the ballnut has also been tested.

3.3 MATERIAL

Precipitation hardening stainless steels have been used for the ballscrew and ballnut components.

For ballscrews which act as the ram itself and are exposed to high temperatures in the reactor fuel channel end fitting, the hardness has been limited to preclude stress corrosion cracking. The mating nut remains within the F/M with relatively lower operating temperatures, hence hardness has been specified without danger of stress corrosion cracking.

Generally, the ballscrew outlasts the ballnut, hence a worn nut can usually be replaced with a new one on the original screw.

3.4 BALLSCREW

The ballscrew thread form is either a single uniform radius or Gothic arch configuration. Some manufacturers favour the Gothic arch since it permits control of the contact angle between the balls and races for optimum performance.

Backlash on the ballscrew assembly is important to ensure smooth operation. Gothic arch configuration allows more flexibility in the control of backlash.

Single start threads are most commonly used. However, multiple thread starts have been used where the application required such a design.

Lead error on the thread is controlled to ensure smooth operation. The lead is generally selected so that the screw will possess backwinding capabilities.

In the event that the F/M ram is stalled against a component in the reactor fuel channel end fitting, and the ram cannot be retracted for an extended period, backwinding capability of the ballscrew could relieve any high compressive stresses which may be generated due to differential thermal expansion.

Straightness of relatively long ballscrews should be controlled to ensure smooth operation. It is important that the screw be stress relieved following any straightening operation. Otherwise, the high temperature service environment will tend to relieve the entrapped bending stresses and the ballscrew will partially revert to its original bent condition. Different techniques are available for straightening bent ballscrews.

3.5 BALLNUT

The ballnut will usually wear faster than the ballscrew, since the wear will be more uniformly concentrated over a smaller area. In the most extreme case, the deflectors or pick-up fingers on the return tubes will begin to rub on the side of the ballscrew thread form, after sufficient wear occurs. However, corrective steps can be taken well before this occurs.

At the extreme ends of travel of the ballscrew assembly, provision can be made so that the ballnut does not jam as a result of wedging action. Ballscrew assemblies with small lead angles are particularly susceptible to jamming, unless provision is made to prevent the wedging action from happening. One possible solution involves provision of a mechanical stop so that at the extreme ends of travel, radial contact of separate screwed and nut mating stops will prevent the wedging action from taking place. A relatively large lead angle on the thread will also tend to alleviate this situation, but other factors such as desirable speed and torque must be considered.

When balls fail to recirculate, skidding results. This is evidenced by equally spaced brinnel marks near the entrance of the ball return passage holes.

3.6 RETURN TUBES

Return tubes which guide the balls from the end of the circuit to the start of the same circuit are often made from formed tubing. It is imperative that bending of the tubes does not restrict the smooth passage of the balls.

Some manufacturers make the return tube in two halves to ensure a uniform passage for the balls. However, this design often leads to possible mismatch between the two halves when constructed from tubing. AECL CANDU has developed an improved robust design, whereby the two halves of this component are machined from barstock to overcome any mismatch.

3.7 DEFLECTORS

To understand the ball recirculation system, an understanding of the ballscrew assembly detail is required. Ball circuits consist of a quantity of balls which are intended to roll along the thread as either the ballscrew or ballnut is rotated. The balls have to be continuously picked out of the thread and returned back to the thread during the motion. This is achieved by "ball deflectors" inserted in the ball path which deflect the balls into return tubes (or ports) which allow the balls to transfer out of the thread and travel along the return tube for re-insertion back into the thread, upstream of the linear movement.

The face of the deflectors must provide a smooth passageway with the ball return passage. Any appreciable mismatch will impede the smooth passage of the balls. Some manufacturers will hand fit each deflector to ensure a smooth passage. This, however, results in time-consuming maintenance, especially if any deflector requires replacement.

The face of the deflectors is subject to repeated impact of the balls as they are deflected into the return path. Early development experience indicated that a hardened face would be required.

On some ballnut designs, separate deflectors may not be incorporated. Such a design will be furnished with pick-up fingers on the return tubes, which extend into the ballscrew groove, in a manner similar to a deflector. Should the pick-up fingers break off, it is possible to cause jamming, since the balls may no longer deflect into the return tubes in the normal manner. Wear of the pick-up fingers on the return tube may also be a problem since hardening techniques would be limited on the relatively thin wall of the return tube.

3.8 BALLS

Balls must be of uniform size and should be used in matched sets. Size variation could result in only the large size balls carrying the load, whereas the smaller balls are not loaded at all. As each ball enters the recirculating passageway, it must displace all of the other balls within the same circuit in a chain reaction. If the number of balls is relatively high, balls may have difficulty in recirculating uniformly. The ball size can be increased in any new design to reduce the number of balls per circuit, or multiple ball circuits can be used. Alternatively, manufacturers often incorporate spacer balls. That is, each alternate ball is slightly undersized so that only the alternating larger balls carry the load. This results in improved recirculation, but the life of the assembly is reduced due to higher concentrated loading on the load carrying balls alone. AECL CANDU has specified some plastic balls as spacers to reduce the wear rate relative to metal spacer balls. It is important that the chosen plastic material is compatible with the water chemistry. With plastic spacer balls, more frequent maintenance may be required.

The balls are radiographed in two planes to ensure that no cracks are present. However, this is a time consuming process since each ball must be re-oriented for the second set of radiographs. AECL CANDU has developed a more efficient method which combines radiography and eddy-current method of non-destructive examination.

3.9 QUALIFICATION TESTING

Each new or rebuilt ballscrew assembly is immersed in a water-filled test rig and cycled under simulated loading for about 200 cycles as a part of the qualification program. This is to avoid any unnecessary disassembly and servicing after installation in the F/M, due to any malfunction.

Before any ballscrew can be purchased from a supplier for use in an operating F/M, an extensive test program is carried out to qualify the product.

4. ANTI-FRICTION BALL BEARINGS

During development of water lubricated anti-friction bearings, various corrosion resisting material combinations were tried. Simultaneously, mechanical modifications were incorporated in angular contact bearings in an attempt to alleviate excessive retainer wear, high torque, and some skidding in the raceway.

In one scheme, the retainers were segmented into three separate pieces. At the recommendation of one manufacturer, unloading chutes were provided singly or in multiples in either of the races. The unloading chutes were basically a small local relief in the ball groove in the race to allow each ball to become unloaded during each revolution. Tests carried out by the bearing manufacturer indicated reduced wear rates. However, when bearings were procured on competitive tender, some angular contact bearings were purchased without unloading chutes since it was a proprietary design, available from a sole source.

As a result of development and qualification testing, it was found that proper material combination was the successful key for water lubricated anti-friction bearings and mechanical modifications were unnecessary.

4.1 APPLICATION

Due to the relatively high cost of stainless steel ball bearings, a minimum number are used within the pressure boundary of the F/M.

Where possible, the shaft penetration into the pressure boundary uses grease lubricated ball bearings externally to resist the axial thrust due to the pressure differential, and uses the internal water lubricated ball bearings to carry only radial loads. However, care is taken to ensure that installation and maintenance features of the design are not jeopardized.

4.2 DESIGN

The retainer is centered on the race so that it will not jam as a result of looseness caused by wear. Retainers centered on the rolling elements could cause jamming, if they were allowed to wear excessively.

Angular contact bearings are specified as matched sets. Deep groove ball bearings feature Conrad construction, with riveted retainers. Radially split ball bearings with one piece retainers, which allow an additional ball for any fixed geometry, have also been used successfully.

Roller bearings are not recommended since the ends of the rollers tend to gall due to sliding contact, and not rolling contact, as in ball bearings.

4.3 MATERIAL

During development testing, carbon steel ball bearings have been used in water lubricated applications with limited success. Bearings have been autoclaved to provide a wear resistant oxide coating to improve their performance. Some dimensional change was found to occur after oxidizing, depending upon the initial heat treatment. Alternatively, carbon steel bearings were fitted with stainless steel balls with limited success during development testing as an economical readily available scheme. It has also seen limited short term applications on operating F/Ms.

4.4 RATING LOAD/LIFE

In calculating the rating life of water lubricated anti-friction bearings, standard formulae must be modified to take account of the lubrication conditions. In the conventional application, the bearing lubricant provides a film separating the balls from the races, and that the bearing fails due to fatigue. With water lubricated bearing, there is no film separating the balls and the races, with direct rolling contact resulting. Consequently, the failure mechanism is wear, not fatigue. Accurate prediction of ball bearing wear life is very difficult, thus conventional formulae are applied with various modifications, varying from one bearing manufacturer to another.

4.5 QUALIFICATION

Anti-friction bearings for water lubricated applications are subjected to qualification testing in the laboratory before they were approved for use on operating F/Ms.

5. SEALS

Both dynamic and static types of seals are used in the F/M to seal water/air and water/oil interfaces.

Temperature, process medium and radiation are prime considerations which affect seal selection.

Commercially available seals were generally adequate to meet the requirements. However, AECL CANDU has developed rotary shaft seals to achieve improved performance compared to those normally available on a commercial basis.

5.1 DYNAMIC SEALS

5.1.1 Rotary Shaft Seals

Commercially available hydrodynamic balanced shaft seals were incorporated in the Douglas Point F/M which was the predecessor to the CANDU F/M.

The magazine shaft seal which was subjected to relatively low intermittent speed provided trouble-free service. However, the higher speed rotary shaft seals used on the ram assembly faced problems associated with inconsistent high torques which affected ram force control. This was partially resolved by reducing the shaft size, and thus the seal size so that the seal friction was reduced to a smaller percentage of the overall torque. That is, if the operating torque of the mechanism is considerably greater than the seal friction, variation or a small increase in the torque due to the shaft seal will become insignificant.

In the subsequent Pickering and CANDU 6 F/M, hydrostatic shaft seals were developed to minimize friction loss. Hydrostatic seals require a separating flow to separate the two sealing surfaces. For the ram assembly, the separating flow is provided continuously.

The advantage of the hydrodynamic seal over the hydrostatic seal is that its performance is less dirt sensitive and precise control of filtered separating flow is not required, thus simplifying the hydraulic circuit.

For the Gentilly 1 F/M, a 660 mm (26 in.) diameter hydrostatic seal was used on the magazine turret. This assembly was normally sealed tightly due to mechanical springs and internal pressure under static conditions. Flow was provided through a combination of plenum chambers and orifices to separate the sealing surfaces during indexing of the rotor. Due to the relatively larger size of the seal cross-section, considerable difficulty was experienced in keeping the sealing surfaces parallel, when separated. Tendency to distort was due to the temperature difference between the separating flow and the magazine water temperature, and the normal thermal gradient across the seal.

A hydrodynamic seal was provided as a back-up ring. One of the combinations which was successful was made from martensitic stainless steel with a hard face coating.

5.1.2 Rod Seals for Linear Motion

Seals made from segmented rings, retained circumferentially by a garter spring have been used in the F/Ms.

In some applications where the operating stroke is very short and the sealing requirements are very stringent, a rubber T-shaped ring which has phenolic non-extrusion rings on either side, has been used. The shape of the ring is such that it will not tend to roll, as with a standard O' ring.

5.1.3 Oil Seals

Generally, commercially available oil seals have been successfully used. They are generally used to prevent contamination of water by the lubricating oil or grease in the bearings. No development work was necessary.

5.1.4 Piston Rings

Piston rings have been used in water applications. For small diameter applications, where more flexibility is required for installation, polyimide material has been used.

5.2 STATIC SEALS

5.2.1 Metallic

The CANDU F/M relies heavily on the use of Grayloc seals to seal the joints between the major housings. This seal design is based on an oversized double-tapered seal ring which is forced inside two mating housings by an external clamp which wedges the housing tightly together.

During assembly, the internal tapers on the housings, the tapers on the seal rings and the external tapers on the housings are liberally coated with lubricant to prevent galling and seizure.

Problems have been experienced in attempts to reseal large Grayloc joints. Recutting of the hub seal surface may be possible which would require an oversized ring, but this is more expensive and Code parts are affected.

Some development testing was carried out with an alternative seal ring which is interchangeable with the Grayloc seal ring, but with a lower sealing force.

A metallic static seal is also used to seal the F/M snout to the reactor fuel channel end fitting. This is a double bellows, self-energizing metallic seal. The life of this seal is in excess of 100 cycles.

The key to successful application of the metallic static seals is that the mating surfaces must have a good lapped surface finish without any radial defects. Grooves should be avoided since the sealing surface would be difficult to lap.

5.2.2 Elastomer

O' rings are used extensively in the F/M. In the Bruce F/M an O' ring is used to seal the rear cover on the magazine housing. O' rings are always replaced on re-assembly.

However, if the operating temperature of the F/M is low enough, the use of elastomers appears to have considerable justification.

6. GEARS

Some of the CANDU F/Ms incorporate water lubricated gears within the pressure boundary. Conventional gear design was found to be adequate using stainless steel and aluminium bronze as mating materials, although the latter material has exhibited higher than desirable specific wear. Spur gears and strength bevel gears have both been used successfully.

However, in the CANDU 6 design, it was not necessary to incorporate gears within the pressure boundary of the F/Ms.

7. FASTENERS

With respect to the choice of fastening hardware in high temperature water, care must be taken to ensure that failure will not occur due to stress corrosion cracking. Retaining rings and spring pin material are often susceptible to stress corrosion cracking due to their hardness. Retaining rings are generally avoided because they may be subjected to possible overstressing during installation if improperly handled, and could fail in service.

All fasteners must be provided with proper means for locking. Wire locking which was used for some fasteners was abandoned because it does not particularly lend itself to handling with rubber gloves. Captive fasteners, together with captive lock washers which have been used on occasion, resulted in improved handling. Compounds such as Loctite have been avoided because they are not considered to be a positive means for locking. Where spring lockwashers are used with socket head cap screws, counter-sunk holes are used to prevent the lockwashers from expanding out of position.

Fastener materials are also chosen to ensure that they do not gall. Aluminium bronze has been used commonly for large nuts as fasteners on stainless steel components. Use of proven anti-galling compound on fasteners during installation is also important. Care must be taken to ensure that the compound is compatible with the process medium when used with wetted components.

Commercial units such as gearboxes are often used in the drive system. it is important that they match the quality of the other F/M components. AECL has experienced the use of commercial gearboxes of inferior quality. In some cases, the locking on the gearbox fasteners has failed in service such that power transmission was no longer possible.

8. CATENARY

Flexible rubber hoses are used to supply water and oil to the various actuators on the F/M. Hose flexing is generally confined to bending. Twisting is avoided as much as possible.

Flexible rubber hoses have a limited service life on the F/M due to irradiation, abrasion, mechanical damage and possible attack by the environmental condition in the reactor vault, such as ozone or nitric acid, if present.

A major factor in reduced service life has been mechanical damage or radiation damage (hardening and cracking) to the outer sheath of the hose. This exposes the wire braiding beneath to attack by the corrosive vault atmosphere and can lead to failure of the weakened hose if it is not replaced.

It was found that thorough visual examination is not possible and in some cases it cannot be relied upon to predict the remaining useful life of the hose.

AECL experience has shown that replacement of hoses on a regular basis is the best solution to prevent hose burst during operation.

Flow fuses which are essentially automatic shut-off valves that close upon excess flow have been incorporated in some systems, but they were found, on occasion, to interfere with normal operation under spurious high flow conditions. Solenoid valves used in conjunction with pressure switch actuators may be better suited in some applications to protect the system from gross leakage in the event of hose failure.

Use of metallic hoses have generally been restricted to high temperature water applications. Metallic hoses are capable of longer service, but are more costly compared to rubber hoses. During pressure testing, metallic hoses have a tendency to stretch. Some difficulty was encountered in forming them into a multi-hose hanging catenary loop, comprising hoses of equal length. In the Gentilly 1 F/M application, however, all of the catenary hoses were of the metallic type.

In the Pickering application, the catenary loop including oil and water hoses, as well as power and control electrical cables are formed into a long hanging loop. Some twisting occurs when the F/M is rotated by 90° but because of the long length of the loop, there has been no detrimental effect.

Power tracks have also been used extensively in some applications to control the bending motion of the hoses and cables as a group.

On the Gentilly 1 application, a quick disconnect assembly was provided to allow remote removal of the F/M from the suspension. Manual intervention was only required to re-connect the electrical connectors.

9. DEVELOPMENT PROGRAMS

Continuing development programs serve to further advance the technology of the CANDU fuel handling system.

9.1 F/M BEARING MATERIALS FOR USE IN WATER LUBRICATED SYSTEMS

Various components in the F/M are subject to sliding and rolling loads in a water lubricated environment. Some of the components which perform well in a grease or oil lubricated system exhibit premature wear and failure in water.

A continuing program exists that examines various systems or components used in the F/Ms and carries out applicable tests to evaluate different materials. The aim of the program is to recommend superior materials that prolong component life or provide other system benefits.

9.2 IMPROVED SEPARATORS

The separators that are required on CANDU 6 F/M are relatively complicated and require frequent maintenance. They are D_2O activated requiring associated equipment such as specialized valves that are costly as well as precision machined.

The program will investigate a different method of achieving the requirements that are presently provided by the separators. This program is not intended to improve the design of the present separators.

9.3 'C' RAM TAPE DRIVE

The 'C' ram on the F/M ram assembly is basically a D_2O operated telescopic ram. Position monitoring is achieved using a tape anchored at the front of the ram that is unwound from a spool provided at the back of the ram. A spring motor is used to provide the tension on the tape. However, this system is prone to failure due to non-uniform tension on the tape.

A development program is underway to replace the spring motor with an electric motor.

9.4 BORE SEAL CLOSURE

Adoption of a bore seal closure will allow significant changes to be made to improve the design of the F/M, optimization of core physics and refueling schemes.

A bore seal closure was previously used on the Gentilly 1 reactor, however there were short comings to this design. The Fugen reactor in Japan has successfully used an improved version of the Gentilly 1 design. A further improved version of the Fugen design is presently being developed for the DATR reactor in Japan.

Work is underway at AECL CANDU to establish the requirements for a similar design that will be suitable for CANDU and to be followed by development of a prototype.

9.5 IMPROVED RAMS

The existing mechanical ram assemblies incorporate water lubricated ballscrews to convert rotary actuation to linear ram motion.

Ballscrews have been developed to a stage where reliable operation is assured. However, with the intent to reduce maintenance and cost, and to achieve longer component life, a program is underway to produce an alternative design.

9.6 MULTIPLEXING

The concept of multiplexing control signals to/from the F/M and the control system, with the aim of reducing or eliminating the need for conventional catenary cables is being developed. Equipment is scheduled to be installed on the Bruce 'B' fuel handling system for testing.

9.7 ZIRCONIUM FARE TOOL

The FARE tool causes a so-called "spatial flux tilt" when in the core, due to excessive neutron absorption by stainless steel parts. This results in a reactor setback.

Single channel trip occurs due to low flow when the FARE tool is inserted or removed from the channel. This would result in a reactor trip if there is another single channel trip already in prior to the FARE fueling.

Possible modifications to FARE tool are proposed to reduce neutron absorption. A preliminary study will be made to assess the feasibility of using Zirconium alloys instead of stainless steel. Two groups will be examined: those which will not alter material combinations at sliding surfaces and those that will, thus allowing more steel to be replaced by other materials.

An assembly will be fabricated and the operation of the sliding surfaces will be tested in SPEL.

9.8 NON-CIRCULATING BALL SPLINE

The existing guide sleeve tool incorporates a ball spline with re-circulating balls to convert linear motion to rotary motion. Due to space limitations, small balls are used and frequent maintenance is required. In order to improve the designs, a ball spline with non-circuiting balls has been provided and successfully tested in the laboratory.

10. PRESSURE TUBE IN-SERVICE INSPECTION

Manual and semi-automated tools have been used in the past to carry out eddy current and ultrasonic inspection of fuel channel pressure tubes using a modified F/M as a delivery system for the tooling.

Equipment and instrumentation can also be mounted on the snout area of an operational F/M to measure fuel channel axial creep and for leakage detection.

11. RETUBING

For retubing purposes, the F/M bridge and column together with the carriage is available for manipulation of the shield work stations or testing equipment.

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CHAPTER 5

FUELING MACHINE RECOVERY

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CHAPTER 5
FUELING MACHINE RECOVERY

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FUELING MACHINE RECOVERY

1. INTRODUCTION

In the event that a malfunctioning fueling machine (F/M) is required to be recovered from the reactor end fitting, provision is made by built-in redundancy and manual drives that can be driven with hand tools through penetrations into the reactor vault.

In abnormal cases, experience has shown that tooling can be built as required at the time, rather than to have a number of tools on hand to meet postulated events. One exception, however, is the grapples which permit use of a functioning F/M to defuel a fuel channel with the reactor shutdown, working only from one end of the channel, including removal of fuel from a disabled F/M at the far end of the channel.

This chapter describes the recovery aspects of the CANDU fuel handling system. Examples are given to show how significant malfunctions have been resolved in the past. Subsequent to these occurrences, modifications have been incorporated into the F/M to preclude recurrence.

This chapter will cover most major incidents that have generic implications, therefore, the information will not be confined to CANDU 6 experience.

2. SNOUT LOCK-UP

The snout mechanism temperature increases when clamped to the high temperature reactor fuel channel end fitting. Difficulty with hydraulic lock-up occurred when the temperature of the oil in the actuating hydraulic system increased with a corresponding rise in the entrapped actuating pressure. This temporarily prevented unclamping of the mechanism. The oil hydraulic system has since been redesigned to preclude a similar incident.

In many of the CANDU F/M snout designs, the anti-friction bearings which support the actuating screw are provided with belleville washers to allow for any differential thermal expansion in the unclamping mechanism. The bearing races are tempered at a relatively low temperature, hence brinnelling of the bearing races was experienced at one time due to over-tempering of the races from the heat conducted from the reactor end fittings. This created difficulty in unclamping the snout. As an emergency measure, it was necessary to cut the return line on the hydraulic circuit to reduce the back pressure, hence increasing the differential hydraulic pressure in the mechanism to achieve a higher actuating force.

The snout is designed to maintain sufficient clamping force to maintain a leak-tight joint with the reactor end fitting. There was an incident where the mechanism was found to backwind and have a tendency for the snout to unclamp. This was overcome by specifying a more suitable lubricant in the Acme screw mechanism.

At Gentilly-2, the snout became stuck on the fuel channel end fitting, apparently due to lack of maintenance, resulting in deterioration of the lubricant in the snout mechanism. Reducing the back pressure in the oil hydraulic actuating system to increase the unclamping force was ineffective. Finally, the 'B' ram was used to relieve some pressure on the snout mechanism belleville washers located adjacent to the anti-friction thrust bearings to enable the snout to unclamp.

3. RAM ASSEMBLY

The ram assembly in the Pickering and CANDU 6 F/M is designed so that it can be readily replaced without having to remove the F/M from the carriage. Before any serious problem is encountered with the mechanical ram, warning of any impending malfunction is generally forecast by evidence such as increased operating torque or seal leakage. Ballscrew problems usually occur due to broken or worn balls. It is important that all load balls are of equal size and that they be kept in matched sets. Should there be any appreciable variation in the ball size, only the larger balls will carry the load, thus resulting in overloading and possible failure.

When the ballscrew assembly reaches its extreme ends of travel, jamming of the nut could occur, the extent being dependent upon the lead angle of the thread. It was necessary to avoid this jamming action for proper operation of the ram. One method which has been used to avoid jamming is to provide dog stops on the ballnut and ballscrew members so that at the extreme ends of travel, the dog stops terminate the relative rotary motion.

The rotating members of the mechanical ram drive are designed with low inertia to minimize any undesirable impact forces, particularly with respect to the fuel string.

In the event that the mechanical ram is coupled to the reactor fuel channel hardware, and the ram becomes inoperative, provision is made to ensure that differential thermal expansion will not result in high stresses in the mechanism. The ballscrew lead is selected so that the unit has backwinding capability.

There have been instances when the ram head became jammed on the fuel channel hardware due to the 'C' ram preventing the latch ram to retract. 'C' ram balls on the ram head have now been preloaded with belleville washers such that an increase in ram force will allow the 'C' ram balls to retract and release the latch ram. This has resulted in a significant improvement since a stuck ram head on a shield plug or channel closure in the fuel channel will otherwise prevent the normal closing of the fuel channel and subsequent operation of F/M snout unclamping from the end fitting.

Mechanical shaft seal malfunction is usually evident from leakage or improper separating flow rates in the case of hydrostatic seals due to plugged jets. Mechanical ram force control is important and worn seal surfaces could result in increased input torque. The seal friction and other variable losses are designed to be a small percentage of the running torque, therefore, variation of the starting and running torque of the seal becomes less important. The manual emergency drives that are provided on the mechanical ram are designed so that the input torque for manual intervention is possible with a manageable torque requirement.

An alternative position monitoring system such as a mechanical digital counter is used during manual intervention. It has been found that position monitoring read-out equipment with small shafts using couplings which rely on friction, tend to drift. Components are selected with adequate shaft sizes to allow the couplings to be positively fastened with locking pins.

On CANDU 6, stationary calibration ports are provided where they are readily accessible by the F/M to set the ram forces. A commercial load cell is used to sense the ram forces. Since force calibration is carried out under pressure, pressure differential across the sensor rod which penetrates the pressure boundary must be compensated.

Calibration is required to provide the correct settings on the pressure control valves so that the oil hydraulic motors will provide the required ram forces.

On most CANDU F/Ms, precise force control is required during installation of the channel closure to provide the correct seal disc deflection, since a high installation force may result in difficulty during removal.

4. MECHANICAL DRIVES

On some of the F/Ms, a central gearbox is provided with multiple outputs to provide the different drives. It is equipped with two a.c. induction motors to provide redundancy. Speed control is achieved by variable frequency. Torque control is only moderate. The output drive shafts are equipped with clutches that are interconnected by a series of spur gears. Provision for manual emergency drive is provided on each output shaft on the shaft extension at the non-driving end.

Other CANDU F/Ms generally use oil hydraulic drives. Oil hydraulic motors provide excellent speed and torque control. However, maintenance of oil hydraulic systems often leads to some oil spillage. Frequently, problems have been encountered in trying to obtain spare oil hydraulic components several years after they were initially specified. In many cases, it was found that the manufacturer no longer makes the identical component, hence creating installation problems with substitute components, particularly when space is at a premium.

Several failures have occurred in mechanical drives when couplings on the shaft of the drive systems were lost due to the failure of a fastener (tab washers, locknut, key). Some of these incidents prevented reinstallation of the channel closure in the channel end fitting after fueling. Costly unit outages were required to recover the incapacitated F/M. In some cases, the keyed coupling between the shaft and the gear were changed to a more reliable splined connection. In other cases, improvements were made to preclude recurrence. The capital cost of retrofitting splined shafts would be somewhat expensive. Problems arise in modification of existing commercial equipment such as gearboxes.

5. EMERGENCY DRIVES

Over the years, manual emergency drive capability has been incorporated on the major drives of the CANDU F/Ms.

These drives generally feature a mechanism to disconnect the drive motor prior to manual drive input. This is particularly important with hydraulic motors to avoid torque resistance. For the electrical system, it may be possible to specify an electric motor with double-ended shaft so that the emergency capability is available from the shaft extension.

On some CANDU applications, access to the F/M in the reactor vault is available at the floor opening which is provided for the bridge. On other CANDU applications, openings with removable plugs are provided in the reactor vault floor at different locations to provide access for remote tooling.

The emergency drive shafts are generally pointed downwards and are equipped with cone-shaped funnels to provide guidance for the manual tools. An air motor attached to the end of extensions has been used to actuate emergency manual drives.

Manual emergency tools are not generally fabricated in advance. On occasion, when they have been required, tools have been designed and fabricated to meet the need.

When a F/M with a disabled mechanical ram is clamped onto a fuel channel containing irradiated fuel, the second F/M at the opposite end of the fuel channel has been used to remove the irradiated fuel using special grapple tools, thus allowing access to the disabled F/M during reactor shutdown. Extra features are provided on the CANDU 3 single-ended fueling concept. These are discussed further in this chapter.

6. GUIDE SLEEVE STATION

The guide sleeve is installed in position, partially in the end fitting in the channel closure position and in the F/M snout, to provide a constant bore passage for the fuel bundle to pass from the F/M magazine station into the fuel channel. However, the guide sleeve station in the F/M magazine is left with a bore larger than that of a fuel bundle outside diameter.

There was an incident at Pickering 'A' when a fuel bundle inadvertently entered the guide sleeve magazine station in the aforementioned condition. It was a very difficult task to remove a fuel bundle that had broken apart, from a large bore into a smaller bore. Special tools, including a scoop was designed to remove the damaged fuel bundle over the step in diameters.

Unfortunately, a portion of the fuel bundle pencil dropped into the bottom of the magazine housing. It was necessary to remove this F/M from the carriage and place it in quarantine for several months in a specially designed water-filled tank. This F/M was eventually disassembled in a new water filled pool that was constructed for Pickering 'B', as part of the F/M maintenance facility.

The guide sleeve insertion tool was subsequently redesigned with an extension so that in the absence of the guide sleeve, it was not physically possible for a fuel bundle to enter the guide sleeve station in the magazine.

7. SEPARATOR

When the separator side stop is in the advanced position, it provides a mechanical restraint for the fuel string which is under the influence of the hydraulic drag force due to channel flow.

A mechanical safety lock is incorporated in the separator assembly to maintain the side stop in the advanced position which prevents accidental release of the side stop which could allow the fuel string to move into the F/M, possibly with a high impact force.

The safety lock actuation is achieved by means of a canned solenoid, used on a large solenoid valve.

An incident occurred at Pickering 'A' when the solenoid failed and the separator side stop could not be retracted. In the resulting condition, it was not possible to move the fuel string which was partially located inside the F/M snout.

A manual override assembly was incorporated in the separator assembly but access was very difficult. It was necessary to use the bridge as partial shielding to allow a manually operated tool with an extension to actuate the manual override lever.

Subsequently, the separator safety lock manual override lever has been equipped with a flexible cable extension shaft to improve access for emergency actuation.

8. GRAPPLES

In the event of malfunction of a F/M or during a shutdown, it may be necessary to remove fuel bundles from the fuel channel or from a disabled F/M. Grapples may be utilized and defueling is possible using only one F/M.

A grapple is a mechanical device that can be attached to the ram head on the ram assembly and manipulated in the same manner as in handling a channel closure or a shield plug. The grapple length is equivalent to one fuel bundle. It incorporates spring loaded fingers that can be used to latch onto the fuel bundle at the end plate.

Once the fuel bundle is attached to the grapple, the F/M ram assembly can pull the grapple and the attached fuel bundle into the F/M magazine station.

One or more ram extensions are used to allow the grapple to reach inside the fuel channel and as far as the disabled F/M magazine at the far end to retrieve any stuck fuel bundle. These ram extensions are two bundle length, comprising cylindrical sections that can be attached and detached to one another as well as the grapple. They can be stored in the F/M magazine stations in a similar manner to a pair of fuel bundles.

The ram extensions and grapples may become contaminated but they can be discharged from the F/M during maintenance and servicing.

For single-ended fueling as in CANDU 3, recovery of a malfunctioning F/M from the reactor is mostly done from the outlet end of the fuel channel without grappling the fuel string. Additional features have been incorporated in the CANDU 3 F/M such as shielding around the magazine housing and an isolation valve between the magazine and ram assembly to allow some recovery operations to be performed.

The shielding around the magazine housing will permit limited access to a malfunctioning F/M while it is still clamped onto a fuel channel. The isolation valve will allow replacement of a malfunctioning ram assembly while a F/M is still connected to the fuel channel.

The concept for recovery at the inlet end on the CANDU 3 single-ended fueling system involves blocking off the fuel channel to maintain the trapped fuel in a submerged condition and then breaking the inlet feeder connection to allow access for fuel grappling.

The blocking of the fuel channel is to be achieved by means of an inflatable plug which is transported through the inlet feeder by a pneumatic pipe crawler system which is inserted at the inlet main header of the heat transport system. It should be noted that blocking only takes place when the feeder connection has to be uncoupled. Once the inlet feeder connection is uncoupled, transition piping and a valve/stuffing box arrangement is added through the inlet vault rear wall and connected both to the inlet connection and to a flask/grappling system. At this point the channel can be defueled with the system reflooded and subsequently, access to the F/M can be gained to allow it to be removed.

A back-up fuel cooling water supply will be provided through the pipe crawler system and the inflatable plug.

9. FUELING MACHINE BRIDGE TILT

The vertical motion of the F/M bridge is achieved by a pair of ballscrews located in the support columns at each end.

Incidents have occurred that have resulted in tilting of the bridge to a small degree. In one instance a locknut that fastened the thrust ball bearing at the top of one of the ballscrews had detached from the threaded end. This was rectified by an improved tab washer on the locknut that secures the ball bearing. Also, a switch signal system was added to detect axial displacement of the ballscrew (which is an abnormal state if the ballnut loosens).

Bridge tilt of a more significant amount occurred at Pickering 'A' in 1990 May during the current retubing program. The F/M and its carriage assembly had been removed and replaced by a shielded work station that is used for the retubing work. The flexible coupling that is located on the cross-shaft between the two column drives had failed due to loss of a key on the shaft in one half of the coupling.

An improved tab-lock key is now recommended as a more reliable arrangement. Splined connections between the shafts/couplings and gearboxes are also being implemented. Additional brakes are also implemented to ensure back-ups are provided for all modes of failure.

It is also necessary to ensure that a supplementary device such as a mechanical brake or hydraulic lock is also provided as a back-up.

In order to detect minor tilt conditions, instrumentation to detect tilt has been incorporated in some installations.

A bridge tilt estimated at 1.4 m (56 in) occurred at Bruce 'A' on 1980 October during vertical traverse. Bridge stop was initiated immediately after a bridge tilt alarm. With the aid of the periscope, the bridge tilt was corrected by manual intervention.

Apparently the cross-shaft coupling had failed due to cracking of the tapered bushing in one hub. It was postulated that the retaining set screws loosened and fell out due to vibration and/or improper initial installation.

There was no apparent visible damage to the bridge elevating mechanism and a new replacement coupling was installed on the cross-shaft.

However, nine months later during maintenance outage, it was discovered that mounting bolts on the two of the roundway bearings that locate the bridge had failed. The failure might have occurred during the prior bridge tilt, or the bolts may have been overstressed and had failed later.

10. FUELING MACHINE BRIDGE VERTICAL DRIFT

An incident happened at the Bruce NGS in 1990 January in which the F/M bridge drifted downwards with the F/M clamped onto a reactor fuel channel end fitting. This resulted in tilt of the F/M causing a breach in the leak tight joint between the F/M snout and the rector fuel channel end fitting. This had occurred as a result of software error in the fuel handling protective computers. A change had been made to the operating sequence at the site to eliminate the error but the revision had not been fed back to the design office where the source codes for the operating sequences are located.

In the event of abnormal fueling, operator intervention of F/M control is intended. The incident occurred during such an operator intervention mode because the designer was not aware of the changes made to the computerized operating mode and had designed the operator intervention mode in accordance with the original design. This error, along with others, was detected during commissioning of the changes. However, it was the only error that was not corrected. Subsequent testing and software validation failed to reveal that the error was still present.

The bridge drive was not actuated but the brakes were released inadvertently and the bridge drifted downward. The end fitting that was attached to the F/M deflected about 100 mm (4 in) and contacted the end fitting that was located just below it and deflected to by about 38 mm (1.5 in).

This incident resulted in leakage of 20 000 L (5300 U.S. gal.) of coolant of which 98.4% was recovered.

There was no apparent damage to the lower end fitting which sprung back to its original position within the permissible tolerance. The end fitting that was clamped to the F/M was bent in two places; namely at the tube sheet and at the channel closure location. There was significant damage to the F/M suspension and no damage to the F/M itself was apparent.

Two design changes were made:

- The protective computer and control computer must be fully operational before bridge movement is permitted. When one of the computers is not available, no control power will be permitted to the bridge or carriage drives or to release the brakes.
- Hard-wired interlocks will inhibit bridge and carriage drives whenever the 'Z' drive is advanced.

As a result of this incident, fuel handling software configuration management system, particularly the software change procedure, is being thoroughly reviewed. All future fuel handling software changes will be subjected to a more rigorous change control procedure.

11. CARRIAGE DRIVE

Some commercial gearboxes have been specified on the carriage and related drives. There have been instances when the drive was lost due to failures resulting from loss of a key at the shaft and coupling joint.

Especially in critical applications, precaution is taken to ensure that the specifications and quality of the commercial units meet minimum standards to specify fasteners equipped with a positive means of locking.

12. HOSE FAILURE

Elastomeric and metal flexible hoses are used on the catenary system for the D_2O and oil hydraulic systems.

In the event of hose failure associated with safety systems, flow fuses or excess flow valves have been used as well as individual solenoid valves to stop the leakage of fluid. Redundancy is built into the systems so that a hose failure does not result in a significant consequence.

Hoses are only purchased from approved suppliers and development of more reliable hoses is carried out on an on-going basis.

Visual inspection of hoses and cables was found to be unreliable, leading to replacement at pre-determined intervals as part of a preventative maintenance program. Pressure testing and destructive tests are performed on in-service hoses and cables to provide data regarding service life.

If temperature permits the use of elastomeric hoses, they are preferred over metallic hoses due to lower pressure drop characteristics.

.3. CONCLUSIONS

The fuel handling systems have been proven to be reliable and station incapability due to fuel handling is traditionally less than 1%.

Upgrading of the fuel handling system is carried out on an on-going basis to enhance capability, improve maintainability and reduce radiation exposure.

Research and development of generic nature for possible back-fits to existing operating equipment, as well as for future advanced systems is carried out separately under programs sponsored by the CANDU Owners Group (COG), over and above specific improvements pertaining to any plant design.

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CHAPTER 6

INTERACTIONS OF FUEL HANDLING WITH REACTOR PHYSICS AND FUEL DESIGN

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CHAPTER 6

INTERACTIONS OF FUEL HANDLING WITH REACTOR PHYSICS AND FUEL DESIGN

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INTERACTIONS OF FUEL HANDLING WITH REACTOR PHYSICS AND FUEL DESIGN

1. INTRODUCTION

On-power fueling operations are intimately related to reactor physics and the design of the fuel. The following two sub-sections establish this relationship for reactor physics and fuel design, respectively.

2. REACTOR FUELING AND PHYSICS

2.1 INTRODUCTION

The CANDU reactor design was predicated on the basis of using natural uranium as fuel. Even with the use of heavy water as a moderator and coolant, the bulk excess reactivity of an initial fresh core is small, approximately 30 mk compared to a typical excess reactivity of > 200 mk for a LWR. Consequently, on-power fueling is necessary to achieve a reasonable energy production per unit mass of fuel.

Analytical studies show that an ideal reactor from the point of view of fuel utilization is one which is continuously fueled (i.e., slurried fuel) and hence operates on the average with very little neutron absorption in non-fuel components such as control rods. Thus from the very beginning CANDU fuel design evolved in the form of short bundles of elements about 0.5 m (20 in) long to approximate this ideal. The reactor fueling is done by pushing the fuel bundles through the channels in opposite directions in adjacent channels. This bi-directional fueling scheme provides flexibility in fuel management to achieve maximum fuel utilization and ensures a symmetric axial power distribution in a global sense. This was easy to accomplish by providing a F/M at each end of the reactor. One F/M inserts fresh fuel at one end of the channel and the other F/M receives irradiated fuel discharged from the other end. Based on the design of the F/M magazine, the minimum number of bundles moved in the fueling process is two bundles. Various channel fueling schemes consisting of replacement or movement of two or four or eight bundles are used.

With the development of software able to simulate discrete bundle movements, it was possible to evaluate the advantages and disadvantages of replacing more than two bundles per visit to a channel. It was found that the penalty on fuel utilization was not very large even if four or eight of the twelve bundles in a channel were replaced each channel visit. Therefore, CANDU reactors operate today mostly with replacement schemes of four or eight bundles per visit (referred to as four- or eight-bundle shift fueling schemes). More details are provided in the references (1),(2).

The number of bundles replaced per visit affects the physics since, as the number increases, the local perturbation in channel power caused by the fueling operation also increases. This is called "fueling ripple". The fueling scheme also affects the axial power distribution or the peak bundle powers. For example, use of an eight-bundle-shift scheme tends to flatten an otherwise cosine power distribution.

The ability to change fuel in any channel at any time provides the option to control the radial power distribution very effectively. This is done by ensuring suitable burnup differential in the radial direction. Therefore, the CANDU design assumes this method of power shape control is utilized. This means that, except for an initial transition period from an all-fresh core to one with an equilibrium distribution of fuel irradiations, the power distributions and physics characteristics remain constant in a global sense. This is described as a core at "equilibrium" burnup.

2.2 REQUIREMENTS

To ensure successful CANDU reactor operation, from the reactor safety and fuel utilization point of view, several requirements are imposed on the following parameters:

- excess reactivity
- fuel bundle and channel power constraints
- F/M capability
- liquid-zone-control level requirements

The following sections discuss those requirements in detail from the physics point of view. Examples are based on CANDU 6 operating parameters.

2.2.1 Excess Reactivity

During normal operation, the rate of fueling should be limited so that the concentration of boron in the moderator is restricted to the equivalent of a pre-specified excess reactivity (approximately 5 mk for CANDU 6). The reason for this upper limit is that the amount of reactivity capable of being added by poison displacement after the reactor has been shut down is a critical parameter in the design basis accident analysis. In the event of a channel failure, the primary coolant being discharged into the moderator would dilute the boron poison.

The reactor should be operated such that the Reactor Regulating System (RRS), acting alone, is capable of introducing sufficient negative reactivity to shut it down under normal operation. The design philosophy for CANDU plants requires a strict separation between process systems and special safety systems. In terms of reactivity control this means that the Shutdown Systems (SDS) are used only to achieve a rapid shutdown in the event of an accident.

2.2.2 Fuel Bundle and Channel Power Constraints

The operating target during normal operation is the preservation of fuel element integrity. In practice, this means operating the fuel so as to avoid systematic defects. The second target, directed to preserving fuel element integrity, is the prevention of centerline melting of the fuel in normal operation. This is done by ensuring that the licensed bundle power limit is not exceeded. The third target is to prevent the channel powers from exceeding the license limit. These three targets influence the fueling schemes used in various regions of the core.

At equilibrium fueling conditions, there is little (approximately 2 mk) or no excess reactivity in the core. The bulk reactivity control system compensates for the daily variations due to burnup and fueling. The normal operating reactivity control range of this system is, however, only ± 2 mk. Should there be an interruption of fueling for a longer period of time, the adjuster system provides sufficient excess reactivity to allow operation (called shim-operation) without fueling for up to approximately 45 days at reduced power level.

2.2.3 Fueling Machine Capability

Burnup is optimized by the fueling strategy which is designed to keep bundle and channel powers within the axial and radial power shape. The desired axial shape is achieved by varying the number of bundles fueled in a channel per channel visit. Radial shape is achieved by ensuring appropriate differential burnup, that is, different burnup values in inner and outer core regions. This is achieved in practice by four-bundle fueling in the inner high-power region and eight-bundle fueling in the outer low-power region. Usually, the burnup can be increased by reducing the number of bundles fueled per visit. To allow for maintenance of the F/M, there is an upper limit on rate of channel visits. Quite often, there is a trade-off between burnup and channel visit rate. On-power fueling permits operation with an essentially constant power shape.

2.2.4 Liquid Zone Control Level Requirements

Adjusting the average water level in the Liquid Zone Control (LZC) compartments is the primary means to control the bulk reactivity.

Conceptually, the reactor core is divided into 14 zones, with each zone controller establishing the power in a zone. Bulk power is continually controlled by raising or lowering the water level in the 14 zone controllers. The normal reactivity range attainable by liquid zone control is approximately ± 2 mk. Spatial control (for instance to control zenon instability, which may be caused by movement of reactivity devices) is effected by differentially filling or draining of individual zone controllers.

Under normal operation, the average zone water level is kept at about 50% with individual zone levels between 20% and 80%. On-power fueling capability helps ensure these constraints.

2.3 FUEL MANAGEMENT

The excess reactivity in an initial CANDU core is approximately 30 mk compared to 1 mk for an equilibrium core. This is suppressed by boron dissolved in the moderator. Onset of fueling occurs about 90-110 full power days after initial criticality. For an equilibrium core, the reactivity depletion rate at steady-state conditions is approximately 0.4 mk full-power-day. To compensate this reactivity depletion rate, three or four channels are usually fueled (assuming an eight-bundle-shift fueling scheme) per day for five days a week.

2.3.1 Channel Selection for Fueling

The primary criteria for channel selection are burn-up and channel power-ripple. The highest burnup channel is normally selected, provided the post fueling state satisfies bundle power, channel power, ripple and zone level requirements. About 3% margin to trip is ensured during actual fueling. In addition it is ensured that no 'hot spot' is created in the core.

2.3.2 Short-Term and Long-Term Power Profile

The reactor fueling is done in such a way that the deviation from the long-term time-average target in power and burnup is minimum. In addition, it is ensured that zone control levels do not become limited high or low for transient situations, that is, when the freshly fueled bundles have not attained equilibrium xenon concentration.

2.3.3 Premature Fueling to Remove Defected Fuel

Fuel defects are first indicated by the Gaseous Fission Product (GFP) system. This system analyzes a flowing sample of Primary Heat Transport System Coolant (PHTS). After defect identification is done, the defect location (channel identification) is done using a Delayed Neutron (DN) monitoring system. The severity of fuel defect degradation dictates the urgency to remove the defect to keep the heat transport system relatively contamination free. An effort is made to remove the defect as soon as possible, even at the expense of burnup loss if the channel is not ready for fueling. To minimize the probability of 'hot spot' creation, sometimes one or two depleted fuel bundles (i.e. initial enrichment less than natural (0.72%)) are used. Predictive computer simulations can be carried out to ensure that:

a. Bundle power and channel power constraints are satisfied for the steady-state (i.e., equilibrium xenon established);

b. Post-fueling channel power 'ripple' is acceptable;

c. During actual fueling (xenon-free fresh fuel), none of the zone control levels becomes limited-high or limited-low.

2.3.4 Computer Code Simulations

Obtaining optimum average discharge burnup of the fuel is an important aspect of the physics design and operation of the reactor core. This requires a three dimensional code which is capable of calculating the time history of the flux and power distributions in each fuel bundle from any particular starting point in time.

Computer simulations are usually done twice a week to track steady state burnup and power.

2.4 CONCLUSIONS

On-power fueling is a major contributor to the economic competitiveness of a natural uranium reactor. Its successful achievement results in six major advantages:

1. It enables the reactor to have a high capacity factor, typically at least 6% better than reactors with off-power fueling;
2. It permits major outage scheduling independent of fueling;
3. It permits higher utilization of natural uranium and therefore lower fueling costs;
4. It allows the on-power identification, location, and removal of defected fuel. This helps to keep the heat transport system relatively free from fission-product activity and reduces the need to shutdown the reactor for defected fuel removal;
5. It leads to very safe reactivity control devices' design such that there is never a large amount of absorbing material that can be quickly removed from the core;
6. It facilitates satisfaction of bundle power, channel power, and zone power limits set by regulatory agencies.

3. REACTOR FUELING AND FUEL DESIGN

3.1 BACKGROUND

In Canada, the development of power-reactor fuels began approximately 30 years ago and was based, from the start, on natural uranium[3]. At the end of 1990, 22 CANDU reactors above 500 MWe were operating successfully in Canada and overseas at high capacity factors with low fueling costs. Eight others were committed and under construction at the end of 1990 (one in Korea, five in Romania and two remaining at Darlington). The success of these reactors depends on strict neutron economy and the low-cost fuel.

3.1.1 Fuel Design Evolution

The goal of high neutron economy is met with a fuel bundle consisting of only the fuel material itself, and a minimum of containment material. The original fuel charge for the first CANDU power reactor Nuclear Power Demonstration (NPD), a 22 MWe reactor consisted of seven-element bundles in the outer zone of the reactor core and 19-element bundles in the inner zone. These original bundles were made with "wire-wrapped" elements. The replacement design of fuel for the NPD reactor and the later KANUPP (Pakistan), Douglas Point and RAPP (India) reactors was based on a "brazed spacer" design of element; these original and replacement bundles are shown in Figure 6-1. Performance data from these reactors were used in the evolution of the currently used CANDU fuel; the Pickering 28-element bundle, the Bruce and CANDU 6 reactor 37-element bundles. Future CANDU fuel now under development is the CANFLEX 43-element bundle[4], shown in Figure 6-2. The cross-sections of these bundles are shown in Figure 6-3.

The nominal bundle powers and the mass ratio of UO_2 to Zircaloy are also shown in Figure 6-3. While the normal operating bundle power has increased from 220 kW (NPD bundle) to 900 kW (Bruce bundle), the element (or rod) linear powers have remained relatively unchanged: 50-60 kW/m for the larger CANDUs. The mass ratio of UO_2-to-Zircaloy has decreased from 11.1 to 9.4. This is being partially redressed in the CANFLEX-43 bundle for which the power is 1080 kW (same linear element power as Bruce) while the mass ratio has returned to 11.1.

The principal requirements and designs of these bundles are similar. The requirements which have the strongest influence on these designs are:

- fuel channel size including changes due to irradiation;
- specific power requirements;
- the F/M detailed requirements.

3.1.2 Fuel Handling System Evolution

The NPD bundle was designed to operate inside an 80 mm (3.15 in) pressure tube at a bundle power in excess of 220 kW, and to interface with the fuel-handling system employing the "fuel latch method" - also used in the Bruce and KANUPP reactors. The Douglas Point and RAPP bundles are similar to NPD, but are designed to interface with the fuel handling system employing the "fuel separator method". The next generation of CANDUs used a larger diameter (100 mm, 3.9 in) pressure tube. The Pickering bundle was the first 100 mm (3.9 in) diameter bundle. The design included the same element size as the NPD bundle (15 mm, .59 in) diameter, but in a 28-element configuration. With more elements, the larger bundle can operate at powers in excess of 700 kW. The fuel handling system for Pickering is of the same generic design (fuel separator) as that of the Douglas Point reactor.

The Bruce fuel channel has the same pressure tube diameter as in Pickering but employs the fuel handling similar to those of NPD and KANUPP. The Bruce bundle has the same overall dimensions as the Pickering bundle but uses 37 elements of smaller diameter (13 mm, .51 in). Again with more elements, the bundle can operate at higher powers than the Pickering bundle, at more than 1000 kW.

The CANDU 6 reactor has the same fuel channel and fuel handling system as Pickering . The CANDU 6 bundle is similar to the Bruce bundle, but is designed to interact with fuel separators.

The CANDU 3 fuel channels will have 100 mm (3.9 in) diameter pressure tubes, but different end fitting designs to be compatible with the single-ended fueling concept. The F/M is similar to Pickering and CANDU 6 which employs fuel separators. For this reason, the CANDU 3 fuel design is almost the same 37-element CANDU 6 fuel bundle, except that the design incorporates the new T-pad bearing pads as described in Section 3.3.

3.2 REQUIREMENTS

To ensure successful fuel performance. several requirements are imposed on the design of the fuel bundle and on the reactor systems that must interface with the fuel bundle. One of the interfacing systems is the on-power fuel handling system. Typical requirements on fuel and fuel handling systems that employ the separators are listed below.

3.2.1 Fuel Handling Requirements Imposed on Fuel

1. The fuel bundle end geometry must be compatible with the operation of the fueling machine separator sensors and sidestops.
2. The fuel bundle shall withstand all normal fuel handling loads applied by sidestops, ram, shield plug and pusher, without significant dimensional changes and without significant degradation of performance.
3. The fuel bundle must withstand the thermal shocks that occur during fueling operations at the ambient temperature (F/M at 30-45°C).
4. Fuel bundle spacers shall not become interlocked due to thermal bow or due to normal axial forces in pressure tubes with and without radial creep.

5. The fuel bundles shall be designed with allowance for irradiation swelling of fuel elements so that they will pass through the worst combination of fuel channel diameter and misalignment between the pressure tube and end fitting components.
6. The extra force (if any) required to move a thermally bowed irradiated bundle in a fuel channel shall not cause fuel damage or impede fueling operations.
7. Refueling impacts due to bundles sticking in the channel and then releasing, may occur occasionally. The impact speeds and forces shall be determined for a range of axial impact scenarios. For each scenario, it shall be shown that either:
   a. the probability of the event is very low, or
   b. the impact would be acceptable even when the sidestops are engaged.
8. The fuel bundles shall withstand the maximum flows predicted during fueling in axial flow, radial flow and combined axial and radial flow at the outlet feeder, liner tube for representative fueling dwell times.
9. The time period when bundles reside in the crossflow region of the liner may occasionally be prolonged when fueling problems arise. The mode of bundle failure and the time to failure shall be determined for a range of flows corresponding to one or more bundles (partly) in the flow.

3.2.2 Requirements Imposed by the Fuel on the Fuel Handling System

1. Provision shall be made for new fuel to be visually inspected for damage, to be checked for interlocking and to have the serial numbers verified.
2. The F/M separator sensors must not damage the fuel bundles.
3. The F/M separator sidestops shall not contact the bundles when they are driven in or withdrawn. (The load shall be applied to the sidestops only when the fuel moves axially.) The sidestops shall only contact the conical surfaces of the end caps, and should do so in such a way as to minimize the eccentricity of the axial load on the element.
4. Fueling operations shall be such that no torque is applied to the fuel bundles at any time during the refueling cycle.
5. The coolant temperature in the F/M containing irradiated fuel shall not be less than 30°C during fueling sequences.
6. The Flow Assist Ram Extension (FARE) tool which is basically a pusher inside the pressure tube with and without radial creep, shall be designed to:
   a. minimize vibration of the fuel in its normal position and in other positions during fueling so that the bundles retain sufficient structural integrity for further irradiation without restriction, and
   b. minimize the likelihood and magnitude of bundle impacts. (The FARE tool shall push hard enough to overcome the combined effects of friction due to bundle weight and eccentric radial exit flows in the outlet end fitting, due to bowing, due to irradiation swelling of elements, and due to misalignments and pressure tube sag.)
7. The F/M shall be capable of withstanding the effects of fuel bundle impacts against the ram or sidestops.

8. The normal fueling operation in which fuel is removed from the channel and some of it is re-inserted, shall not expose any bundle to crossflow at each fueling for a period longer than has been shown to be acceptable in tests.
9. The need for flux suppression to be built into the pusher shall be evaluated, taking into account the relative requirements of the fuel and reactor control from the effect on zone controller detectors.
10. New fuel bundles can cause severe gouging of pressure tubes when they are first loaded manually into a new reactor. To prevent this damage the bundles shall be loaded while resting on metal shimstock which is then removed manually.
11. When the F/M contains irradiated fuel to be reloaded into the core, it shall not normally be depressurized. Occasionally depressurizations during abnormal events are acceptable provided that there is no indication of fuel damage. (Depressurization causes the sheath to release its grip on the cracked pellets and permits relocation of pellet fragments. This causes a minor reduction in fuel performance which is acceptable in abnormal events but not for routine events.)
12. The irradiated fuel transfer system shall generally keep all fuel surfaces wet, however, exposure to air for a short period is permitted so that fuel can be transferred out of the heavy water system and into the fuel bay. Emergency water sprays or floodings are needed to cool the irradiated fuel if the system delays the operation during fuel transfer to the bay.
13. Provision should be made for inspecting defected fuel in the bay so that the causes of defects can be quickly assessed and can then be eliminated by changes in manufacturing or in operation. Equipment needed includes:
    a. inspection table,
    b. bundle rotator,
    c. periscope, telescope or underwater TV,
    d. lights,
    e. handling tools, and
    f. camera.

3.3 FUEL BUNDLE DESIGN FEATURES

The external features of the fuel bundles are designed to meet all the requirements placed on fuel. Specific bundle features include end caps, inter-element spacers, bearing pads and end plates as described below.

3.3.1 End Caps

Fuel element closure is provided by two end caps welded to the sheath. The end caps are appropriately profiled to interface with the fuel handling system components. They are designed to ensure adequate mechanical strength when subjected to the loads imposed by the fuel handling system. The material used is specified and inspected to ensure adequate strength and lack of porosity, which is needed for fission product containment.

3.3.2 Inter-Element Spacers

The end plates maintain separation among the elements at the bundle ends while inter-element spacers maintain separation at intermediate points. The spacers have a length to width aspect ratio of about 3.5. They are mounted with their major axis slightly angled (skewed) with respect to the sheath axis. The spacers on any two adjacent elements are skewed in the opposite direction. This skewing increases the width of possible contact between the spacer pairs and decreases the probability of spacer inter-locking.

3.3.3 Bearing Pads

The bundle is supported on bearing pads distributed along the length of the outward facing aspect of the outer element sheaths and attached to them by brazing or welding. They protect the fuel sheaths from any mechanical contact throughout the fuel bundle lifetime. The pads are profiled to minimize surface damage to the pressure tube during the bundle residence in the reactor and during refueling operations. The pads are also designed to minimize local corrosion of the pressure tube.

To eliminate crevice corrosion of pressure tubes, bearing pads will now have a "T-shaped" cross-section. Out-reactor and in-reactor testing of several designs of advanced pad geometries has confirmed the selection of the T-pad as the optimal design to reduce the heat flux through the pad surface. The reduction in temperature of the pad surface at the pressure tube contact zone is sufficient to prevent excessive concentration of the LiOH regardless of the severity of the crevice formed at the pad/tube interface. Tests in a corrosion research loop and in-reactor in NRU and NPD have shown no crevice corrosion. Post-irradiation examination has found hydride/deutride formation and distribution in the T-pads to be similar to that seen in standard pads.

3.3.4 End Plates

The end plates hold the fuel elements together in a bundle configuration. They are designed to be strong enough to maintain the configuration and also to allow axial loads to be distributed among many elements instead of being concentrated on a few. Simultaneously they are flexible, to allow differential axial expansion among the elements, and to permit bending and skewing of the bundle. The end plates are thin, to minimize the quantity of neutron absorbing material and to minimize axial separation between the fuel pellets in adjacent bundles.

3.3.5 Fuel Bundle Dimensions

The fuel bundle dimensions are specified to ensure that the bundle will interface with the fuel handling and fuel channel components.

A bent tube gauge is used by the fuel bundle manufacturers to monitor the maximum diameter of the bundle and its ability to pass through the rolled joint sections of the fuel channel and channels at the end of life.

The bundle length is controlled to ensure that the total fuel bundle string length including fuel pusher, during operation, will not exceed the distance available in each fuel channel.

Dimensions B, E, H and α, as illustrated in Figure 6-4, are specified to ensure that the profile of the bundle ends will be compatible with the fuel separator assembly. Dimension B is sized to ensure that the bundle diameter is large enough to mate with the sidestops. Dimension E is sized to ensure that the end plate does not contact the sidestops during refueling. The minimum value of dimension H ensures sufficient axial clearance for the insertion of sidestops between two bundles, and between a bundle and shield plug. The maximum value of dimension H ensures that there is sufficient clearance for the fuel pusher to separate and push bundles into the fueling machine magazine, and minimizes the incidence of interference between bundles in the magazine and bundles held back by the sidestops. Angle α is chosen so that the sidestop load on the conical end cap tends to be applied at the tip of the sidestop.

3.4 PROOF-TESTING PROGRAMS

An extensive program of fundamental work has been underway in Canada for many years to investigate UO_2 irradiation properties, material properties of Zircaloy sheathing, and critical heat-flux behaviour.

For each new reactor design, specific proof-tests are done to demonstrate that the fuel design will meet all the requirements associated with the fueling system. These tests are done in out-reactor full-scale loops located in the Sheridan Park Engineering Development Laboratory in Mississauga, and at other test facilities operated by the Canadian industrial consultants. The test loops are built with reactor components and the test conditions are representative of coolant pressure, temperature, and flow. The following tests were done for the CANDU 6 design:

- hydraulic flow resistance tests to measure pressure drop and hydraulic drag forces for the fuel column. The drag generated by the coolant represents the main load imposed on the fuel separators during fueling.
- strength tests to demonstrate that the loads imposed on the fuel during fueling will not damage the fuel.
- fueling impact test to demonstrate that impacts that normally occur between bundles during fueling do not adversely affect fuel performance.
- sliding wear tests to demonstrate that the wear damage caused by normal fueling operations is within wear allowances for the fuel and pressure tube.
- endurance test to demonstrate that the fretting damage caused by fuel vibration is within the fretting allowances. The duration of the tests normally corresponds to the maximum dwell time of a bundle in one position in a high flow channel. The dwell depends on the fueling scheme.

3.5 FUELING POWER RAMP EVALUATION

As part of normal fueling operations, fuel bundles can be shifted to two or more positions in one fuel channel. Any resulting power ramps must not cause systematic or multiple fuel element defects. The criteria for evaluating the risk of systematic fuel defects are represented by empirical correlations which were derived from a large database. The database includes many multiple fuel element defects that have occurred during the past 25 years in the NRU experimental loops and during the early years of operation in some CANDU power reactors. In most cases, the defect mechanism was stress corrosion cracking of the fuel sheath, brought on by a power ramp.[5,6] The probability of fuel defect increases during a power ramp if the ramped (final) power and the power increase both exceed threshold values which are burnup dependent.[5]

Figure 6-5 shows three sets of threshold curves for predicting power ramp conditions that cause stress corrosion cracking fuel defects. These curves which have evolved since about 1974, have crept upward to reflect good fuel performance in CANDUs and in the NRU reactor. The 1979 curves were originally recommended for use in CANDU 6 reactors where bundle powers peak at about 900 kW. They represented the stress corrosion cracking defect threshold values for CANDU fuel that contained graphite coatings (Canlub) on the inside surface of the fuel sheaths. In the 1970s, Canlub was recognized as an effective solution to stress corrosion cracking problems. In 1982, the curves were adjusted upward to reflect good fuel performance during four bundle shifts at Bruce A. At that time, thousands of fuel bundles were successfully power ramped beyond the 1979 threshold curves. The operating bundle power envelope peaked at about 1000 kW. In 1985, the curves were redrawn again to reflect good fuel performance in NRU where CANDU-type fuel with good quality thick CANLUB graphite coatings survived very high power boosts[5]. Since the 1982 curves are based on CANDU power reactor data (four bundle shift experience at Bruce A), they are recommended for use in evaluating fuel performance in CANDU 3 for base load operation. At this time, the 1985 curves are not considered "proven" for power reactors because the database does not include power reactor data[8].

The fueling operations currently used in all CANDUs generally expose bundles to power ramp conditions that fall below one or both of the 1982 stress corrosion cracking defect thresholds. There has been no evidence of fueling operations causing stress corrosion cracking fuel defects since the mid 1970s.

3.6 CURRENT PERFORMANCE

The 37-element bundle design has performed with acceptably low defected fuel rates in operating CANDU reactors. This defected fuel rate has been less than 0.1% of bundles irradiated. About 500,000 bundles of the 37-element design have been irradiated to 1990. The CANDU 6 reactors have bundle power limits up to 935 kW, while the Bruce reactors are licensed for powers up to 1035 kW. The bundle has been successfully tested to an equivalent 1200 kW power.

There have been minor "excursions" where a number of fuel elements defected simultaneously in some reactors. Such excursions have generally been detected and resolved quickly without having to derate the reactor. Defected fuel detection and location systems, combined with on-power refueling capability, permit prompt removal of defected fuel. Fuel inspection equipment located in the fuel bay enables the utilities to pinpoint the cause of defects soon after the excursion. By resolving fuel performance problems soon after they occur, the extent of radioactive contamination within the reactor building can be minimized.

The on-power fueling capability and defected fuel location systems reduce the need to derate or shut down the reactor during a defect excursion.

4. CONCLUSIONS

Details on the interaction of on-power fueling with reactor physics and the fuel design itself have been provided. In addition, operational details and computer codes which are used to evaluate the impact of fueling operations on physics and fuel have been discussed. Benefits which accrue from on-power fueling have been identified.

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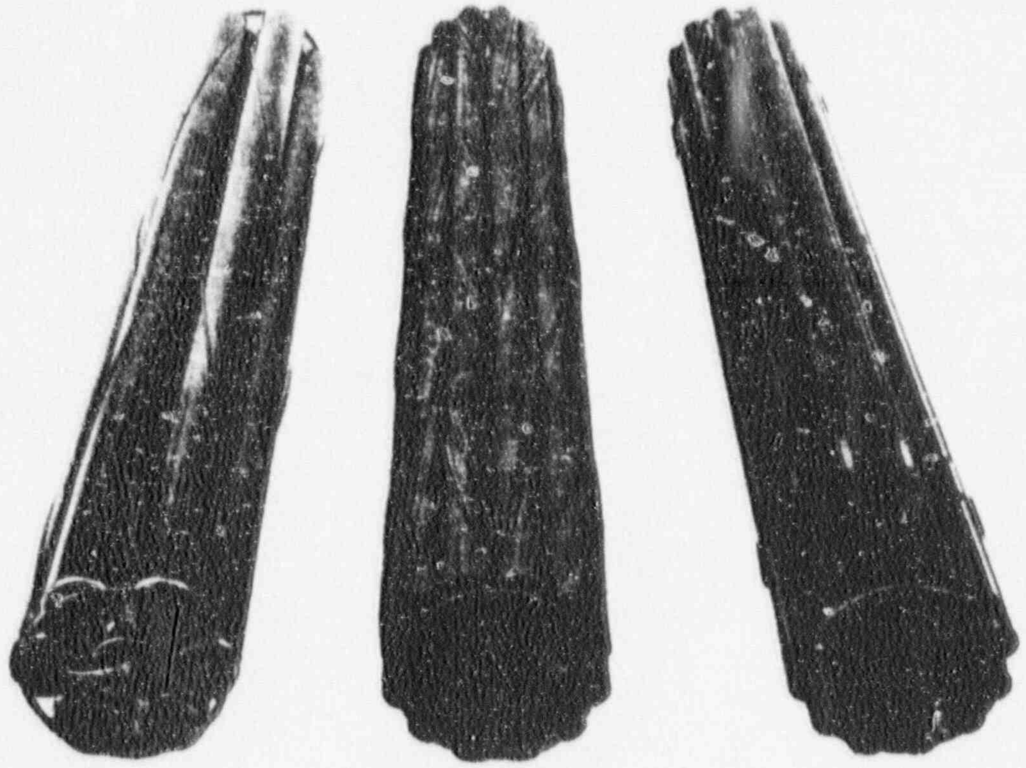
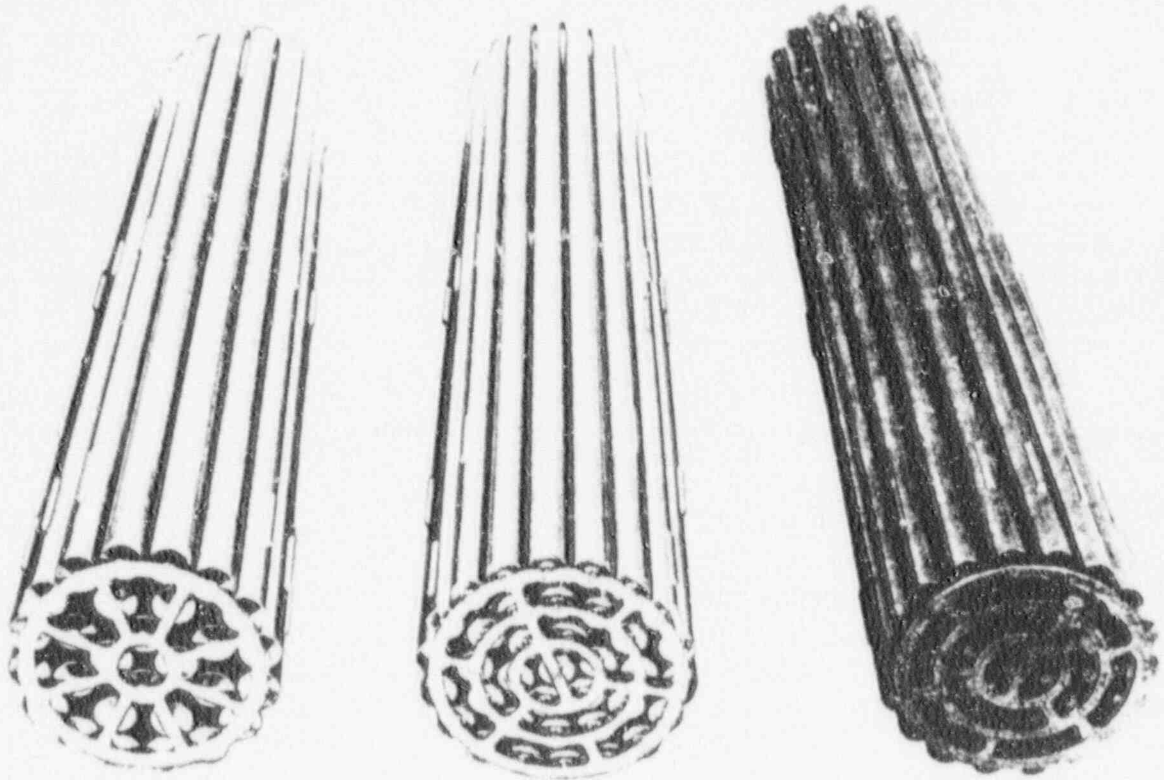


7 ELEMENT WIRE-
WRAPPED NPD BUNDLE

19 ELEMENT WIRE-WRAPPED
BUNDLE AS USED IN NPD
AND DOUGLAS POINT

REPLACEMENT BRAZED SPACER
19 ELEMENT BUNDLE

FIGURE 6-1 CANDU FUEL BUNDLES - 82.5 mm DIAMETER x 495 mm LONG



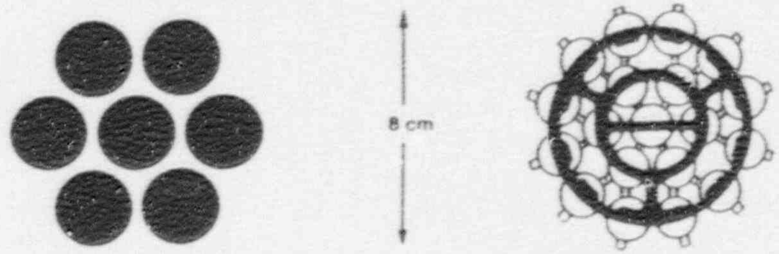
28 ELEMENT
PICKERING BUNDLE

37 ELEMENT
BRUCE BUNDLE

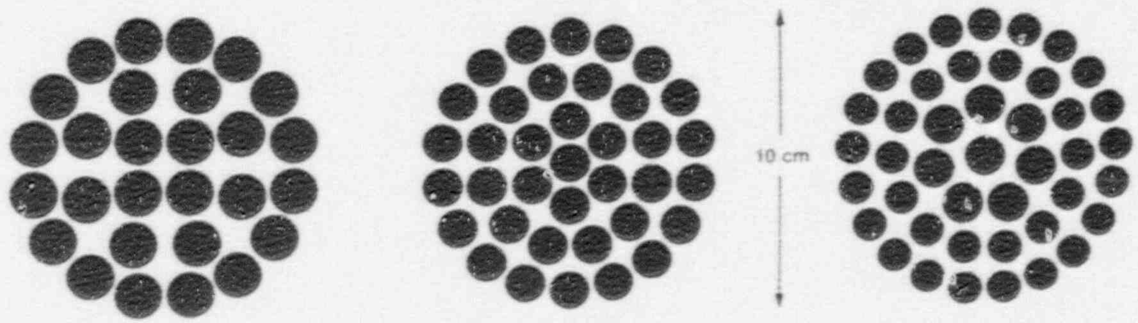
37 ELEMENT
600 MW BUNDLE

FIGURE 6-2 CANDU FUEL BUNDLES - 102 mm DIAMETER x 495 mm LONG

BASIC DATA FOR CANDU FUEL BUNDLES



REACTOR	N.P.D.	N.P.D. & DOUGLAS PT.	
NUMBER OF RODS/BUNDLE	7	19	19
ROD DIAMETER mm	25.4	15.25	15.22
NOMINAL BUNDLE POWER kW	220	221	420
MASS RATIO UO_2/ZIRCALOY	11.1	10.2	10.1



REACTOR	PICKERING	BRUCE AND CANDU-6		CANFLEX
NUMBER OF RODS/BUNDLE	28	37	37	43
ROD DIAMETER mm	15.19	13.08	13.08	
NOMINAL BUNDLE POWER kW	640	900	800	
MASS RATIO UO_2/ZIRCALOY	11.1	9.4	9.4	

NOTE: END PLATE AND INTER-ELEMENT SPACERS AND BEARING PADS ARE SHOWN FOR NPD AND DOUGLAS POINT BUNDLE, OMITTED FROM OTHER BUNDLES FOR CLARITY

FIGURE 6-3 BASIC DATA FOR CANDU FUEL BUNDLES

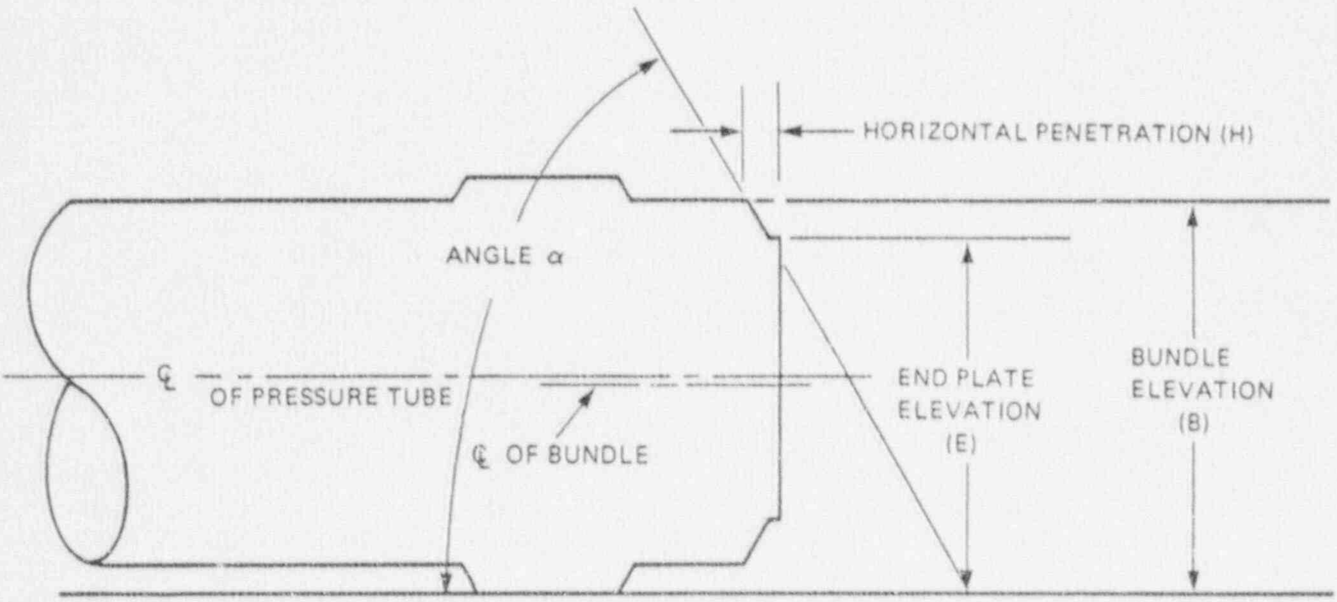
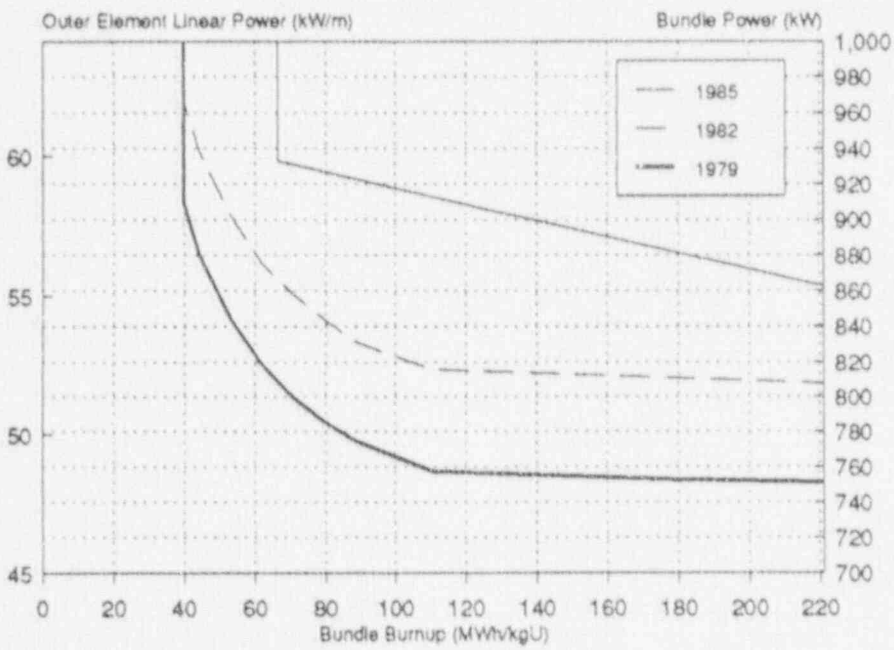


FIGURE 6-4 CANDU 3 FUEL BUNDLE END PROFILE

SCC THRESHOLD CURVES for RAMPED POWER



SCC THRESHOLD CURVES for POWER INCREASE

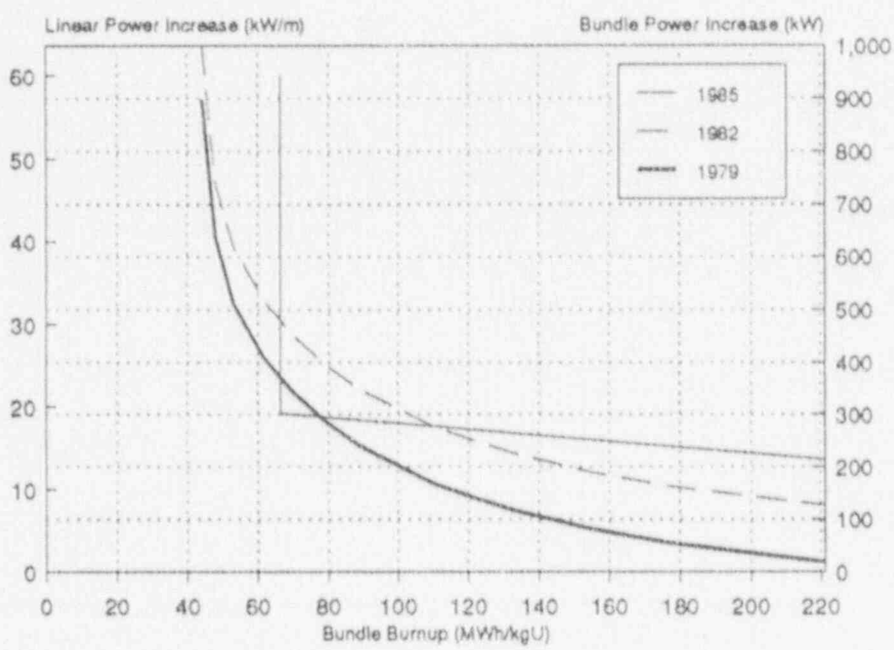


FIGURE 6-5 SCC DEFECT THRESHOLDS

Atomic Energy of Canada Limited
CANDU Operations

Énergie atomique du Canada limitée
Opérations CANDU

TTR-305
Rev. 0

CHAPTER 7

SAFETY ASSESSMENT OF FUEL HANDLING

1991 January

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Sheridan Park Research Community
Mississauga, Ontario, Canada
L5K 1B2

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CHAPTER 7

SAFETY ASSESSMENT OF FUEL HANDLING

1. INTRODUCTION

This chapter considers CANDU nuclear fuel handling primarily from a safety viewpoint. For protection of the workforce, the public and the environment, undesired events include:

- approach to nuclear criticality by fuel outside a reactor
- fuel failures during or due to fuel handling
- fuel handling induced dispersal of radioactivity
- fuel handling induced dispersal of tritiated heavy water
- excessive radiation fields around fuel handling equipment when operator access is permitted.

Defence against such events, and mitigation of unavoidable events, are built into the design of the fuel handling system.

The CANDU reactor safety is designed for defence–in–depth, meaning that an intact fuel sheath is the first line of defence against activity release; if there is a fuel defect, then an intact pressure boundary of the primary heat transport system retains the activity. The CANDU fueling machine (F/M) is part of the primary system, because at least while the F/M is "on–reactor", the F/M also represents the primary pressure boundary.

If the seal between the F/M and an end fitting fails, then activity may escape into the containment. As a next defence, the containment is designed to prevent dispersal of radioactive materials, and as further defence against concentrated activity reaching the population at large, a stack may disperse filtered, vented gases, and an exclusion zone is maintained around the nuclear power station. To keep the fuel sheath from failing, various cooling means are provided to mitigate the hazardous consequences. Also, shielding, protective clothing and rigorous controls minimize radiological exposure of the operators. Even so, some hazards remain and must be provided for.

Any abnormal operation of the fuel handling systems which may result in fuel overrating, as manifested by high burnup, excessive fuel temperatures and failures of the nuclear fuel has to be considered. Depending on the severity of the event, the consequences may affect some operating personnel at a reactor station, perhaps the environment or even a part of the population near a nuclear generating station. Minimizing fuel failures during fuel handling can simplify the short and long term storage of the irradiated fuel and reduce the related safety issues.

The CANDU fuel handling system consists of equipment for new fuel loading into a F/M, the actual F/Ms, which are sophisticated remotely operated machines to remove and replace fuel channel closure and shield plugs, and charge and discharge fuel bundles to and from individual fuel channels of the reactor, and transfer mechanisms which deposit the irradiated fuel in an underwater storage bay. The detailed functions, operating principles, monitoring, control and maintenance of these systems, and the recovery after a malfunctioning of a fuel handling system are described in other chapters of the this report.

CANDU "on–power" fueling has a 35 year history of shared development efforts among AECL, Ontario Hydro and several other utilities and manufacturers in Canada and abroad. Since some undesired events occurred in the fuel handling systems of the various operating reactors, experience gained from all CANDU power reactors built to–date were shared by the affected utilities and organizations. In 1984, a CANDU umbrella organization called CANDU Owners Group (COG), was founded to coordinate common efforts. COG collects data on safety related events, and undertakes joint funding of development of safety related improvements, modifications and new designs. The lessons learned from past operation of CANDU stations and from COG development efforts reflect in the safety benefits of the new generation CANDU 3 reactors.

As the CANDU power reactors evolved, their operation and safety have been subject to strict government licensing. Thus, it is instructive to point out that although there are no regulatory requirements codified for CANDU fuel handling safety, the relevant government guidelines [(1)] state that the licensee has to perform a comprehensive and detailed review of the design to identify failures of equipment. The licensee must analyze or predict the consequences of these postulated failures of fuel handling equipment. Indeed, this was done for each CANDU reactor to satisfy the government licensing requirements. Good engineering practice and the licensing guidelines dictate that the causes of each undesired event related to fuel handling systems of CANDU reactors should be understood, and a solution developed which would eliminate the event, or at least alleviate the consequences.

The safety of the CANDU fuel handling systems is judged by three methods:

– review of fuel handling related undesired events at existing CANDU power plants

– probabilistic assessment of accidental occurrences

– deterministic calculation of the consequences of selected hypothesized accident cases.

The current CANDU design criteria for maximum permissible doses to atomic radiation workers [(2)] are listed in Table 7.1. Although the limit doses do not distinguish between the sources of the radiation, they are of vital importance to workers, who may be in the containment building on a regular basis, (e.g., on fuel handling related work). The maximum permissible doses to any other person (outside containment) are also specified [(2)] but these are covered in the other safety related discussions, for example, in connection with the CANDU containment system.

The terminology of the International Nuclear Event Scale (INES) [3] is used in this report to classify undesired events at nuclear power plants. Table 7.2 gives this classification. Undesired events may be referred to either by level numbers or by equivalent descriptive names.

2. OPERATIONAL SAFETY EXPERIENCE

2.1 REVIEW OF ACTUAL ACCIDENTS AND INCIDENTS

The Canadian designed and built power reactors, the CANDUs, have already operated for an accumulated service life of about 250 reactor years. During this operating experience, there have been no fuel handling "accidents with off–site risks", that is, with radioactivity releases from reactor containments, in which the emissions represented a health risk to the public at large. There were a very limited number of "accidents mainly in the installation", affecting the operations and causing some radiation overdoses in a few operators. There were a few "major incidents": some cases with modest activity release within the containment building, and a few cases resulting in operator radiation doses in excess of the regulatory limits. Lesser incidents were more numerous, but mostly of the readily corrigible type. The fuel handling incidents experienced from 1980 to 1989 and their methods of recovery or technical remedies are discussed in Chapter 5. This chapter groups and discusses the most important events in fuel handling with safety implications from a broader period, covering all fuel handling related undesired events in CANDU.

2.2 FUELING MACHINE EVENTS

Few fuel handling problems with safety implications were experienced. These events could be categorized as cases where F/Ms were "on–reactor", that is, with a F/M attached to an end fitting, or events with improper interface between a F/M and the matching end fitting, or with F/Ms "off–reactor", that is in transit or at the irradiated fuel port. The undesirable events included irradiated fuel bundle damage in transfer mechanisms (other than the F/Ms) on the way to the irradiated fuel storage bay, and an irradiated fuel bundle dropping to the vault floor, and remaining there without liquid cooling.

2.2.1 Fueling Machine On–Reactor

With the F/M attached to an end fitting, undesired events included:

a. Break or puncture of inlet or outlet hoses to a F/M. Such events occurred within the predicted service life range of the flexible rubber hoses in spite of regular inspections for pinholes, and preventive maintenance programs which replace unfailed hoses at regular intervals. The consequences of hose failures were spillages of tritiated primary heat transport coolant via the F/M into the containment. Most spillages were terminated by automatic excess–flow valves or fail–closed isolation valves. Very rarely has such a valve failed as well. There were no fuel failures in the reactors or in the F/M due to such hose breaks.

b. Damage to fuel bundles in a fuel channel. Such events occurred at an end fitting seal face, at a magazine face by irregular maneuvers of the F/M and by failures of some components of the mechanisms (e.g., too many bundles loaded, lack of fuel carrier tube, malfunctioning bundle stop, rotated magazine shearing a mislocated fuel bundle). During the recovery operations, some activity was released into the F/M vaults.

c. Damage to a fuel channel. Such an event occurred when a F/M bridge moved while the F/M was attached to an end fitting. The end fitting was permanently deformed (requiring fuel channel replacement), but the F/M remained attached to the end fitting. A primary coolant leak at the F/M to end fitting interface started at 1400 kg/hr (96 slug/hr), but after a reactor shutdown, cooldown and depressurization according to normal operating procedures, the leak rate was reduced to 8 kg/hr (0.6 slug/hr) within a few hours. There were no fuel failure consequences.

d. Damage to parts of a F/M. For instance, a guide sleeve was jammed in the magazine with consequent loss of availability of the F/M.

e. Stuck components (e.g., shield plug) prevented removal of fuel. Event a. as previously described, resulted in leakages of less than about 4 Mg (4.4 tons) of D_2O. In most cases the D_2O discharge amounted to a small spillage. The D_2O was almost completely recoverable from the sump and the containment atmosphere.

Events b., d. and e., on occasions, prevented fuel removal for several days, sometimes necessitating a reactor shutdown to prevent fuel failure or allow defueling the channel by one F/M. If defected or damaged fuel had to be removed, it increased the radioactive contamination of the primary coolant system and of the F/M, or released some activity into the containment atmosphere during removal of defected fuel by grapples or scoops.

Only one instance of event type c. occurred. This discharged tritiated heavy water coolant into the containment, and some of the containment atmosphere was vented by the normally operating ventilation system. This resulted in a minimal radioactive emission through the stack.

2.2.2 Fueling Machine to End Fitting Interface Failure

There were the following types of undesired events:

a. Improper seal at snout to F/M surfaces. This resulted in some heavy water spillage.

b. Channel closure failure. The success of a channel closure sealing is routinely checked by a leak test after fueling, before uncoupling the F/M from an end fitting.

On a few occasions, foreign material or debris at the sealing surfaces resulted in incomplete closing of the end of the fuel channel. When the leak could not be stopped by reseating the channel closure, the F/M had to be backed off for capping the end fitting until maintenance could be carried out.

c. F/M uncoupling from an open fuel channel. When the channel is under pressure, this is prevented by a pressure actuated safety lock. Once, however, when a reactor was shut down, and a fuel channel was depressurized for maintenance, a F/M backed off from its end fitting when the channel closure was not in place. Some spillage of heavy water occurred.

These events resulted in leakage or spillage of tritiated heavy water into containment. There were no fuel failures due to such occurrences.

2.2.3 Fueling Machine Off–Reactor

With irradiated fuel in the F/M, various events with safety implications occurred:

a. Break or puncture of inlet or outlet hoses to a F/M, or liquid coolant line or hose breaks causing tritiated heavy water spillages. Once after an outlet line break, boiling–off partly depleted the liquid coolant in the F/M and some irradiated fuel overheated for a short time, but there was no fuel failure.

b. Loss of pressure control in a F/M. Once after a safety relief valve opening, it failed to reclose, the pressure control was lost and spillage of D_2O ensued. There was no fuel failure.

c. Loss of coolant level control in a F/M. This occurred once, when spillage from a broken hose short circuited the level control connections in a distribution box on the F/M and caused exposure to air of irradiated fuel bundles in the magazine of the F/M. Some fuel failure ensued.

d. Mechanical failure of a F/M. On one occasion, a fuel transfer ram became stuck while irradiated fuel was in the magazine above the coolant level. Operator intervention by flooding the machine with water from the fuel bay prevented fuel failure. Once, a magazine could not be rotated to submerge the fuel in an upper site into the coolant, and an irradiated fuel bundle overheated and defected.

e. Oil spill from a F/M. On one occasion, up to 230L (60 U.S. gal.) of oil spilled from a filter break on a F/M ram operated by the oil hydraulic system. There was no ensuing oil ignition.

Inlet or outlet hose breaks on an off–reactor F/M are isolated by automatic valves or within 15 minutes after the breaks by remote isolation of the flows by the reactor operator. This is the same procedure that is used for on–reactor hose breaks.

In the events where a hose broke or a supply line weld failed, or an operator erred resulting in a F/M calibration port vent valve remaining open, tritiated D_2O coolant was spilled. The worst spill was about 92 Mg (100 tons) of heavy water into containment, but in all cases, the heavy water was recovered.

Short circuiting of control wiring by water outside the F/M is now prevented by individual water–tight caps for each wire junction, and by physical separation of the redundant control devices and their wiring.

2.2.4 Fuel Failure Outside Reactor and Fueling Machine

Fuel failure outside a reactor and outside a F/M occurred during loading of fresh fuel into a F/M, and during irradiated fuel transfer from the F/M.

Fresh fuel is fed manually to a new fuel loader and from there to the F/M. Mechanical damage to new fuel occurred in the new fuel loader, but the damage was detected and the fuel was discarded before insertion into the F/M.

Irradiated fuel from a F/M is fed via an irradiated fuel port to a transfer device and from there to the water pool in the irradiated fuel storage bay. In these devices, a few incidents occurred without appropriate cooling to the fuel. In one case, irradiated fuel remained exposed to air and defected in a fuel transfer mechanism located in the fuel bay entrance because a closed vent valve prevented water ingress. Once a fuel bundle remained without water cooling in an irradiated fuel transfer port, and a similar event occurred on an irradiated fuel elevator. In the latter case, the elevator got stuck with irradiated fuel only cooled in air for a long period and the fuel overheated and disintegrated. Spray cooling was retrofitted to devices for which such incidents could be foreseen.

On one occasion, an irradiated fuel bundle was dropped to the floor of the F/M vault from the open snout of a F/M. Without liquid cooling, the fuel overheated, its sheath defected and its UO_2 oxidized to U_3O_8.

In serious incidents, when fuel disintegrated and broke into small pieces, (e.g., in the irradiated fuel elevator incident), most of the activity in a fuel bundle was released into the containment atmosphere. Although off-site activity releases were minimal, radiation exposure of the recovery work force, within the permissible limits, could not be avoided.

For the rare events involving defected fuel removal, there are remotely operated grapples, and robotic devices with scoops and buckets of various degrees of sophistication.

2.2.5 Non–Generic Fueling Machine Events

The following events are not specific to F/Ms, but occurred in connection with F/Ms:

a. Overexposures to F/M maintenance staff. On a few occasions, in the F/M servicing bay, fuel handling operators received full body, or extremity (hand), or skin overexposures while performing maintenance operations which took longer than anticipated, e.g., fixing quick disconnects, repairing a flow transmitter, or when the operators estimated lower radiation fields near a F/M than existed. Routine monitoring was sometimes not enough to detect the high radiation fields, or the methods of extremity dosimetry were not sufficient.

b. F/M heat exchanger failure. Once a F/M heat exchanger failed such that tritiated D_2O was spilled via the service water coolant to the lake which supplied the coolant.

These events are not unique to the fuel handling system. Use of an inadequate radiation monitor during maintenance, or human errors caused the overexposures. The heat exchangers are designed against tube wall failures, but there is a small probability for defects. Thus, the F/M heat exchangers were modified such that there is now no direct heat exchange to the service water, but to an intermediate recirculated water loop, which in turn transfers the heat to the service water.

2.2.6 Summary of Operational Experiences

The undesired events in fuel handling showed no major LOCA or major accidental radioactive releases or contamination.

The releases that were experienced (a few fuel pencils' worth of fission products or some tritiated heavy water spills) dispersed into the containment atmosphere or the irradiated fuel bay water, with the containment functioning normally. The heavy water was reclaimed both in liquid and vapor phases.

In all cases with failure of irradiated fuel bundles when fission products (uranium oxide or tritium activity) were released into the containment, the doses to the atomic radiation workers were less than the permissible limits (Table 7.1). Off-site activity releases and radiation doses in all fuel handling events were within allowable limits.

Protection of radiation workers against contamination in all events was carefully controlled, but some overdoses above the limits in Table 7.1 still occurred.

There were a few events of worker exposure to excessive radiation doses during F/M maintenance. The over-exposures were classified as human error, due to improper selection or use of radiation measuring instruments. There was one event of leakage of 2.3 Mg (2.5 tons) of tritiated D_2O from a F/M heat exchanger into the environmental water source. This event is not specific to the CANDU fuel handling system.

All undesired events were thoroughly investigated, and suitable mechanical, control and operational improvements were made to prevent future recurrences, or to mitigate consequences of unavoidable events. In cases where recurrence due to human error could not be eliminated by hardware and software changes, procedural changes and further advanced operator training were implemented as remedial measures. Naturally, to achieve safe operation of fuel handling systems, responsible management is needed by the CANDU owners/utilities.

Epidemiological surveys of the workforce at CANDU nuclear stations and at AECL research reactors, which supported the development of CANDU reactors for more than 35 years, did not show health effects beyond that experienced by the population at large. This is also an indicator of CANDU fuel handling safety, since the epidemiologic surveys did not distinguish the fuel handling workers from other atomic radiation workers at the CANDU reactor plants.

3. PROBABILISTIC SAFETY ANALYSIS OF FUEL HANDLING EVENTS

3.1 EVENTS CONSIDERED FOR RELIABILITY STUDIES

The operational incidents or accidents in CANDU fuel handling were small in number and limited in range. In order to learn more about the possible accidents for each type of CANDU reactor design, detailed event and fault tree analyses were performed to identify possible modes of occurrence of undesired events and assess the expected frequencies of such events.

The evaluation of safety concerns for the fuel handling system includes a systematic probabilistic study of conceived undesired events which may result in some risk of:

- nuclear criticality of fuel outside a reactor, but inside the containment building
- primary heat transport system loss of coolant due to fuel handling system malfunctioning
- fuel damage inside or outside a reactor associated with fuel handling
- activity release from defected fuel into the containment or the irradiated fuel storage bay
- tritiated heavy water spills and loss of coolant to containment
- activity dispersal within containment and exposure to operating personnel
- activity dispersal off–site, exposure to the public, and contamination of the environment.

These events alone or in combinations were analyzed using various probabilistic analysis techniques.

3.2 METHOD OF ANALYSIS

The CANDU practice for probabilistic safety analysis (PSA) follows the International Atomic Energy Agency guidelines [(4)]. The probabilistic analysis starts with an identification of the potential initiating events from a review of the design and plant operating experiences of the fuel handling system and of other impacting systems. The initiating event may be the failure of any component or system. The probability of the initiating failures differ for different causes and components. Starting from the initiating events, "event sequences" and "event trees" are made.

Event sequence analysis maps out the initial response of different plant systems, in parallel. This is a qualitative study covering the sequence in which other components and systems may be affected, the time frame from occurrence of the initiating event to the latest safe time for initiation of corrective action by the operator. This is also used for development of operator response guidelines.

Event tree analysis is then carried out for each initiating event. The event tree depicts various possible sequences which could occur after the initiating event, by modeling combinations of availabilities or unavailabilities of mitigating systems. Each event tree concludes when stable conditions (with or without activity releases) are achieved, or when there are no mitigating systems left to call upon.

Starting from a postulated initiating event, a number of outcomes are possible depending on the success or failure of the available mitigating systems. Each event sequence or outcome is expressed in a logic equation form, using a name for each event, linked by Boolean algebra. Those functions which are not shown in the equations of the various end states have either been successful or are not relevant to the sequence under consideration.

The outcome of each identified event sequence is quantified by the frequency of occurrences in the event tree. The simplified logic equations are put in a "fault tree" form, which allows easy sequence quantification and changes of logic (if necessary) and facilitates a review, due to the graphical form. The fault tree model is used to estimate the probabilities for individual event tree branch points. The fault tree models the failure of individual components in a system, and connects these through AND/OR logic to arrive at a final event frequency in a sequence, called a "top event" for that fault tree. Of course, it could be the starting frequency for other events.

From the very large number of fault trees, many can be omitted because the ensuing event sequences may overlap and often the mitigating systems function identically, independent of the initiating events.

Accident sequence quantification is undertaken to estimate the frequency for individual event tree endpoints. The objective is to factor into account any modeled failures that are common among systems.

Reliability, or the frequency of failures of each component is usually available from the manufacturer of the component or from data based on operational experience. Human reliability is modeled where human interaction dependencies might occur.

The safety concern is not only the release of radionuclides into the containment, after undesired fuel handling event but more often the off-site release.

This is done by feeding the fuel handling related activity release frequencies into a containment event tree. This tree models the availability/unavailability of various containment subsystems, (with each branch point supported by a fault tree), and the endpoints which can show the frequencies of releases from containment.

A reliability and maintainability analysis is also performed to predict the expected maintenance dosage.

3.3 PREDICTED EVENT FREQUENCIES

The most important safety concern is the frequency of release of radionuclides into the containment and off-site and the probability of radioactive exposures to the public. Accordingly, fault trees were made and evaluated for failure frequencies for the most critical events. Some typical values of predicted event frequencies of operating CANDU 6 or 9 rectors are as follow:

Description of Events Involving F/M Operation	Predicted Occurrence Frequency (event/reactor year)
Single channel end fitting failure results only in a so-called small LOCA (< 70 L/s (18 U.S. gal/s) coolant discharge) after a postulated ejection of channel closure and shield plugs and of all fuel bundles from the channel. It might be assumed that this event is initiated by a malfunctioning F/M on–reactor or backing off from an end fitting.	2.0E–03
Loss of fuel cooling in an off–reactor F/M due to:	
hose break and malfunctioning valves and relays	2.0E–03
loss of Class 4 (off–site) power followed by loss of Class 3 power, based on two 100% on-site diesel generators. In CANDU practice this does not cause a station blackout (CANDUs have a seismically qualified emergency power supply source backing up the Class 3 standby diesel generators).	1.0E–03

After a loss of Class 4 power, that is, the normal off–site power, Class 3 power (from standby diesel generators) becomes available within minutes for the cooling pumps of the F/M, but otherwise the F/M remains without power. Thus, unless other systems also fail, the loss of cooling to a F/M due to electrical causes is predicted to have a frequency of 1.0E–03 occurrences/year.

Damage to fuel during transit to or inside the transfer port, and during transfer to the irradiated fuel storage bay are less important events, since they usually affect only one fuel bundle.

In CANDU licensing practice, accidents or incidents with safety concerns of release of radionuclides into the containment and possibly outside the containment are further analyzed deterministically, to predict the consequences. Generally the more severe the accident, the less probable is its occurrence. Event sequences which reach stable plant conditions without significant activity release are not analyzed further. Undesired top events with predicted frequencies of less than 1.0E–07 occurrence/year are considered sufficiently improbable and not analyzed for their consequences. Risks arising out of the undesired events are assessed, based on the frequency and the consequences of the event, such as related to radioactive exposure effects on the health of the recipients.

4. DETERMINISTIC ANALYSES OF POSTULATED ACCIDENTS

4.1 CHOICE OF ACCIDENTS TO BE ANALYZED

With a fuel handling related failure as the initiating event, diverse types of accidents could be hypothesized: there may follow a primary heat transport system LOCA, or even a coincident loss of emergency cooling. Subsystems of the special safety systems (e.g., containment) may be impaired. For the hypothesized accident scenarios, the consequences have to be analyzed: how many fuel elements will defect, how much dispersal of radioactivity will ensue into the containment and off–site, how much the worst dosage could be to an operator or to the public.

The safety analyses for reactor licensing looked at a number of postulated fuel handling accidents:

- fuel criticality outside a reactor
- loss of coolant of the primary heat transport circuit with F/M on reactor
- improper interface connections between F/M and end fittings
- loss of coolant from F/M off–reactor
- stuck fuel in irradiated fuel port
- loss of cooling in fuel transfer device between irradiated fuel port and irradiated fuel storage bay
- irradiated fuel dropped in vault
- fuel damage in irradiated fuel storage bay.

For calculation purposes, it is assumed that the fuel handling system accident occurs while either all reactor safety and accident mitigating systems operate normally, or while there is a coincident failure or impairment of the safety or mitigating systems. The cases to be analyzed cover all relevant events recommended by the government regulatory guide [1].

4.2 METHODS OF ANALYSIS

The questions asked in the analyses are manifold: would the event become an uncontrollable power runaway (that is, nuclear criticality outside the reactor); if the power is controllable, would there be a loss of primary coolant, fuel heat up in and out of the reactor and the F/M, fuel failure, chemical reactions, release of radioactivity to and from the containment and radiation doses to the work force and to the public outside the exclusion zone of the nuclear power station.

To answer all these questions, a host of one and multi–dimensional, special or general purpose computer codes are used, for nuclear physics, thermal–hydraulics, heat transfer, stress analysis, chemical kinetics, shielding, dispersion and diffusion of fission products, and health physics calculations.

Nuclear criticality is checked by physics codes, loss of coolant predictions by thermal hydraulic codes, fuel heatup without liquid cooling by heat transfer codes, fission product release from the fuel is predicted by fuel behaviour codes, the containment performance and activity transport and dispersal to the environment and the doses to operators or to the public by various special purpose codes. The principal computer codes, and their verification, as used in CANDU licensing analysis practices, are briefly described elsewhere [5].

The analyses predict the consequences of each selected event; when conservative assumptions cannot be guaranteed due to uncertainties, then parametric studies are performed.

Although CANDU reactors are designed with redundancy and duplications of the safety systems, the analyses do not allow for the action of all the safety systems which may mitigate an event, but allow for the later acting systems or only for a part of the available safety systems.

If a fuel handling related event can be shown to be less severe than an analyzed primary heat transport system LOCA, then the consequences of the primary LOCA may be construed as a bound for the less severe accident. The predicted outcome of some severe primary LOCA, [5], may bound the activity release consequences of some fuel handling related loss of coolant accidents. For instance, the end fitting failure, with all fuel bundles from a fuel channel ejected to the vault floor, bounds the fission product release consequences of an improbable event of a F/M dropping all its fuel bundles to the vault floor. If in a fuel handling related accident, the activity releases to the environment could be larger than after an end fitting failure event, then these aspects are analyzed.

Subsequent to analyzing single failure accidents, dual failure accidents are analyzed. The dual failure accidents are postulated from a matrix of fuel handling related accidents coincident with safety system or subsystem malfunctions. A companion report [5] discusses the Canadian single/dual concept in some depth.

Table 7.3 lists a representative set of postulated fueling accidents and gives any assumed coincident events. The containment is assumed to be either operating normally, or to have an impairment of loss of isolation, of deflated airlock seals, or of another subsystem.

The modeling and the assumptions for the calculations of atmospheric dispersion of released radioactivity are generic to all accidents for a given licensing case.

The most undesired consequences of failures are radiation exposure and doses to operating personnel and to the off–site public. Operating personnel, in spite of protective gear and measures, might be exposed to high radiation fields or radionuclide inhalation or ingestion.

If any radioactivity is released into the containment before containment isolation, or if isolation fails, then some activity may also be released outside the containment. Doses to the most exposed critical individual and the collective dose to the whole population within a radius of 100 km (62 miles) from the accident site for a duration of one month after the initial accident are calculated.

4.3 FUEL STORAGE AND NUCLEAR CRITICALITY

The safety of fuel handling and storage against nuclear criticality has been amply demonstrated in the various CANDU reactors. Fresh fuel bundles, each with overall dimensions of about 102 mm (4.02 inch) outside diameter and 495 mm (19.5 inch) length, are individually stored in styrofoam packing cases to prevent physical damage. The packing also provides fuel spacing not conducive for nuclear criticality. Criticality of new and irradiated CANDU fuels is of no concern, whether flooded by light water or not, as long as the fuel is natural uranium based. Flooding of a large number of fuel bundles with heavy water is not considered a credible event. A tight physical proximity of the fuel bundles would not promote criticality, even with heavy water moderation. In fact, the CANDU reactor fuel channel lattice pitch of about 286 mm (11.3 inch) was optimally selected to maximize the criticality.

4.4 FUELING MACHINE ON-REACTOR LOCA

A loss of primary cooling accident from a feeder, header, or in-core fuel channel break, while a F/M is on-reactor, that is, attached to the end fitting of a fuel channel, is similar to that of the LOCA without F/Ms attached, except for the slightly increased primary coolant inventory available in the F/Ms (but only at one fuel channel). The resulting extended blowdown period makes such LOCAs with a F/M on-reactor less severe than with a F/M off-reactor.

Fuel failure in a F/M on-reactor, as a consequence of a feeder, header or in-core fuel channel break is less severe than for the fuel in the reactor core, because of lower heat generation rates and longer period of water cooling in the F/M. Thus any fission product release from such a failure of irradiated bundles is small, and later, in time, compared to the principal primary coolant system LOCA postulated without F/M on-reactor.

4.5 FUELING MACHINE INDUCED LOCA

This is hypothesized to occur by either of two ways:

a. LOCA via severed heavy water supply and return hoses of a F/M on-reactor. LOCA via a F/M is envisaged as a consequence of breaks of F/M inlet or outlet hoses, or less credibly of some fracture of the F/M housing. In either case primary coolant would have to blow down through the F/M at relatively slower rates than in an end fitting failure LOCA. The resulting slightly extended blowdown period makes such LOCAs with a F/M on-reactor less severe than with hose failures on a F/M off-reactor. In the on-reactor case no fuel failures are expected until the operator takes action. Fission product releases are limited to a fraction of the radionuclide burden of the blown down primary coolant. However, to provide an estimate of doses to the public, releases into containment are assumed the same as for a small primary LOCA, and the containment pressure is assumed to rise to the pressure isolation setpoint. If the pressure remains below the isolation setpoint, then the operator manually engages the emergency core cooling system, unless recovery operation and heavy water feed can maintain the necessary inventory for primary circuit cooling. If the operator does not compensate for the coolant losses, then the doses to the public would still be bound by the corresponding small break primary LOCA predictions.

b. Failure of snout-to-end fitting connection with F/M on-reactor. A F/M snout malfunction induced primary heat transport system LOCA might occur after a failure of the F/M snout to channel end fitting clamp and safety lock. Coincident failures of the snout clamping mechanism and the snout safety lock never occurred, and is a highly improbable scenario. Still this accident is analyzed assuming that the F/M backs away and leaves a gap between the snout and the end fitting of the fuel channel.

If no fuel can be ejected via the end fitting to F/M snout gap, then the consequence of a structural or control failure of the snout locking device would be only a small leak from the primary heat transport system with no fuel failures. In some CANDU reactors, the F/M can back off 180 mm (7 inch), and then the roughly 500 mm (20 inch) long fuel bundles ejected from the fuel channel may enter the F/M snout and hit previously ejected fuel bundles. This impact or the radial forces associated with the expanding coolant jet may damage a fuel bundle. Any fuel lodged in the channel or in the F/M remains well cooled by the relatively slowly escaping coolant. The radioactive source term in this case would come from about one or two bundles.

If the gap between the F/M snout and end fitting becomes larger, then all fuel bundles of the channel might fall onto the F/M trolley or the vault floor, and for awhile the fuel might remain cooled by the unflashed part of the escaping primary coolant jet which rains down from the end fitting. For conservatism, it is assumed that all irradiated fuel bundles of a maximum rated fuel channel are without any liquid cooling on the vault floor. So far this scenario is similar to that of an end fitting failure case.

The fission product releases derived for an end fitting failure are overestimated as follows. The short term radioactive source term in an end fitting failure LOCA is derived by assuming intact bundles on the floor without water cooling for heat transfer calculations, to over-predict heat up rates and temperatures of the fuel, and by assuming fuel pencils broken to pieces, for maximum activity release from free and grain boundary fission product inventories. These assumptions result in over-estimated excessive oxidation rate of the UO_2.

For the long term fission product releases (say beyond an hour), it is conservatively assumed that the source term is the sum of those derived for the end fitting failure with the ejection and overheating of all fuel from the affected channel, plus fuel overheating and defecting in the open F/M. Since the water inlet flow to the F/M continues, only partial uncovering of, at most, the top four bundles in the F/M magazine would occur. These bundles without liquid cooling may fail, but the release of activity from the F/M would be slow due to low pressure in the F/M. Thus the radidonuclide releases from these bundles hardly contribute to those from an end fitting failure primary LOCA.

The source term also includes an allowance for the activity release from the tritiated heavy water coolant flow to the containment.

If the end fitting failure LOCA were followed by a loss of emergency coolant injection (LOECI), which is a primary system dual failure event, then after a short blowdown, there would be a lack of coolant for the fuel ejected to the vault floor. An end fitting failure LOCA with coincident LOECI with one channel load of fuel ejected and heating up without coolant on the vault floor, followed by more fuel failure within the reactor core, would result in more long term activity source term than would a LOCA without LOECI. This accident, with intact containment was demonstrated to be within the permissible activity release rates from the containment.

Containment analysis and dose-to-public calculations are carried out with unimpaired and with impaired containment. The activity release from the containment is calculated by assuming intact containment. If the pressure or activity in the containment atmosphere is high enough, then the containment is. .ates automatically. If the pressure and activity levels are too low for triggering automatic isolation, then the reactor operator would initiate a containment isolation.

The activity release predictions from the containment after an end fitting failure with coincident LOECI are rather conservative when applied to a backoff of a F/M from an end fitting case, since with LOECI much more fuel can fail in various channels of the reactor than in a F/M.

The derived doses for the various F/M induced LOCA scenarios are within the allowed limits [2]. Since the models for the analyzed cases were all conservative, the safety design objectives associated with F/M induced LOCAs are achieved with considerable safety margins.

4.6 LOSS OF FUEL COOLING IN A FUELING MACHINE OFF-REACTOR

In off-reactor F/M failures, (whether by loss of electrical power, coolant line or hose severance, pump or motor failure, or by jammed or broken components), the fuel bundles stored in the magazine of the F/M can overheat after evaporation or leakage of coolant to a level lower than that of the irradiated fuel. A loss of coolant flow or loss of heat exchanger to the F/M coolant might precipitate the heat up. The heat up is slowed down with decaying activity in the fuel. The release of any fission products from defected fuel is further slowed down by the lack of a powerful blowdown from the F/M.

This event assumes that the coolant level in a F/M is either lost rapidly due to some hose breaks and isolating valve failures, or lost slowly due to boiling of the water in the F/M without replenishing flow. The F/M magazine is assumed to contain irradiated fuel bundles in all magazine sites (at most a fuel channels complement of fuel). In reality, such fuel loading in the F/M is not the operating practice. In either case a heat transfer calculation predicts the fuel heat up rate. Even without containment isolation the fission product releases and doses to the operators or to the public are less severe than the case of a F/M backing off an open end fitting, discussed in the previous section.

4.7 UNCONTAINED FUEL HEATUP

There is a possibility of one or two fuel bundles being ejected from a mechanically failed F/M. After an end fitting failure of a primary heat transport system up to 12 fuel bundles of the affected fuel channel might be ejected to the vault floor. Thus dropping one or more fuel bundles to the vault floor during fuel handling, or losing water cooling in the transfer mechanisms other than the F/M, were treated as a special case bounded by an end fitting failure primary LOCA.

With irradiated fuel remaining without liquid cooling on the vault floor or on some fuel transfer device, such as an irradiated fuel port, the activity releases to the containment are less than those from an end fitting failure, mainly because the fuel activity during fuel handling is more decayed than that of fuel ejected after a break. Also the timing of the release and the containment pressure transient and isolation response would differ. If the containment were not isolated by a high activity signal, and the ventilation flows continued, or if the containment isolation system failed (dual failure event) the activity releases and the doses to the public would still be less than in an end fitting failure LOCA with a coincident loss of containment isolation. The difference is because the containment pressure would be higher (and could cause more release from the containment) after a primary LOCA than after a fuel heat up on the vault floor or in a fuel transfer port or fuel elevator.

4.8 IRRADIATED FUEL BAY INCIDENTS

Heat–up of the water in an irradiated fuel storage bay could result either from a loss of flow in the cooling/purification circuit, or from a loss of service water to the heat exchangers. For all cases, high water temperature alarms at about 32°C (90°F) would be initiated. Based on maximum irradiated fuel heat load in the bay, and with about 29°C (84°F) initial water temperature, the high temperature alarm would be triggered within three hours at the earliest, after the loss of cooling, and the water would start bulk boiling within three days at the earliest, after the loss of cooling. This calculation was done conservatively, without crediting the heat capacity of the bay structures or heat losses from the bay. Three days is ample time for the operators to restore the cooling. There would be no fuel failure and fission product release caused by the slowly boiling bay water. The concrete walls of the bay, however, might suffer hairline cracks, but the overall structural integrity of the bay would be maintained.

A loss of fuel bay inventory (say by leakage through an irradiated fuel port) would trigger a low level alarm at least 4 m (13 ft) above the highest irradiated fuel bundle storage module assuming an inventory loss rate limited by that possible through a fuel transfer port. Subsequent to the alarm the operators would have at least 10 hours before the water level would drop to the top of the fuel module. This is ample time for the operators to manually close the bay side valve on the irradiated fuel port, or to provide make–up water from an emergency service water supply. This incident would not result in fuel failures with fission product release.

For the case of a full fuel storage module being dropped from a crane into the bay, the mechanical damage to about 10% of the fuel elements was predicted due to the impact. The water soluble fission products are cleaned up by the bay purification system. Only a part of the noble gases and of the iodine in the defected fuel elements would reach the atmosphere above the bay, and their release would have a minimal impact on the existing airborne activity burden, which is caused by a small defect rate in the large number of fuel bundles in a bay.

4.9 VALIDATION OF ANALYTICAL PREDICTIONS

Although tests were performed to ascertain that fuel elements of a bundle can survive the impact on the floor after an ejection, bundle failure by subsequent lack of cooling is still a possibility. The thermal consequences of such events were investigated by tests on electrically heated fuel bundles on concrete slabs. All of the computer codes used in the deterministic analyses were subject to various amounts of validation, either for separate effects or for the overall simulation models. Detailed validations were performed both for fuel heatup and activity release simulations, as noted below.

A broad range of specific tests relating to fuel handling was performed on electrically heated, high power fuel bundles. In some tests, heatup of bundles were carried out until failure of the heater. The bundles were tested in environments corresponding to fuel channel, F/M magazine, fuel transfer port and mechanism, or simply on concrete and steel floors. In some of the latter cases, various sprays were rained on the fuel bundles, or the bundles were sitting in pools of water of various depths and consistency, and there were tests in various stagnant or flowing air, steam or fog environments. The analytical predictions of the tests compared favorably with the measurements.

In several series of tests on actual irradiated fuel bundles, the fission product releases were measured. From variously irradiated and defected fuel, the activity release data was measured, including the release of gases from the free gas space, and the temperature dependent release of fission products bound in the fuel crystal structure both interstitially and intra–granularly. The data from these tests were used to select the source terms for the consequence analyses.

4.10 SEISMIC EVENTS

The analysis of consequences of earthquake induced accidents with the F/M on-reactor are not required, since the F/Ms are designed to be seismically qualified (see Chapter 3) for a station site dependent "design basis earthquake". This means that on-reactor machines are designed to remain attached to the end fitting during the DBE event.

The radiological consequences of an earthquake, however, have been analyzed for loss of cooling to the F/Ms containing irradiated fuel, and for two high power irradiated fuel bundles overheating in air in the transfer port/mechanism to the irradiated fuel storage bay. The latter event could occur, since on a postulated loss of electrical power at the onset of a DBE the defueling sequence may not be completed at the irradiated fuel port.

The containment system is seismically qualified, but for calculating the doses to the population outside the containment it was assumed that the containment is not isolated for one hour after the earthquake. The combined predicted releases and doses were found to be acceptable.

4.11 SUMMARY OF CONSEQUENCE ANALYSES

The risks and possible consequences of postulated accidents are evaluated by analytical simulations of the events, and when needed, supported by separate effect tests.

Nuclear criticality due to fuel handling failures is not a possible accident with natural uranium fuel, without the presence of high purity heavy water and the right spacing of the fuel bundles.

Deterministic analyses were performed on event sequences with a possible release of radioactive fission products. Both with on-reactor and off-reactor fuel handling accidents, the activity releases and radiological exposure or doses from the postulated most severe accidents would be less severe than the consequences of an end fitting failure LOCA plus coincident LOECI. This extremely severe and very low probability accident would result in radiation doses still within the permissible limits.

Loss of cooling or loss of coolant inventory incidents in the irradiated fuel storage bay would be manageable by the operators without causing fuel failures. Dropping a fuel storage module into the bay would slightly increase the airborne activity in the atmosphere above the bay.

On-reactor F/Ms are seismically qualified, but the radiological consequences of earthquake induced loss of cooling in an off-reactor F/M and of heat up in air of irradiated fuel in the fuel transfer ports were analyzed, and found acceptable.

5. CONCLUSIONS

In the 250 years of accumulated CANDU fuel handling experience, there has been no serious accident causing harm to the operators or the public. Some incidents with minor dispersal of activity, within or even outside containment occurred, and in some cases operators received more irradiation than allowed.

The evaluation of the probability of the conceived undesired events shows that fuel failures and fission product releases due to loss of cooling within a F/M or due to fuel ejection to a vault floor are probable top events of the fuel handling system failures, but with rather small frequencies of occurrence. The probabilistic predictions of the frequency of occurrences are so far supported by the 250 years of operating experience.

The consequences of fuel handling system failures are predicted to be less severe than allowed by the government licensing regulatory guides. The deterministic analyses of postulated events have been validated by fuel heat–up, defect and fission product release experiments, and also were supported by the outcome of the actual experience from the mild fuel handling related accidents and incidents at CANDU stations. For each CANDU station, safety analyses are completed to show that the operation of the fuel handling systems will not pose an unacceptable risk to the public. Epidemiological evidence suggests that neither the workforce nor the public has suffered from fuel handling (or any other CANDU) operation to date.

6. REFERENCES

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TABLE 7.1
MAXIMUM PERMISSIBLE DOSES

(Based on Reference 2)

Organ or Tissue	To Atomic Radiation Workers mSv (rem) per Quarter of a Year	To Atomic Radiation Workers mSv (rem) per Year	To Any Other Person mSv (rem) per Year
Whole body, gonads, bone marrow	30 (3)	50 (5)	5 (0.5)
Bone, Skin, Thyroid	150 (15)	300 (30)	30 (3)
Any tissue of hands, forearms, feet and ankles (extremities)	380 (38)	750 (75)	75 (7.5)
Lungs and other single organs and tissues	80 (8)	150 (15)	15 (1.5)

TABLE 7.2
INTERNATIONAL NUCLEAR EVENT SCALE (INES)

(Based on Reference 3)

Type of Event	Level	Description	Consequences in Terms of Radioactivity Release, Dose, Protective Measures
Accident	7	Major accident	Off-site release radiologically equivalent to I-131 release of > 10000s terabecquerels (270 000 Ci). Acute and delayed health and environmental effects over wide areas.
	6	Serious accident	Off-site release radiologically equivalent to I-131 release of 1000s to 10000s terabecquerels (27000 to 270 000 Ci).
	5	Accident with off-site risks	Off-site release radiologically equivalent to I-131 release of 100s to 1000s terabecquerels (2700 to 27000 Ci). Partial implementation of emergency plans needed to lessen the likelihood of health effects.
	4	Accident mainly in installation	Off-site release with dose to most exposed individual a few millisieverts (< 1 rem). Local food control needed. On-site worker's doses > 1 sievert (100 rem). Some damage to reactor core.
Incident	3	Major or serious incident	Off-site release with dose to most exposed individual .1 to 1 sievert (10 to 100 rem). Off-site protective measures not needed. Overexposure of on-site workers with individual doses .05 to .1 sievert (5 to 100 rem).
	2	Incident	Undesired events which, although not directly or immediately affecting plant safety, are liable to lead to subsequent re-evaluation of safety provisions.
	1	Anomaly	Functional or operational undesired events which do not pose a risk, but indicate a lack of safety provisions.
Non-Event	Below Scale	No safety significance	Operational limits and conditions not exceeded and event manageable with adequate procedures.

TABLE 7.3
REPRESENTATIVE SET OF UNDESIRED EVENTS ANALYZED FOR CONSEQUENCES

Undesired Event In	Fueling Accident Scenario	Single, Dual Failure	Coincident Event
F/M on-reactor	Fuel damaged due to fueling	S	Intact containment
		D	Steam generator tube leak
	Primary coolant system LOCA while fueling	S	Intact containment
	LOCA through F/M	S	Intact containment
Primary LOCA induced by F/M	F/M snout malfunction	D	LOECI + Intact containment
F/M off-reactor	Loss of F/M cooling	S	Intact containment
		D	Loss of isolation
		D	Loss of dousing
	Loss of F/M D_2O inventory	S	Intact containment
		D	Loss of isolation
		D	Open airlock
		D	Loss of dousing
Irradiated fuel port	Crushed bundle in fuel port	S	Intact containment
		D	Off-gas system not available
Irradiated fuel bay	Loss of bay cooling	S	Nominal conditions
	Loss of bay inventory	S	Nominal conditions
	Dropped fuel rack in bay	S	Nominal conditions
		D	Contaminated exhaust system unavailable

LOCA = Loss of Coolant Accident

LOECI = Loss of Emergency Coolant Injection

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CHAPTER 8

CANDU 3 SPECIFIC FEATURES

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CHAPTER 8
CANDU 3 SPECIFIC FEATURES

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CHAPTER 8

CANDU 3 SPECIFIC FEATURES

1. INTRODUCTION

The conventional CANDU fueling concept involves the co-ordinated operation of two fueling machine (F/Ms), connected to the ends of a selected fuel channel. For CANDU 3, the fueling concept requires the use of only one F/M, at the outlet end of the fuel channel, resulting directly in lower fuel handling capital equipment and operating costs. This also results in a smaller reactor building, resulting in additional cost reduction of the plant.

The CANDU 3 fuel handling concept is based on proven CANDU technology. This is accomplished as follows:

a. Adaptation of the existing main features of CANDU 6 and Pickering 'B' F/M design with a modified magazine rotor, involving addition of two magazine rotor stations. The downstream fuel channel end fitting is modified to include a short liner tube or a baffle sleeve at the outlet feeder which incorporates a free flow-through shield plug, latched spacer plug and a channel closure. Much of the existing F/M and associated hardware is similar to existing operating CANDUs.

b. The new inlet end fitting requires a fixed shield plug and a resident fuel pusher to push fuel towards the outlet end of the channel into the F/M. New simplified coolant axial inlet feeder connections located at the extreme end of the channel, rather than radially as in the conventional design, are adopted since access for fueling from the inlet end is no longer required.

c. The fuel pusher is required to push the fuel string towards the outlet end in low flow channels and, in all fuel channels, to push the last two bundles into the F/M magazine.

A fuel pusher is resident in each fuel channel at the upstream end. The capability is provided to completely defuel the channel with single-ended fueling. Sufficient magazine rotor capacity allows fueling to be carried out in a single visit to the channel.

The major benefits in adopting the single-ended fueling system are:

a. A reduction in the reactor building size and the accompanying plant reduction.

b. Greatly decreasing the amount of fuel handling equipment to fabricate, construct, test, commission, operate and maintain. This significantly reduces costs and increases reliability.

c. A single access ended fuel channel for fueling facilitates a factory built and inspected composite modular fuel channel assembly which includes the pressure tube and calandria tube. This composite modular fuel channel assembly reduces initial site installation time and cost, and contributes significantly to a shorter duration construction schedule for the plant also resulting in a major cost reduction.

d. The replacement of all the fuel channels in the reactor core within a 90 day outage becomes a realistic target through use of a modular factory built and inspected fuel channel assembly. This is only achieved by adopting a single-ended fueling system.

2. DEVELOPMENT HISTORY

An in depth study was carried out by AECL CANDU in the early 1980's. This study considered the concepts for the design of a fuel pusher and the alternatives for the type of F/M best adapted to the single-ended fueling design. For the single-ended application of CANDU 3, adaptation of the Pickering/CANDU 6 type F/M was recommended as the preferred concept, since it best met the overall requirements of safe and reliable operation with a minimum development effort.

3. FUELING SEQUENCE

3.1 DUAL-ENDED FUEL CHANGING

For a typical CANDU, on-power fuel changing equipment consists of two identical F/Ms (Figure 8-1). Each F/M is suspended in a carriage, from tracks on a bridge at each end of the reactor that extends the full width of the reactor face. The bridge traverses vertically and the carriage traverses horizontally to allow access to all the fuel channel end-fittings. On CANDU 6, powered shielding doors separate the reactor vault from the maintenance lock and, when closed, allow access to the F/M in the maintenance lock while the reactor is operating. While in the maintenance lock area, the F/Ms also have access to the new fuel port to receive new fuel, to the service ports for calibration or maintenance and to the rehearsal facility for testing and check-out operations.

On dual-ended systems, following positioning at the fuel channel end-fittings both F/Ms move forward to home and lock onto the fuel channel. Each F/M, which is filled with heavy water, is then pressurized to match the heat transport system conditions. The F/Ms remove the fuel channel closure plug, shield plugs, and store them in the F/M magazines. New fuel is then inserted at the inlet end while used fuel is discharged from the outlet end of the fuel channel.

Two fuel bundles are inserted from each magazine rotor station containing new fuel in the F/M head. Four to eight new fuel bundles are generally inserted on each visit, thus replacing four to eight of the twelve fuel bundles in the fuel channel. Either F/M acts to load or accept fuel depending on the direction of flow in the particular fuel channel being fueled since fueling is carried out in the same direction as the coolant flow on CANDU 6 and Pickering reactors.

When the required number of fuel bundles have been inserted, the shield plugs and channel closures are replaced and the closures are leak tested by the F/Ms. The two F/Ms then traverse to the used fuel ports where the level of the heavy water in the CANDU 6 F/M is lowered below the discharge snout, and the used fuel is discharged.

With four bundle shift fueling, the F/M can fuel one channel, and then fuel a second one, before returning to the used fuel ports. For a CANDU 6 reactor, fueling is carried out on fourteen fuel channels per week, with eight fuel bundles being discharged at each visit to the reactor. The fueling rate varies proportionately with the size of the reactor.

3.2 CANDU 3 SINGLE-ENDED FUEL CHANGING

The CANDU 3 reactor may be fueled on-power using a single F/M located at the outlet end of the reactor fuel channels. The coolant flow through the reactor is in the same direction in all fuel channels. Fuel pushers, resident in the inlet end fitting of each fuel channel, assist in pushing the fuel from the channel by means of the coolant hydraulic flow force.

The CANDU 3 F/M holds a minimum of eight pairs of fuel bundles. This capacity is suitable for a four-bundle shift operation with one visit to the fuel channel during fueling.

The fuel movement sequence for the CANDU 3 single-ended fueling is shown diagrammatically in Figure 8-2.

On-power fuel changing is performed under fully automatic and remote control. The F/M clamps onto the new fuel port and accepts new fuel. The shielding door is opened and the F/M is transported by the carriage along the tracks to the face of the reactor. The F/M is positioned so that it is located opposite the selected fuel channel.

The F/M moves forward and clamps onto the fuel channel end fitting to form a leaktight joint with the channel. The plug from the snout of the machine is removed and the machine is pressurized to the same pressure that exists in the channel end fitting after a leak test operation.

The F/M removes the channel closure plug and injection flow is established. A guide sleeve is installed and the latched spacer plug is then removed allowing the resident fuel pusher at the inlet end of the channel to move the fuel string and the outlet shield plug towards the F/M. The latched spacer plug is separated from the outlet shield plug and stored in the magazine. A ram adaptor is added to the F/M ram and the shield plug, and irradiated fuel bundles which are separated in pairs, are stored in the F/M magazine rotor. The entire fuel string is removed from the fuel channel during fueling to allow re-inserting of the fuel in the order required by the fuel management program.

The fuel management dictates the irradiated bundles being sent to the irradiated fuel storage bay, and the arrangement of the fuel string with the new and partially used fuel bundles to be returned to the channel. The fuel string together with outlet shield plug, the latched spacer plug and channel closure are returned to the channel. The F/M installs the snout plug in the snout, checks the cavity for leaks to confirm the channel closure plug seal, and unclamps from the end fitting. The F/M is then retracted from the end fitting and returned to the F/M maintenance lock where it unloads the irradiated fuel to the fuel bay through the irradiated fuel port.

Figure 8-3 shows the fuel handling system design layout of the CANDU 3 F/M vault, maintenance lock and fuel transfer system areas.

The fuel changing equipment located in the reactor building includes a partially shielded F/M magazine and is normally parked in the F/M maintenance lock and suspended in a transport carriage. The carriage is on tracks connecting the maintenance lock with the reactor outlet vault. A powered shielding door separates the maintenance lock from the reactor vault and, when closed, provides a fully biologically shielded access area for maintenance of the F/M while the reactor is operating at power.

While in the maintenance lock, the F/M can home and clamp onto the new fuel port to accept new fuel, to the service port for maintenance or service, or to the irradiated fuel port for unloading irradiated fuel.

4. FUEL CHANNEL

Fueling is carried out in the direction of channel coolant flow in CANDU 6 and Pickering reactors. In the central core high-flow channels, hydraulic drag is sufficient to move the fuel string towards the F/M located at the outlet end of the channel. In the outer low-flow channels, a Flow Assisted Ram Extension (FARE) tool is used to create the necessary impedance to move the fuel string. The FARE tool is introduced into the channel during fueling by the F/M located at the inlet end of the channel.

The conventional fuel channel has a latched shield plug assembly in each end of the fuel channel, located within the vertical planes of the end shield.

In the CANDU 3 design, the outlet end of the channel contains a flow-through shield plug with no latch mechanism which is axially supported by the latched spacer plug at the outlet end of the channel as depicted in Figure 8-4. The conventional channel closure is retained while the end-fitting liner tube becomes a short baffle sleeve at the feeder outlet to prevent cross-flow from damaging the fuel during fueling.

At the inlet end of the channel the conventional shield plug is replaced by a combination of a special shield plug and a fuel pusher component. A channel closure is no longer incorporated in the inlet end. The resident fuel pusher performs a similar function to the FARE tool, which was previously inserted by another F/M. The single-ended F/M must have the magazine capacity to carry the required new fuel for fueling the fuel channel and also to completely defuel the channel.

The fuel pusher, part of which fits over the inlet shield plug has a cylindrical shape. The channel coolant flow, through an integral orifice in the pusher, effects a continuous thrust against the fuel.

During single-ended fueling, the channel flow must be maintained at all times within the channel bore up to the feeder outlet tube, for adequate fuel cooling. The flow is used to thrust the fuel pusher, so that it can propel the entire fuel string down the channel until it rests on the fuel separators at the downstgream F/M. That is, the fuel pusher length must subtend the distance between the feeder outlet baffle holes and the F/M separator in order to push the last two fuel bundles into the F/M magazine station. Also, the fue[illegible]her length is compatible with the two-bundle length of the magazine so that the F/M will h[illegible]e capability of replacing any fuel pusher. The fuel pusher has the added capability to push the flow-through outlet shield plug with the fuel string.

5. FUELING MACHINE

The design of the CANDU 3 F/M is shown in Figure 8-5 and is adapted from the Pickering 'B'/CANDU 6 design which includes:

a. A standardized manual drive system is incorporated into the 'B' ram, latch ram and the magazine rotor. An improved manual override is fitted to an upgraded separator safety latch. Also incorporated are standardized 'B' and latch ram ballscrews with a modular gearbox for easy removal and maintenance of the ballscrew seal packages.

b. Fuel sensor and separator assemblies to detect when irradiated fuel bundles are being separated from the fuel string are incorporated. The F/M separator assemblies ensure fuel bundle detection is maintained throughout the fuel handling sequence and provides interlock permissives for reliable and safe handling of irradiated fuel, which prevents damage to fuel.

c. The Pickering 'B'/CANDU 6 type of fuel channel end-fitting is included for CANDU 3. The F/M inserts a guide-sleeve to create a single fuel-size bore for handling the complete fuel string.

d. The Pickering 'B'/CANDU 6 type F/M has two positioning rams. A mechanical 'B' ram for handling channel hardware and components and a hydraulic 'C' ram, for pushing fuel at the fuel transfer port. Having two types of rams (mechanical and hydraulic) is considered an advantage with the single-ended fueling operation. The normal method of positioning the fuel string will be by the more accurately controlled mechanical 'B' ram using its precision ballscrew drive system. If the mechanical ballscrews malfunction, the hydraulic 'C' ram is available as a "back-up" ram and provides an alternate means of pushing the fuel string back into the channel away from the unshielded F/M snout to channel end-fitting interface area. This can be important for F/M recovery operations as the magazine shielding then allows limited access for service work on the F/M and carriage.

   The CANDU 3 single-ended F/M is equipped with a valve to isolate the F/M ram from the magazine housing assembly if the channel closure cannot be installed. This feature allows ram exchange without draining the magazine and can be carried out in minimum time and increases the modularization of the ram assembly.

e. The Pickering 'B'/CANDU 6 type F/M uses fuel pushers (i.e., F.A.R.E. tools) in low flow channels. The single-end fueling concept for CANDU 3 uses fuel pushers residing in each fuel channel inlet end fitting. [illegible] pusher concept of operation is, therefore, similar to the proven equipment in the Pickering 'B'/CANDU 6 fueling handling systems.

   The single-ended fuel channel and hardware for CANDU 3 is designed with fuel pushers that push the full fuel string to the F/M separators allowing complete defueling of the fuel channel during reactor operation.

f. Extra magazine stations in the F/M magazine housing and rotor allows single-ended four-bundle programs with one visit of the F/M to the fuel channel. Equal spacing of the magazine rotor stations is maintained.

The CANDU 3 F/M is designed to operate with the following single-ended fuel channel hardware: fuel pusher, latched spacer plug, flow-through outlet shield plug and channel closure.

6. MAINTENANCE AND SERVICING

All fuel handling equipment, including the control equipment, is accessible for maintenance with the reactor at full power.

Maintenance of the F/Ms and ports is performed in the maintenance lock in the reactor building, with the outlet vault shielding door closed. Servicing may include replacing modular sub-assemblies on the F/M with spares. A crane in the maintenance lock facilitates servicing the heavy equipment.

An ancillary port inside containment permits replacement of channel closures, ram adapters and shield plugs in the F/M. Another port provides facilities for calibration of ram force loads. Calibration of the ram forces is facilitated by the use of a load cell and an adapter. The adapter enables the ram to exert both advance and retract forces on the load cell, thus measuring the actual forces exerted by the ram assembly; that is, measurement of the pre-set value of each force less any retarding forces related to the ram action.

A rehearsal port built into the containment wall allows simulated fuelling functions of the F/M to be done after servicing the equipment.

7. EQUIPMENT TESTING

The CANDU 3 F/M design is based on proven CANDU technology.

As in all previous CANDU stations, the F/M is assembled and operated in a test facility under simulated reactor conditions with respect to temperatures, pressures and flows before being accepted and delivered to site. The test facility at AECL CANDU Sheridan Park Engineering Laboratory includes hot water loops and a full size fuel channel assembly which is loaded with production fuel and all fuel channel internal hardware to represent the reactor conditions. The tests are conducted under fully automatic computer controlled fueling operations using operational fueling sequences.

8. BIBLIOGRAPHY

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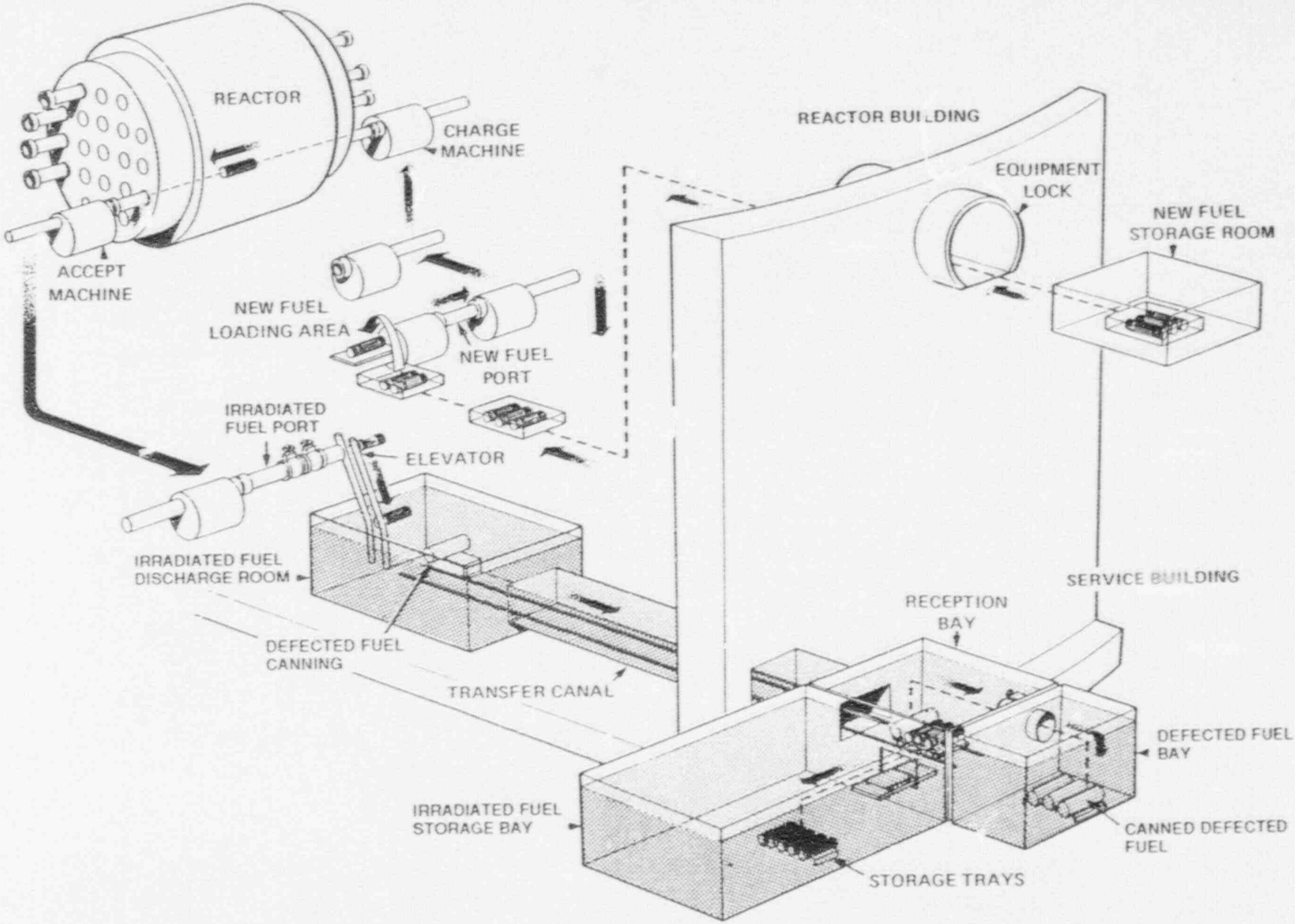

FIGURE 8-1 DUAL-ENDED FUEL HANDLING SEQUENCE

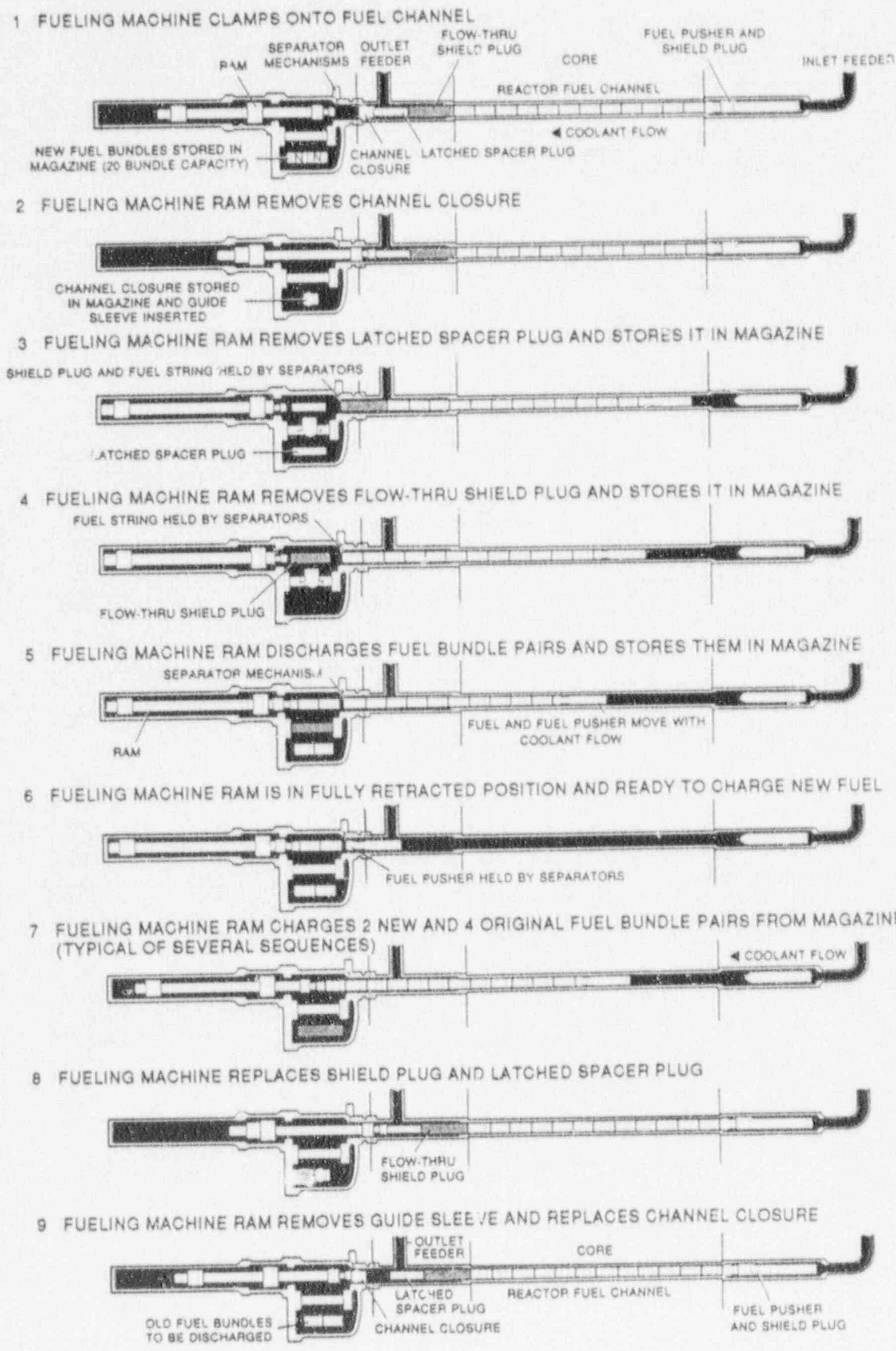

FIGURE 8-2 FUEL MOVEMENT SEQUENCE FOR SINGLE-ENDED REFUELING

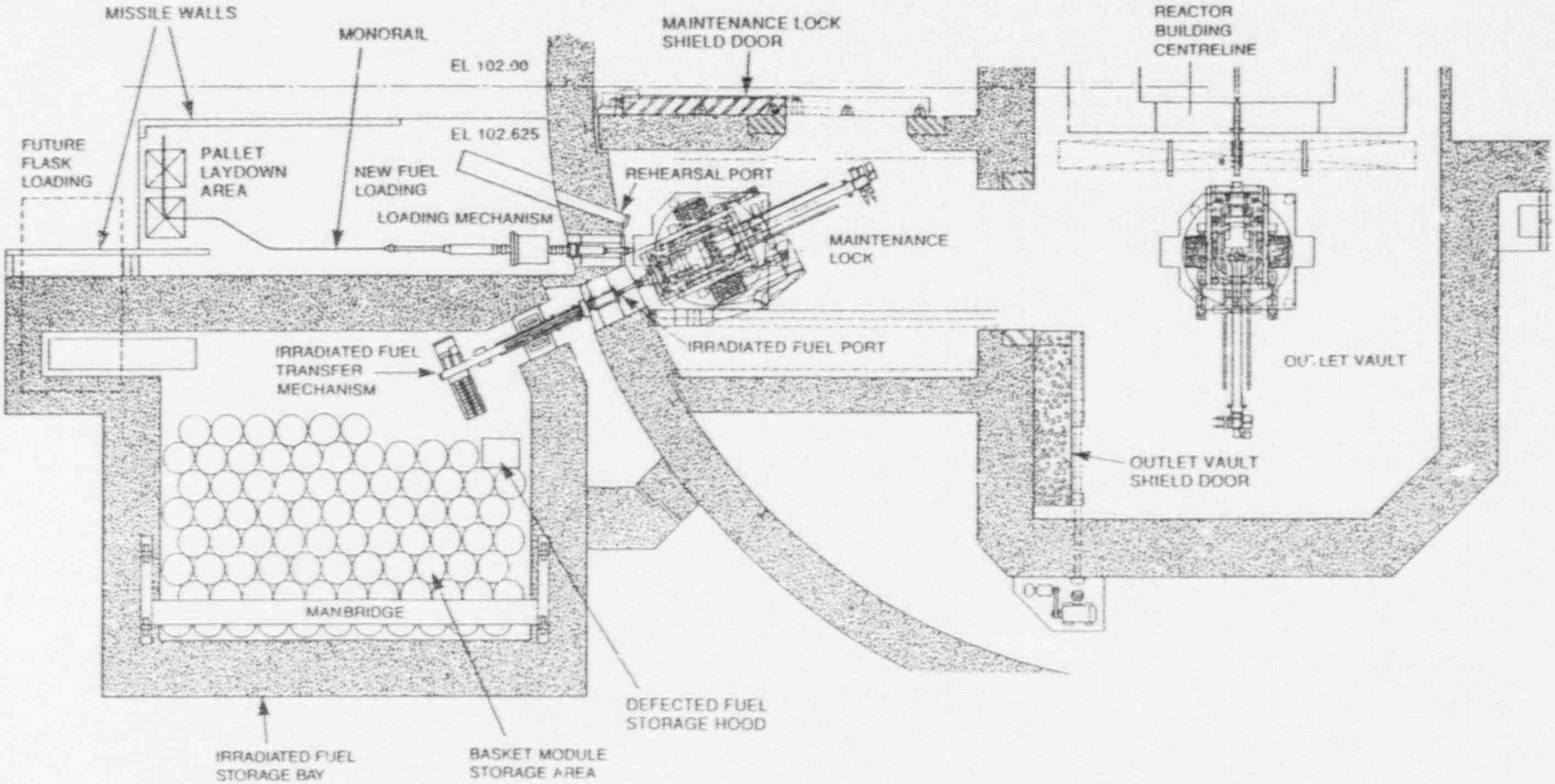

FIGURE 8-3 FUELING MACHINE VAULT, FUEL TRANSFER SYSTEM AND IRRADIATED FUEL STORAGE BAY - PLAN

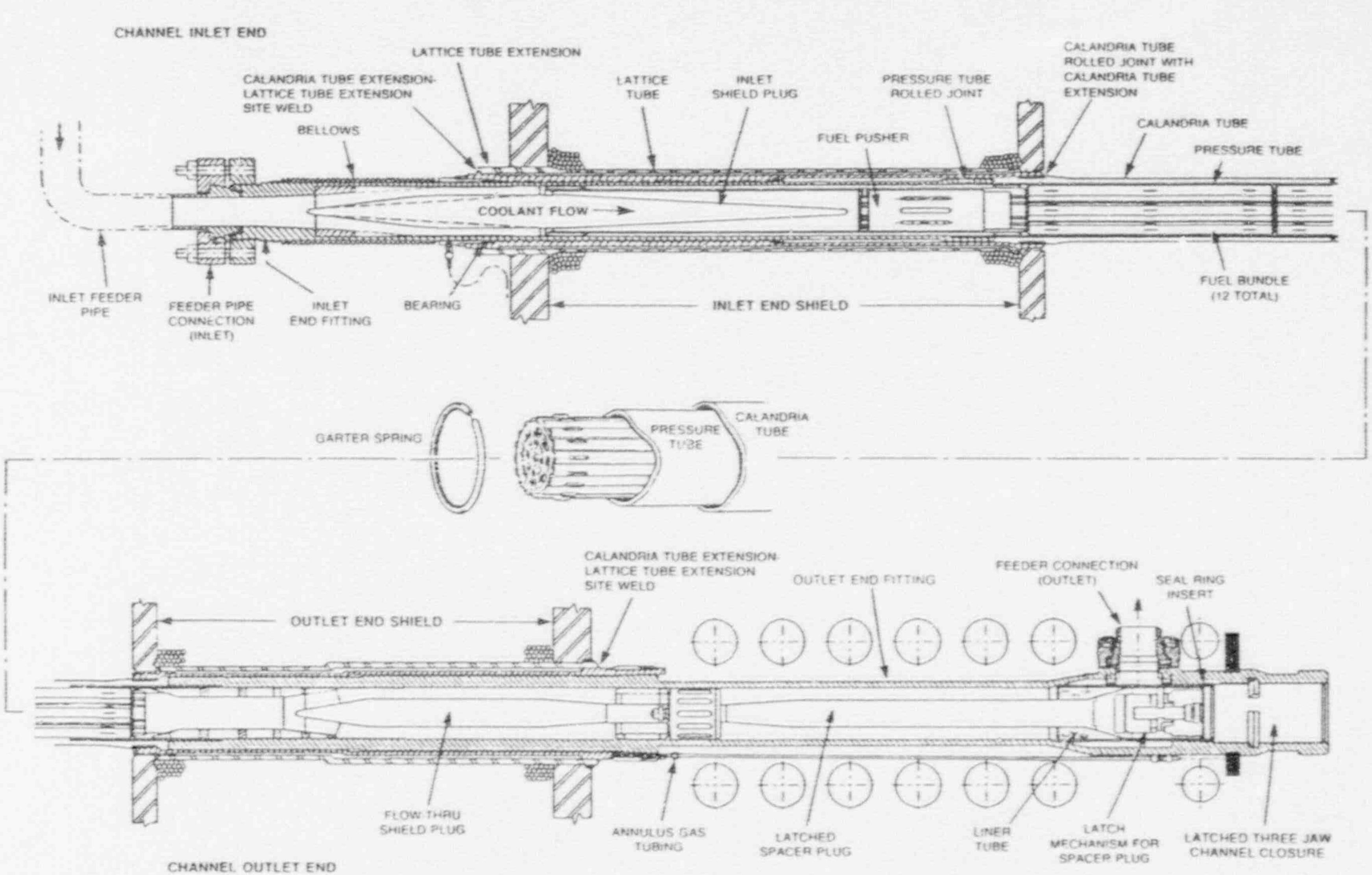

FIGURE 8-4 CANDU 3 FUEL CHANNEL HARDWARE

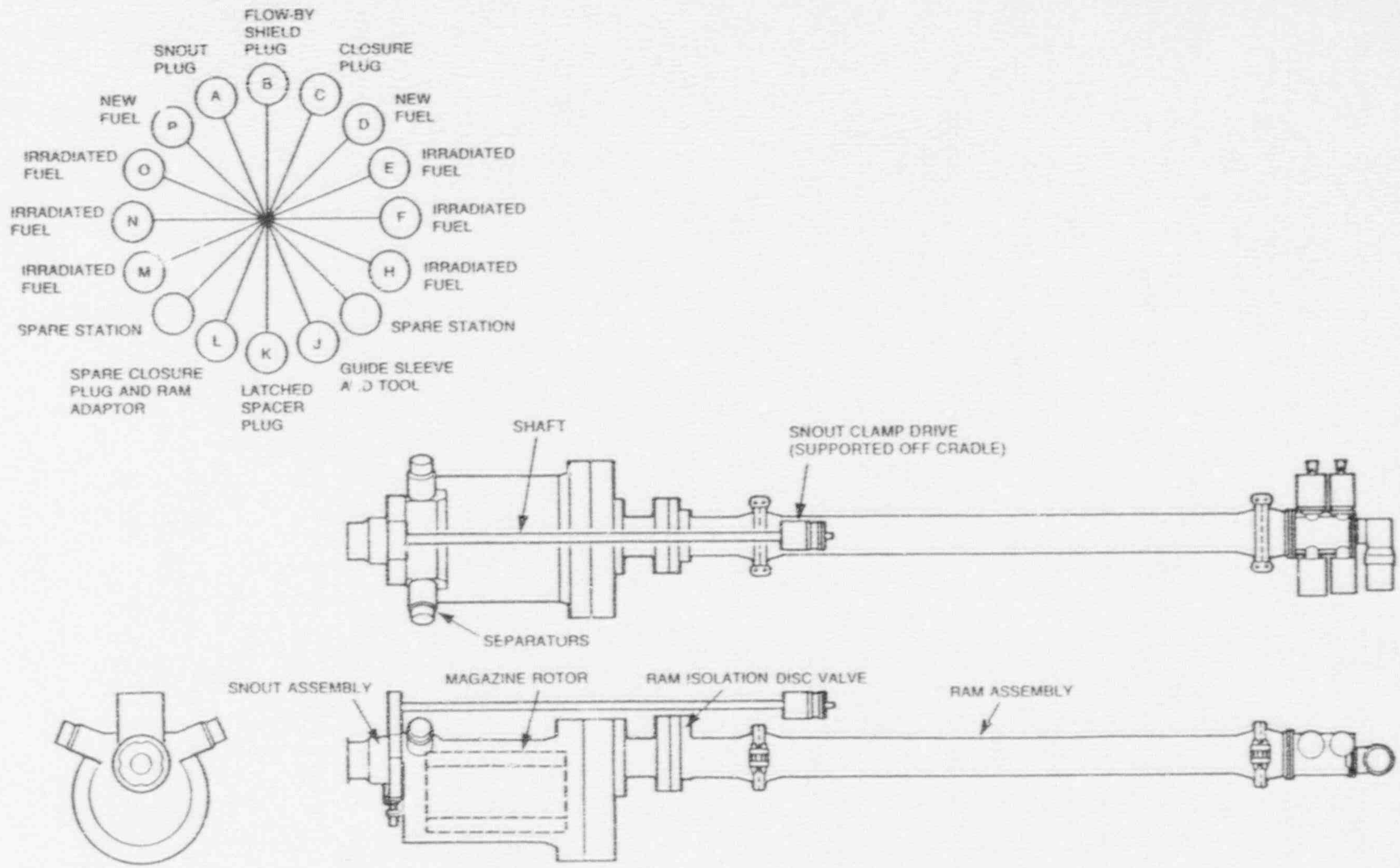

FIGURE 8-5 FUELING MACHINE HEAD - MAJOR GEOMETRY

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GLOSSARY

AECL: Atomic Energy of Canada Limited was incorporated as a Federal Crown Corporation in 1952 to assume responsibility for nuclear research and development, and has roots back to 1945 when Canada's first nuclear research reactor began operation. AECL has corporate offices in Ottawa, research facilities in Chalk River, Ontario and Pinawa, Manitoba, and AECL CANDU in Mississauga, Ontario.

AECL CANDU (formerly CANDU Operations): A Division of AECL that was formed in the early eighties to take responsibility for the development, design, marketing and project management of CANDU projects in Canada and internationally. The 1200 employee company operates out of the Sheridan Park Research Community in Mississauga, with offices in Montreal, Fredericton, and Saskatoon.

AECL Ltd.: The corporate entity of Atomic Energy of Canada Limited.

'B' Ram: A fueling machine component that withdraws and inserts the channel closure and shield plug, and positions the fuel column. The 'B' ram is driven by ballscrews.

Bruce Nuclear Power Development: The nuclear power development located on Lake Huron near Kincardine, Ontario. The development consists of Bruce 'A' and 'B', each having four, 750 MWe reactors. Bruce 'A' reactors have consistently placed in the top ten in lifetime operating performance since completion in the late seventies.

Boiling Water Reactor (BWR): A nuclear power reactor cooled and moderated by light water. The water is allowed to boil in the core to generate steam which passes directly to the turbine.

Calandria: A cylindrical reactor vessel which contains the heavy water moderator. It is penetrated from end to end by hundreds of calandria tubes which provide sites for the pressure tubes. The moderator is cool and at low pressure.

Canadian Standards Association (CSA): A non-profit, independent, private sector organization that serves the public, governments, and business as a forum for national consensus in the development of standards, and offers them certification, testing, and related services.

The standards are written, reviewed, and revised by committee members, who represent users, producers, regulatory authorities, representatives from industry, labour, governments, and the public.

The standards cover a number of program areas: environment, electrical/electronics, construction, energy, transportation, materials technology, and welding.

CANDU: An acronym derived from CANada Deuterium Uranium that identifies a series of nuclear reactors designed and built in Canada. They are fueled with natural uranium and moderated with heavy water (D_2O).

CANDU 3: A new design of CANDU reactors presently being developed by AECL CANDU that incorporates design improvements from CANDU experience to provide a more efficient, lower cost reactor.

CANDU 6: The CANDU 600 MWe series nuclear reactors that have been built at Pt. Lepreau, New Brunswick; Gentilly-2, Quebec; Embalse, Argentina; Wolsung, South Korea, and Cernavoda, Romania.

Capacity Factor: Ratio of the averaged operated load for a certain duration to the total rated capacity of the station (maximum load that the station can carry for a long term of steady conditions).

Carriage: A vehicle that supports the fueling machine head on the bridge. It controls the horizontal positioning and 'Z' motion of the fueling machine head at the face of the reactor.

Catenary: An assembly of flexible hoses and cables connecting the mobile fueling machine to the stationary auxiliary power systems. The hoses carry D_2O, air and oil. The cables carry power and control signals to the fueling machines.

Channel Closure (Closure Plug): A removable plug which prevents leakage of the heat transport system coolant from the end fitting. The plug is removed and replaced by the fueling machine during the fueling operation.

Darlington Nuclear Generating Station: The nuclear generating station located in Newcastle, Ontario, presently under construction. Darlington 'A' consists of four, 850 MWe CANDU reactors.

Decay: The decrease in activity of a radioactive material as it spontaneously transforms from one nuclide to another or into a different energy state of the same nuclide.

Decommissioning: The work required for the planned permanent retirement of a nuclear facility from active service. Different regulations will apply thereafter.

Decontamination Factor: The ratio of initial content of contaminating radioactive material to the final content as a consequence of a decontamination process. (The term may refer to a specified radionuclide or to gross radioactivity.)

Defected Fuel: Irradiated bundle that has developed a through-wall defect in its cladding and/or at the end cap weld. It can release fission products to the pool water, if not contained.

Deflectors: Ballscrew nut components that deflect the balls from the ballscrew thread to the return tubes.

Design Basis Earthquake (DBE): The maximum ground motion of the site that has sufficiently low probability of being exceeded during the operating life of the nuclear power plant, for which unacceptable radioactivity releases can be avoided.

D_2O: See Heavy Water

Deuterium: A stable naturally occurring hydrogen isotope (H_2) with a mass number of two. Its natural abundance is about one part in 7000 of hydrogen. Being chemically similar to ordinary hydrogen, it unites with oxygen to form heavy water (D_2O).

Dose: The amount of ionizing radiation energy absorbed per unit of mass.

Double-Ended Fuel Changing: Loading and unloading of fuel bundles where two fueling machines are connected to opposite ends of the fuel channel. One fueling machine accepts irradiated fuel and the other inserts new fuel. All fuel changing is done on-power in CANDU reactors.

Douglas Point: The 200 MWe reactor located on the Bruce NPD site which came into service in 1968 and was decommissioned in 1984. Douglas Point was the first large-scale CANDU reactor, and proved the economic feasibility of large CANDU reactors.

Dry Storage: Outdoor concrete canisters for interim storage of irradiated fuel. Fuel is placed in dry storage after five years in wet storage and after being placed in sealed containers.

Dual Failure: Simultaneous postulated failure of a process system and a safety system.

End Fitting: The end components of the fuel channels projecting out of the calandria face. The end fittings allow connection of heat transport water feeders and attachment of the fueling machine head during refueling.

End Fitting Liner Tube: A tube inside the fuel channel end fitting.

Excess Reactivity: The reactivity suppressed by soluble poison and other reactivity devices. Excess reactivity is expressed in the unit mk (milli–k).

Floor Response Spectrum (FRS): The response of equipment mounted on a particular floor (elevation) of a structure, when the structure is subjected to the design seismic motion.

Flow Assisted Ram Extension (FARE) Tool: A tool used during refueling to assist pushing the fuel bundles along the low flow channels. The tool is essentially a free piston that uses the coolant flow in the pressure tubes to provide a ram force.

Fuel: Natural uranium in the form of compacted and sintered cylindrical pellets of uranium dioxide (UO_2).

Fuel Bundle: An assembly of fuel elements (fuel sheaths containing nuclear fuel pellets) and end plates, ready for insertion into a reactor.

Fuel Channel Assembly: A pressure tube and its end fittings which house the fuel bundles and direct the flow of primary heat transport coolant over the fuel to carry the nuclear heat to the steam generator heat exchangers.

Fuel Element: A cylindrical, hermetically-sealed, zirconium-alloy sheath containing fuel pellets stacked end-to-end. Thirty-seven fuel elements constitute a fuel bundle for CANDU 6 reactors.

Fuel Transfer Port: The port that penetrates the containment boundary providing a site for the fueling machine to clamp onto, in order to transfer fuel between the fueling machine and the fuel transfer mechanism.

Fueling Against Flow: In the Bruce/Darlington reactors, new fuel bundles are inserted in the fuel channel in the direction opposite the coolant flow.

Fueling Machine (F/M): A mobile, remotely-controlled apparatus for extracting irradiated fuel and inserting fresh fuel. The fueling operation is carried out while the reactor is in full operation.

Bridge: A horizontal beam across the face of the reactor supported between two vertical guide columns by electrically-driven ballscrews. The ballscrews move the bridge vertically across the face of the reactor.

Fueling With Flow (Flow Assist Fueling): In the Pickering and CANDU 6 reactors, new fuel bundles are inserted in the fuel channels in the direction of coolant flow. In the high flow channels, coolant flow is sufficient to move the fuel string unaided.

Gentilly: The site of Gentilly nuclear reactors 1 and 2, in Quebec. Gentilly 1 is a 250 MW prototype reactor using light water that has been placed in a partially decommissioned state. Gentilly 2 is a 600 MWe CANDU 6 reactor.

Grapples: A fueling machine contingency tool that allows removal of fuel bundles by one fueling machine only.

Guide Sleeve: A fueling machine tool that provides a constant bore passage for fuel bundles between the end fitting liner and the fuel bundle magazine stations.

Heavy Water (Deuterium Oxide or D_2O): Water in which ordinary hydrogen atoms have been replaced by deuterium atoms. Natural water contains one heavy water molecule for approximately every 7000 ordinary water molecules. D_2O has a low neutron absorption cross section, hence its use as a moderator in the CANDU reactors. D_2O is about 10% heavier than natural water, but has the same appearance and chemical properties. It has a higher freezing point and boiling point than ordinary water.

Hydraulic 'C' Ram: A fueling machine component that pushes the fuel bundles from the fueling machine magazine into the fuel channel. The 'C' ram is driven hydraulically with D_2O.

Hydrodynamic Balanced Shaft Seal: Sealing in which the fluid film thickness is maintained by the fluid film pressure generated by relative motion of the sealing components. A seal is "balanced" when the ratio of the area subject to the working pressure to the seal face area is less than or equal to one.

Hydrostatic Seal: Sealing in which the sealing faces fluid film thickness is maintained by supplying high pressure fluid at the seal face.

Irradiated Fuel: Nuclear fuel which has been irradiated in a reactor to the extent that it is no longer economic as a power producer, that is, the fissionable isotopes have been consumed and fission product poisons have accumulated. It is also termed "spent fuel" or "used fuel".

Latch Ram: A fueling machine component that acts in conjunction with the 'B' ram to actuate the latches on the shield plug and channel closure. The latch ram is driven by ballscrews.

Latched Spacer Plug: A plug inserted in the fuel channel to provide positioning for the shield plug. The spacer plug is latched instead of the shield plug in the CANDU 3 concept.

LOCA: Loss of Coolant Accident.

Magazine: That part of the fueling machine head located behind the snout and separators. It comprises a rotor and drive shaft and is housed in a cylindrical pressure vessel. The rotor has chambers for new or irradiated fuel bundles, channel closures, shield plugs, snout plug, ram adapter and the guide sleeve and insertion tool. During fueling, the magazine can be rotated to align any chamber with the axis of the snout.

Mixed Oxide Fuels (MOX): Nuclear fuels containing oxides other than uranium oxide, for example, thorium. Thorium, when irradiated, will produce an additional fissile uranium, U-233.

Moderator: A material such as heavy water, graphite or light water used in a reactor to slow down or moderate the fast neutrons produced by fission, thus increasing the likelihood of further fission.

Natural Uranium (NU): Uranium whose isotopic composition as it occurs in nature has not been altered (0.7 percent by weight of U-235). The design of CANDU reactors keeps neutron wastage so low that natural uranium can be used as fuel.

New Fuel Transfer Mechanism: A mechanism comprising a magazine and indexing unit, a ram assembly, a loading trough and a new fuel loading ram. Its purpose is to transfer new fuel from the new fuel loading area to the fueling machine.

Nil Ductility Temperature (NDT): In reference to welds, NDT is the highest temperature at which a crack starting at a notched hard-surfacing weld propagates to one or both edges of the tensile surface of the specimen in an impact test.

Nuclear Power Demonstration (NPD): The prototype CANDU nuclear reactor built near Rolphton, Ontario, designed to prove the technical feasibility for future, large-scale reactors. The NPD began feeding electricity into Ontario Hydro transmission lines in 1962. Decommissioning began towards the end of 1988.

On-Power Fueling: In CANDU reactors, refueling is carried out while the reactor is on-power, so that no shutdowns for refueling are required.

Pickering: The site of Pickering Nuclear Generating Station in Pickering, Ontario. Pickering consists of Pickering 'A' and 'B' each having four, 580 MWe units. Pickering began producing electricity in 1971.

Plutonium (Pu): A heavy radioactive metallic element with an atomic number of 94 whose principal isotope Pu-239 is a major fissile material. It is produced artificially in reactors through neutron absorption by U-238.

Point Lepreau: The 600 MWe CANDU 6 nuclear reactor in Pt. Lepreau, New Brunswick, which began service in 1983.

Pressure Tubes: The high strength zircaloy tubes that penetrate the calandria and contain the fuel bundles and pressurized heavy water coolant.

Pressurized Water Reactor (PWR): A nuclear power reactor cooled and moderated by light water in a pressure vessel surrounding the core. The water is pressurized to prevent boiling and is circulated in a closed primary loop through a heat exchanger, which generates steam in a secondary loop connected to the turbine.

Primary Heat Transport System: The heavy water coolant system that removes heat from the fuel bundles and exchanges the heat to the light water which drives the turbines. The primary heat transport coolant flows through the pressure tubes and is separate from the moderator water.

Ram Adapter: A fueling machine head attachment that provides a profile corresponding to that of the fuel and forms an extension of the ram assembly during fueling operations. At other times the adapter is stored in the magazine.

Ram Assembly: The section of the fueling machine that includes the ram housing, drive assembly, 'B' ram, 'C' ram and latch ram. The rams position, insert and withdraw the fuel bundles and associated hardware required for refueling.

Reactor Face: The end planes of the calandria vessel, where the fuel channels can be accessed.

Recovered Enriched Uranium (REU): Enriched uranium obtained by recovering and processing irradiated fuel from a Light Water Reactor (LWR).

Resident Fuel Pusher: A free piston present in each inlet fitting, used to push the fuel column along the fuel channel during refueling for single-ended reactors such as the CANDU 3. The fuel pusher operates similarly to the FARE (Flow Assist Ram Extension) tool.

Return Tubes: Pathways in the ballscrew nut that allow the balls to recirculate around the ballscrew threads.

Safeguards: A system of technical measures within the framework of international non-proliferation policy entrusted to the IAEA in its Statute and by the Non-Proliferation Treaty (NPT).

Separators: Components of the fueling machine that sense the fuel column position, restrain the fuel column, separate the required fuel bundles from the column and move the required bundles into the magazine.

Shielding: A mass of material which reduces intensity to protect personnel and equipment from radiation injury and damage.

Shield Plug: Removable plug which provides shielding against axial streaming of neutron and gamma flux from the reactor end fittings. The upstream plug also redirects the coolant flow axially through the fuel channels, eliminating coolant swirling and uneven bundle cooling.

Sievert: The SI unit of absorbed dose equivalent of ionizing radiation in biological matter. It is the absorbed dose in grays multiplied by a modifying factor which takes into account the biological effectiveness of the radiation. Abbreviated Sv.

Single-Ended Fueling: On-power loading and unloading of fuel bundles where only one fueling machine is required because of a resident fuel pusher in the opposite end of the channel. The single fueling machine both accepts irradiated fuel and inserts new fuel.

Single Failure: Failure of a system of components assembled to perform a process or safety function.

SLAR (Spacer Location and Repositioning) Machine: This is a sophisticated remote machine that operates in the fueling machine position to access the fuel channels, locate the spacers (garter springs) that separate the pressure tubes and calandria tubes, measure the gaps between the tubes, and inspect the pressure tube.

Slightly Enriched Uranium (SEU): Uranium that has been enriched so that the fuel contains more than the natural fraction of U-235.

Snout: The front end of the fueling machine head. The main components of the snout are the antenna assembly, clamping mechanism, seal and outer and center supports. The snout homes onto a selected fuel channel assembly during refueling and clamps and pressure seals itself to the end fitting.

Snout Plug: A latching mechanism and seal assembly which seals the snout of the fueling machine head when it is off the reactor face. This permits the interior of the fueling machine head to be maintained full of water at the operating temperature and pressure.

SPEL: Sheridan Park Engineering Laboratory, located at AECL CANDU in Mississauga, Ontario. SPEL is the field service arm of AECL CANDU focussing on design, assembly and testing of specialized equipment for nuclear power plants.

Spent Fuel: See irradiated fuel.

Storage Bay: A large pool of demineralized water in which irradiated fuel is stored while fission products decay.

Gimbal Assembly: A suspension that secures the fueling machine head to the fueling machine carriage. It also facilitates the alignment and engagement of the head to the reactor or fuel transfer port. The gimbal assembly also accommodates thermal expansion, contraction and misalignment of the fuel channel assembles.

Thorium (Th): A heavy slightly radioactive metallic element with an atomic number of 90 whose naturally occurring isotope Th-232 is fertile and is the source of U-233 when irradiated in a reactor.

Uranium Oxide (UO_2): Ceramic grade uranium oxide from the refinery. When compacted and sintered during fuel manufacturing it becomes a ceramic, having characteristics of chemical and radiation stability, good gaseous fission product retention and a high melting point.

Used Fuel: See irradiated fuel.

'X' Motion: Horizontal motion of the fueling machine across the reactor face.

'Y' Motion: Vertical motion of the fueling machine across the reactor face.

'Z' Motion: Motion of the fueling machine parallel to the longitudinal axis of the fuel channels.

Zircaloy: An alloy containing zirconium. The material is used extensively in the construction of in-core reactor components because it has a very high corrosion resistance to high temperature water and low neutron absorption.

Zirconium: A naturally occurring metallic element with an atomic number of 40.

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ABBREVIATIONS

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ABBREVIATIONS

AECB	Atomic Energy Control Board
AECL	Atomic Energy of Canada Limited
AECL-CO	Atomic Energy of Canada - CANDU Operations (now AECL CANDU)
ALARA	As Low As Reasonably Achievable
AO	Assistant Operator
ASME	American Society of Mechanical Engineers
BNGSA	Bruce Nuclear Generation Station 'A'
BNGSB	Bruce Nuclear Generating Station 'B'
BWR	Boiling Water Reactor
COG	CANDU Owners Group
CNS	Central Nuclear Services (OH)
CSA	Canadian Standards Association
CPPF	Channel Power Peaking Factor
CRNL	Chalk River Nuclear Laboratory
CSA	Canadian Standards Association
CSA	Central Service Area
D & C	Design and Construction
DBE	Design Basis Earthquake
DCCY	Digital Control Computer Y
DEL	Derived Emission Limits

D_2O	Heavy Water
DN	Delayed Neutron
DNGSA	Darlington Nuclear Generating Station A
DPNGS	Douglas Point Nuclear Generating Station
ECY	Exposure Cumulative Year
ETM	East Transfer Mechanism
FAF	Flow Assist Fueling
FAF	Fueling Against Flow
FARE	Flow Assist Ram Extension
F/H	Fuel Handling
F/M	Fueling Machine
Gy	gray
I/F	Irradiated Fuel
IFB	Irradiated Fuel Bay
IFP	Irradiated Fuel Port
in	inch
KANUPP	Karachi Nuclear Power Project
kip	one thousand pounds
kN	kilonewton
LOCA	Loss of Coolant Accident
m	meter

MAPS	Maderas Atomic Power Station
MCCR	Ministry of Consumer and Corporate Relations (Government of Ontario)
mk	milli–k (unit of excess reactivity)
mm	millimeter
MOX	Mixed Oxide Fuel
MW	megawatt
MWe	megawatt electric
NFP	New Fuel Port
NGS	Nuclear Generating Station
NMMD	Nuclear Materials Management Department
NOG	Nuclear Operations Group
NPD	Nuclear Power Demonstration
NPDNGS	Nuclear Project Development Nuclear Generating Station
NSAC	Nuclear Safety Advisory Committee
NSD	Nuclear Safety Department (OH)
NU	Natural Uranium
OH	Ontario Hydro
PHT	Primary Heat Transport
PHWR	Pressurized Heavy Water Reactor
PNGSA	Pickering Nuclear Generating Station 'A'

PNGSB	Pickering Nuclear Generating Station 'B'
PWR	Pressurized Water Reactor
RAPS	Rajasthan Atomic Power Station
REU	Recovered Enriched Uranium
RFSP	Reactor Fueling and Simulation Program
ROL	Reactor Operating License
ROP	Regional Over Power
SCC	Stress Corrosion Cracking
SER	Significant Event Report
SOS	Shift Operating Supervisor
SEU	Slightly Enriched Uranium
Sv	seivert
TLD	Thermo Luminescent Dosimeter
T/M	Transfer Mechanism
WNRE	Whiteshell Nuclear Research Establishment