WAPD-TM--1609

DE88 002087

Distril

LIGHT WATER BREEDER REACTOR ROD REMOVAL SYSTEM

(LWBR Development Program)

G. Fodor
T. J. Kikta
R. L. Matchett
D. R. Roof
R. Wilczynski

R. L. Matchett, Editor

Contract Number DE-AC11-76PN00014

October 1987

Printed in the United States of America
Available from the National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

NOTE

This document is an interim memorandum prepared primarily for internal reference and does not represent a final expression of the opinion of Westinghouse. When this memorandum is distributed externally, it is with the express understanding that Westinghouse makes no representation as to completeness, accuracy, or usability of information contained therein.

Bettis Atomic Power Laboratory West Mifflin, Pennsylvania 15122-0079

Operated for the U.S. Department of Energy by
Westinghouse Electric Corporation

MASTER

NOTICE

FOREWORD

The Shippingport Atomic Power Station located in Shippingport, Pennsylvania was the first large-scale, central-station nuclear power plant in the United States and the first plant of such size in the world operated solely to produce electric power. This program was started in 1953 to confirm the practical application of nuclear power for large-scale electric power generation. It has provided much of the technology being used for design and operation of the commercial, central-station nuclear power plants now in use.

Subsequent to development and successful operation of the pressurized Water Reactor in the Atomic Energy Commission (now Department of Energy, DOE) owned reactor plant at the Shippingport Atomic Power Station, the Atomic Energy Commission in 1965 undertook a research and development program to design and build a Light Water Breeder core for operation in the Shippingport Station.

The objective of the Light Water Breeder Reactor (LWBR) program has been to develop a technology that would significantly improve the utilization of the nation's nuclear fuel resources employing the well-established water reactor technology. To achieve this objective, work has been directed toward analysis, design, component tests, and fabrication of the water-cooled, thorium oxide-uranium oxide fuel cycle breeder reactor for installation and operation at the Shippingport Station. The LWBR core started operation in the Shippingport Station in the Fall of 1977 and finished routine power operation on October 1, 1982. After an End-of-Life core testing, the core was removed and the spent fuel shipped to the Naval Reactors Expended Core Facility for detailed examination to verify core performance including an evaluation of breeding characteristics.

In 1976, with fabrication of the Shippingport LWBR core nearing completion, the Energy Research and Development Administration, now DOE, established the Advanced Water Breeder Applications (AWBA) program to develop and disseminate technical information which would assist U.S. industry in evaluating the LWBR concept for commercial-scale applications. The AWBA program, which was concluded in September 1982, explored some of the problems that would be faced by industry in adopting technology confirmed in the LWBR program. Information developed includes concepts for commercial-scale prebreeder cores which would produce uranium-233 for light water breeder cores while producing electric power, improvements for breeder cores based on the technology developed to fabricate and operate the Shippingport LWBR core, and other information and technology to aid in evaluating commercial-scale application of the LWBR concept.

All three development programs (Pressurized Water Reactor, Light Water Breeder Reactor, and Advanced Water Breeder Applications) have been conducted under the technical direction of the Office of the Deputy Assistant Secretary for Naval Reactors of DOE.

Technical information developed under the Shippingport, LWBR, and AWBA programs has been and will continue to be published in technical memoranda, one of which is this present report.

(Intentionally Blank)

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont)

TABLE OF CONTENTS (Cont)

LIST OF FIGURES

LIST OF FIGURES (Cont)

LIST OF ACRONYMS

CCTV - Closed Circuit Television
CRT - Cathode Ray Tube
ECF - Expended Core Facility
LVDT - Linear Variable Differential Transducer
LWBR - Light Water Breeder Reactor
MINC - Modular Instrument Computer
OSP - Operation Selection Panel
PLC - Programmable Logic Controller
RRS - Rod Removal System
TSD - Touch-Sensitive Display
VDS - Vertical Disassembly Stand

This report describes the design and operation of the robotic equipment for remote withdrawal of fuel rods from the Light Water Breeder Reactor (LWBR) fuel modules for proof-of-breeding assay and physical examinations. The Rod Removal System (RRS) was automated to minimize operator errors in removing specified rods while maintaining maximum control over forces applied during removal to preclude damage. The system determined the exact orientation of the fuel module and the positions of fuel rods within the module. The module being derodded was oriented vertically in a support stand in a 35-foot water pit at the Expended Core Facility at the Idaho National Engineering Laboratory. The tops of preselected rods were engaged by a programmed mechanical grapple, which was capable of collecting rod pull force data while 10-foot long rods were withdrawn vertically from modules. Pulled rods were transferred to preselected ports in a multiport storage container or inserted into shrouds prepositioned in a rod transfer container. The RRS removed approximately 1100 fuel rods from 12 of the 39 LWBR fuel modules without a major equipment or operational problem.

LIGHT WATER BREEDER REACTOR ROD REMOVAL SYSTEM

(LWBR Development Program)

SECTION 1 - INTRODUCTION

The Rod Removal System (RRS) incorporated into one robotic system the capability of removing fuel rods, one at a time, from the Light Water Breeder Reactor (LWBR) modules with literally a "touch of a key." The RRS automatically gathered and stored data as the operations proceeded, and the automated system was programmed to rely on minimal operator input. This report presents a brief description of the LWBR fuel modules and a more thorough description of the underwater equipment developed to remove the fuel rods for end-of-life examinations.

1.1 - THE LIGHT WATER BREEDER REACTOR

The design of a breeder reactor for a light water system imposed requirements on the fuel elements and support grids relative to the neutron spectrum and the need to minimize parasitic neutron capture. One of the requirements for breeding was that the core have a high ratio of fuel-to-water, which resulted in closer fuel rod spacing than in current pressurized water reactor (PWR) designs. The close spacing reduced the slowing down of neutrons by the water and maintained a higher-energy, hard-neutron spectrum favorable for breeding in light water. In the LWBR core, this close-spacing was achieved by placing the fuel, which was in the form of cylindrically-shaped ceramic fuel pellets, into Zircaloy-4 tubes whose ends were capped and sealed by welding. Zircaloy-4 has a low cross section for capturing neutrons. The low water content was obtained by placing the fuel rods in a close-packed, triangular pitch with rod-to-rod spacing of about 0.060 inch. This arrangement was significantly tighter than commercial light water reactors in which rods are generally located in a square-pitched lattice of about 0.120 inch rod-to-rod spacing.

Longitudinal and cross-sectional views of the LWBR core are shown in Figures 1 and 2, respectively. The LWBR core consisted of 12 hexagonal module assemblies arranged in an asymmetric array in the central region, surrounded by a reflector region containing 15 module assemblies. Each of the 12 central hexagonal module assemblies contained an axially-movable, central-hexagonal seed module surrounded by an annular, hexagonal stationary blanket module as shown in Figure 2. Each of the seed, blanket, and reflector modules contained a lattice of fuel rods, approximately 10 feet long. Figure 3, which shows a blanket module, is an example. The seed was made up of 0.306-inch diameter fuel rods. The blanket fuel rods were of two diameters: regular (or standard) blanket rods were 0.572 inch in diameter; power-flattening blanket rods (used for core power distribution reasons unique to this small core application) were 0.527 inch in diameter. The reflector regions contained 0.832-inch

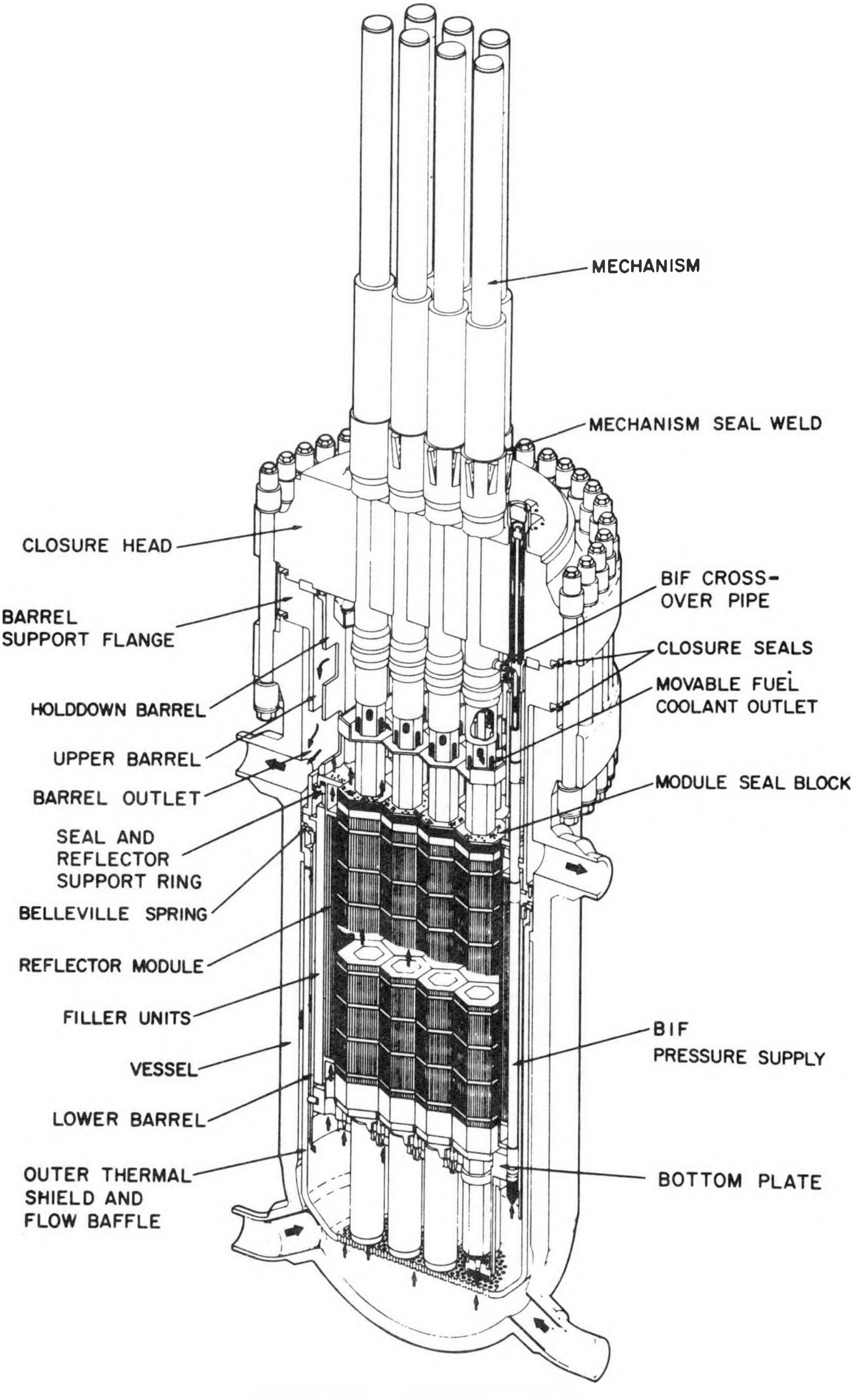


Figure 1. LWBR Reactor

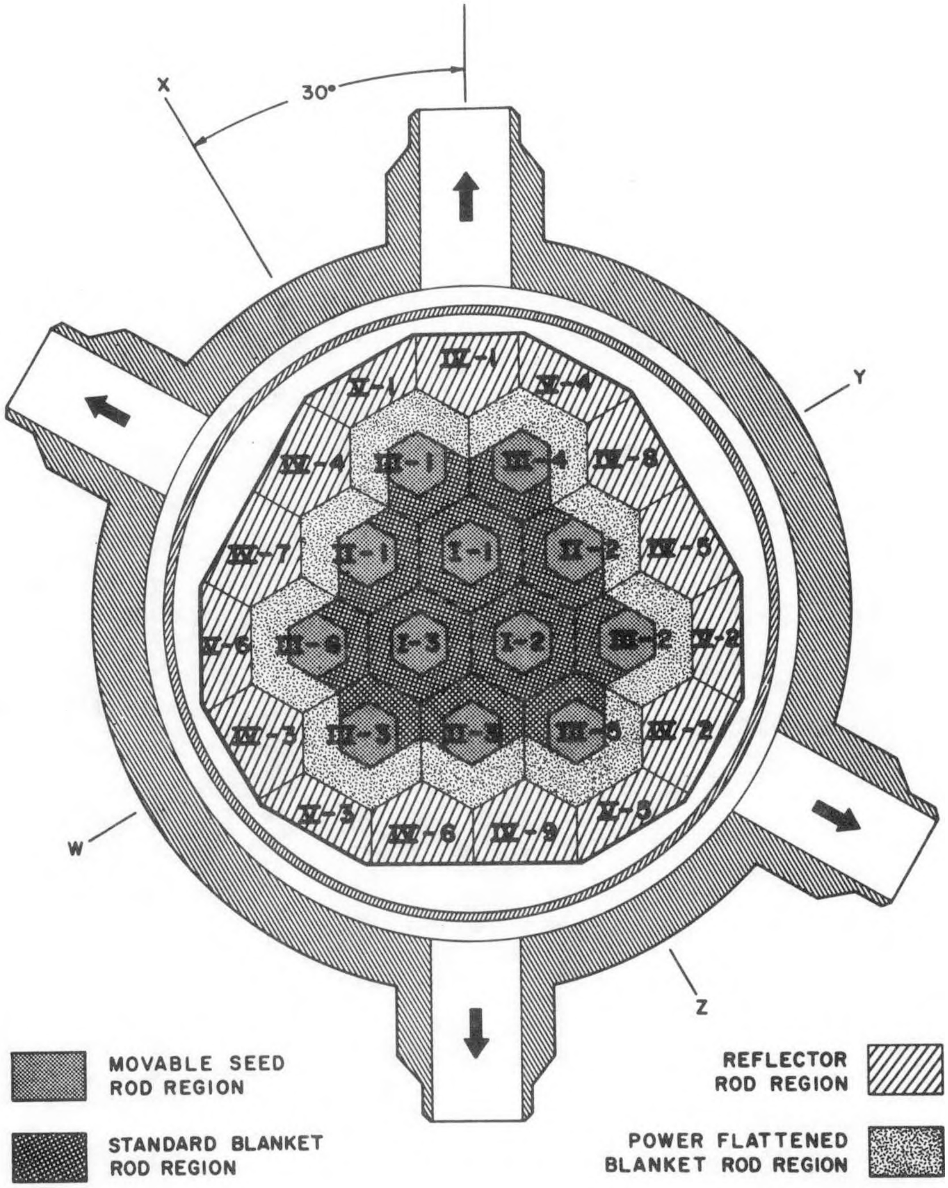


Figure 2. LWBR Core Cross Section

diameter rods. To ensure axial support, each fuel rod was attached at only one end to a support plate and passed through several grids at various elevations. About half of the rods were top-mounted, and half were bottom-mounted.

A lateral grid support structure was necessary to minimize fuel rod bow and vibration while accommodating the effects of dimensional changes (elongation and diametral changes). More specifically, the fuel rod support structure maintained the position of each fuel rod in a manner which satisfied the nuclear and heat transfer requirements of the core (i.e., it maintained the fuel rods in a tight, yet coolable, lattice spacing while minimizing the hydraulic pressure drop across the support structure).

The mechanical design and operating environment of this core are described in greater detail in Reference 1.

1.2 - OBJECTIVES AND OPERATIONAL DESCRIPTION OF THE ROD REMOVAL SYSTEM (RRS)

1.2.1 - Objectives

The RRS was part of the LWBR expended core examination equipment that was installed in the water pits at the Expended Core Facility (ECF). The ECF is part of the Naval Reactors Facility located at the Idaho National Engineering Laboratory. The RRS was designed as an underwater robotic system capable of extracting fuel rods, one at a time, from LWBR fuel modules and depositing them in transfer or storage containers. Instrumentation was needed to locate individual, preselected fuel rods in a module and extract them in a highly-controlled manner. Without acceptable precision in the locating functions, fuel rod damage could occur with potential loss of selected test rods or even release of fission products if cladding failure occurred. A digital computer precisely controlled the electro-mechanical system to align a grappling device over the exposed end of a fuel rod, grip the rod end, withdraw the rod from the module, and place it in a container.

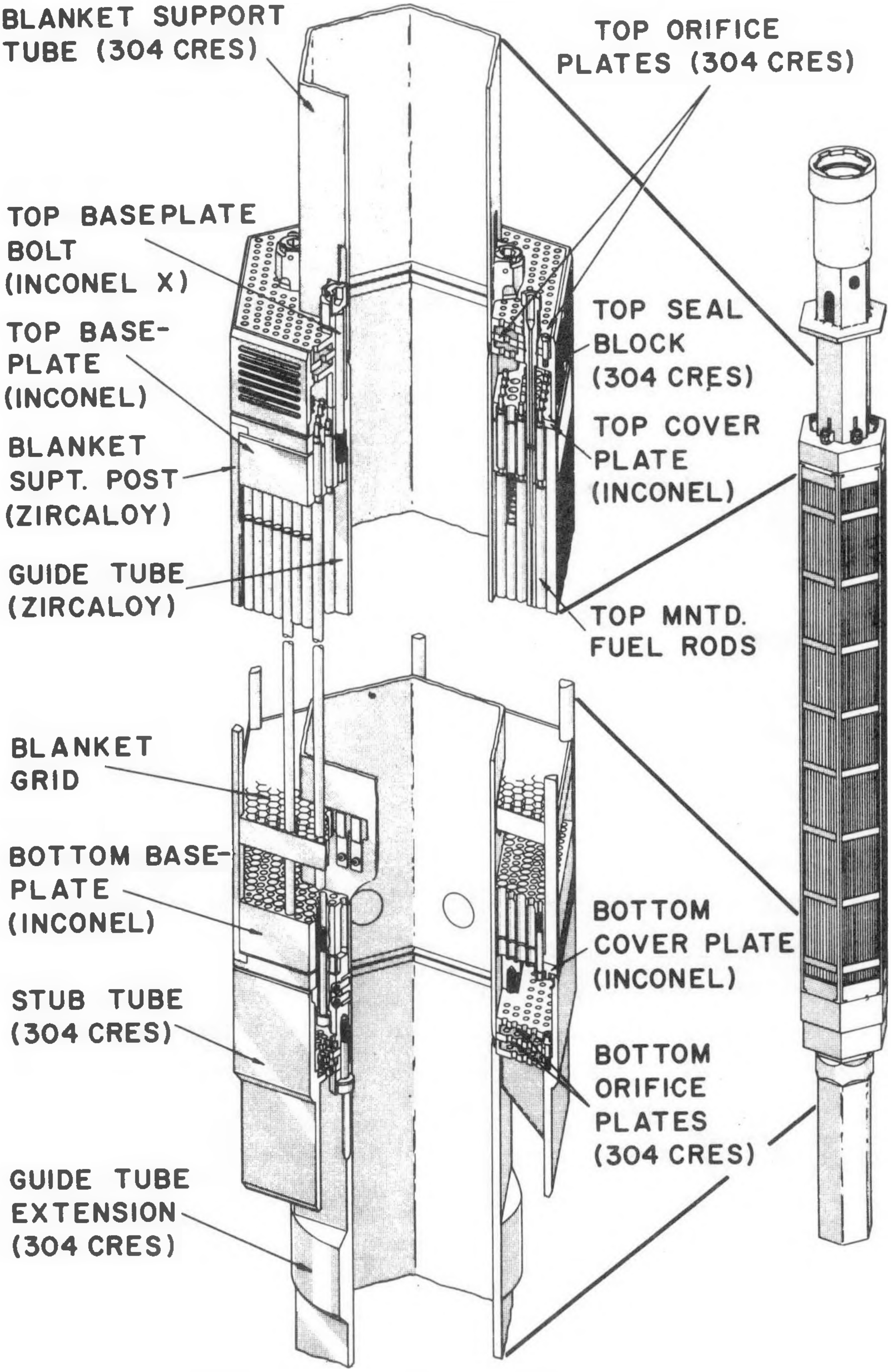


Figure 3. LWBR Type I Blanket Module

Descriptions of the equipment and procedures required to prepare the fuel modules for rod removal and their transfer into a work station under the RRS are found in Reference 2.

Computer instrumentation was required to monitor the progress of RRS operations, to ensure precise control of all rod handling operations, and to ensure adherence to technical requirements for rod removal. Figure 4 is a block diagram of the relationship and interconnection of the various components of the RRS control system. The communication paths radiated from the programmable logic controller (PLC) which served as the central control unit. Included in the system was an on-line microcomputer for positioning RRS components, calculating fuel rod location coordinates, and maintaining rod movement and storage location records. Individual rod handling histories were recorded by the computer for fuel inventory records. The RRS control system is described in detail in Section 4.

1.2.2 - Rod Removal System Description

The RRS support structure, shown in Figure 5, functioned as a double arm jib crane. The support structure provided support, plus radial and angular translation for a grapple mechanism that engaged and removed fuel rods from a fuel module. The upper and lower radial arms had an Acme screw-driven carriage. The upper carriage supported a winch, while the lower carriage supported a rod guide and closed circuit television (CCTV) camera. The vertical support column, from which the arms were cantilevered, was suspended from a rotating platform (the theta drive unit). The theta drive supported the entire weight of the system and was attached to the wall of the water pit. A spherical bearing at the lower end of the vertical support column prevented lateral motion of the RRS. The vertical column was also confined (not supported) at a midpoint by a wall-mounted center restraint.

As shown in Figure 5, the RRS structure was installed above a structure to support fuel modules vertically in the vertical disassembly stand (VDS).

Modules were lowered into the VDS by an overhead bridge crane and landed on the floater (a buoyant stainless steel cylinder), which guided the base of

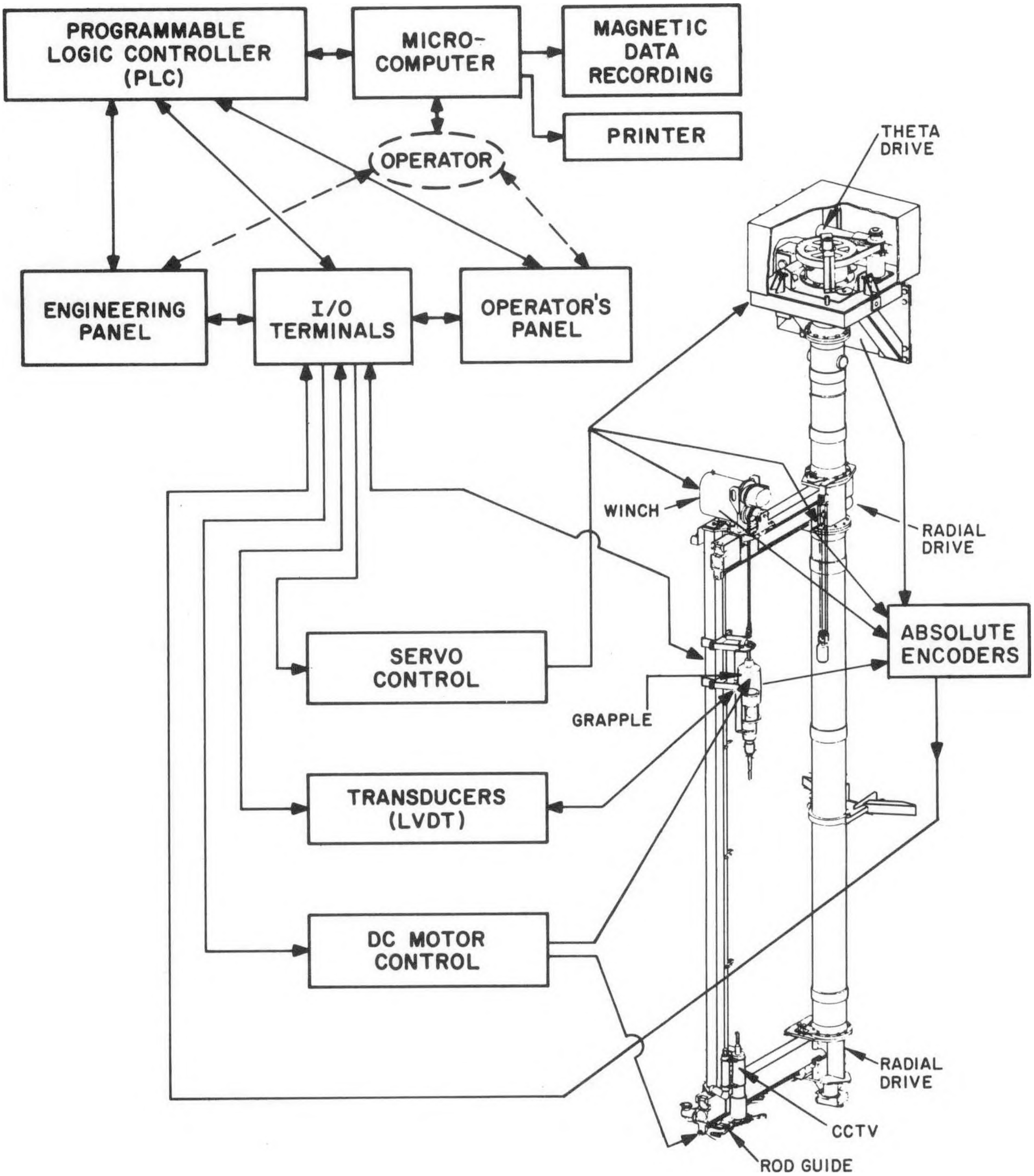


Figure 4. RRS Control Block Diagram

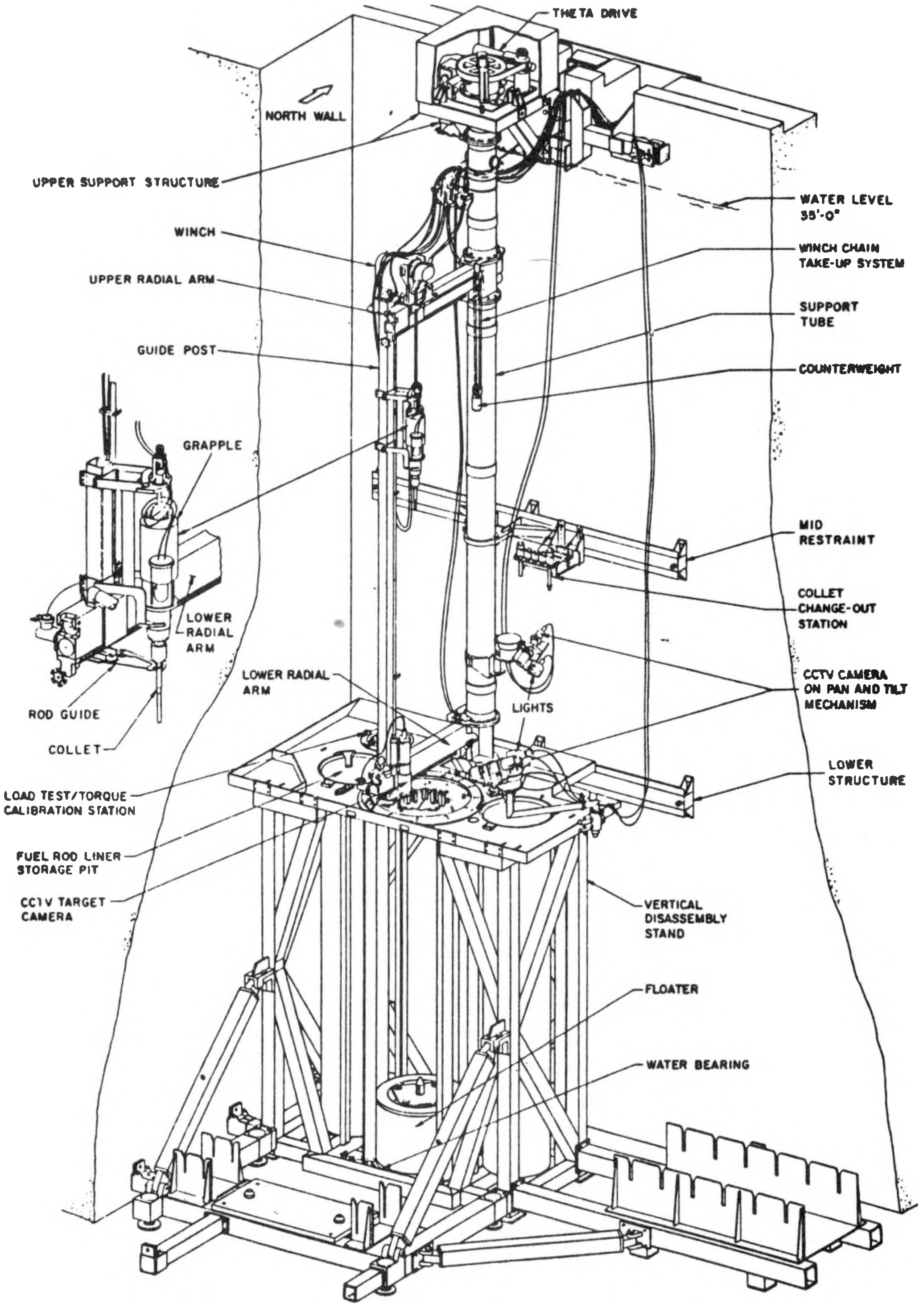


Figure 5. Trimetric of RRS and Vertical Disassembly Stand

the module to the bottom of the water pit. Not only did the floater simplify module installation by bringing the landing base to the top of the stand, it also provided module protection in the event of a drop accident. The floater's buoyancy, hydraulic drag due to its barrel shape, and the crushblock with which the floater was equipped combined to prevent criticality in the event of a drop accident in the module port by absorbing the impact energy, thus preventing the breakup of a module and the scattering of fuel rods. The VDS top cover plate was designed to withstand a module drop accident without collapse. The possible module drop distance was limited by crane elevational limits. The VDS employed a top clamp ring, which featured a unique method of module clamping. The clamps were spring-loaded and bore against the top module grid with only a nominal force; these clamps were then manually locked in position and prevented lateral module motion. A module was rotated using a bottom water bearing. This thrust bearing operated on a thin film (3 mils) of water which allowed virtually frictionless rotation. Reference 3 contains a description of the VDS water bearing.

1.2.3 - Operational Description

The RRS pulled and stored rods through a multiphase automated process which was initiated by providing the identification of the rod to be removed and the sequence of operations to be performed on the rod. This information was entered in the memory of the RRS computer and was accessed from memory, depending on the type of module and the type of rod (top or bottom mounted) being worked.

The three main phases of operation included mapping of module coordinates, removing the rod, and transferring or storing the rod.

1.2.3.1 - Mapping of Module Coordinates

The initial phase for removing rods from a module was to determine the coordinates for positioning the grapple mechanism. Using the CCTV system, the operator logged three easily identifiable location coordinates on the module into the SETUP computer program. The SETUP program calculated the coordinates for all the rods in that module as it was oriented in the support stand. Once this had been established, the RRS determined its own destinations when the sequence of rods to be removed was entered using the scheduling computer program called SCHED. Appendix A2 is a description of the OVERCR computer system used with the RRS. The brief descriptions of the programs and subprograms, including SETUP and SCHED, outline how OVERCR was used.

1.2.3.2 - Removal of the Rod

Prior to the start of an operation for rod removal, the operator determined if the proper rod attachment collets were in the changeout station (see Figure 5). Collets actually gripped the rods, and a different collet was required for each different rod end. If necessary, the operator would install the required collets in the collet changeout station, which was the only exclusively manual operation necessary on the RRS.

A vertical TV camera (target camera), capable of viewing the top end of the fuel rods in the module, was affixed to the lower radial arm carriage. The operator used the camera to check the computer alignment of the rod grapple assembly over a fuel rod, as well as to check rod storage positions selected by the computer. The operator, interacting with the RRS through a touch-sensitive display (TSD) screen on the operation selection panel (OSP) in the system control cabinet, could jog the target camera manually to center the camera cross hairs on the rod to be pulled after the computer positioned the camera to the rod address (see Figure 6). A video pointer was provided to aid target alignment. Upon alignment, the PLC automatically shifted the grapple over the rod centered under the target camera, then lowered the grapple down over the rod. If the collet did not slip over the rod but, instead, bumped the top of the rod or was lowered too far without engaging the rod, the PLC automatically reversed the winch to raise the grapple and the target camera was shifted back over the rod for realignment. As the grapple collet slipped over the rod, the amount of rod engagement was monitored. The grapple then tightened the collet on the rod, and the winch was activated to pull the rod from the module.

Figure 6. Television Image from RRS Target CCTV - Camera Positioned Over Fuel Module Mockup

During rod pulling the PLC performed the following functions:

1. It constantly monitored rod pull forces. The winch would automatically shut down if allowable pulling forces were exceeded. In addition, the operator was given an error message stating the reason for the shutdown.
2. It constantly monitored rod engagement. If collet slippage occurred, the winch was shut down, and the operator was given an error message stating the reason for shutdown.
3. It automatically shut down the winch after 0.75 inch of rod pull. The grapple rotator was activated and the rod was rotated 60 degrees to preserve cladding wear grooves, at the grid contact locations, from being obliterated during subsequent rod removal. The PLC monitored the torque applied to the rods as well as the angle of rod rotation. The grapple rotator was shut down automatically if torque limits were exceeded, and the operator was given an error message stating the reason for the shutdown. After the rods were successfully rotated, rod pulling was resumed.
4. It automatically closed the rod guide to confine the free end of the rod. The operator received a message from the on-line microcomputer on the CCTV monitor to read the rod serial number and enter it on the OSP. The operator at the OSP was able to rotate the grapple to bring the top rod serial number into view of a RRS auxiliary TV camera mounted on the support column or on the side of the VDS.

1.2.3.3 - Rod Transfer or Storage

Following the removal of the rod from the module, the rod was transferred to a storage location in the VDS. "Bump detection" circuits prevented application of excessive compressive (buckling) loads to the rod as it was lowered into its selected port. The rod guide was disengaged automatically from the rod after partial insertion of the rod into the port. "Bump detection" circuits confirmed complete insertion of the rod into its storage port. The grapple then released the rod, and the winch withdrew the grapple. An engagement detector monitored rod withdrawal from the grapple collet to ensure proper release. If a rod remained stuck in the collet, the PLC automatically terminated winch withdrawal of the grapple. A stuck rod could be pushed out of the collet with hand tools from overhead.

Rod identity and storage location were recorded automatically. If a rod was placed in a storage port, coordinates of that port were recorded automatically as an exclusion zone where no other rod could be stored. If a rod was placed in a transfer cassette, its coordinates were recorded as an exclusion zone until the cassette was emptied and a recheck of cassette serial number validity was made. Microcomputer software provided continuously updated records of all rod locations.

SECTION 2 - MECHANICAL EQUIPMENT DESIGN

A description of the functions and key features of system components is provided in this section.

2.1 - SUPPORT STRUCTURE

The support structure of the Rod Removal System (RRS) consisted of the top, middle, and lower brackets and the support tube. The three brackets were fastened to the water pit wall, and the support tube was bolted to the theta drive. See Figure 5 for the locations of structure components.

The upper support and the middle and lower restraints of the support structure were attached to the wall of the water pit. The upper support, a cantilevered table bolted and clamped to the top of the water pit wall, was fabricated from stainless steel box beams and plate. The upper support structure was the only structure that did not contact the pit water. It provided all of the support for the RRS during its operation and was the mounting location for the theta drive.

The middle and lower restraints were also fabricated from stainless steel box beams and were bolted to the water pit wall by means of structural concrete inserts. The middle restraint did not bear any load of the RRS. Its function was to restrict the support tube in the event of an earthquake. Another function of the middle restraint was to provide an accessible location for the collet changeout station. A unique feature of the middle restraint was that, during an earthquake, it would function as a leaf spring allowing deflection at its midpoint. In this way, it would absorb some of the seismic energy before it contacted a hard stop at the limit of its acceptable travel. The leaf spring feature was included in the design to reduce loads on the structural concrete inserts in the water pit wall during a seismic event.

In addition to acting as a restraint during an earthquake, the lower restraint provided the bottom end pivot point and bearing through which the entire RRS rotated. It also provided lateral support to the system to prevent it from being out of plumb when the RRS was rotated about its axis.

The support tube provided the rigid backbone of the system to which the radial arms were mounted and aligned. The support tube was fabricated from stainless steel pipe with two rectangular sockets of stainless tube and plate to support the connection of the radial arms. The pipe was filled with radiologically clean water to prevent the streaming of radiation to the water surface when a fuel module was installed in the vertical disassembly stand (VDS).

2.2 - THETA DRIVE

The primary function of the theta drive mechanism was to rotate the entire RRS about its axis to position the rod grappling mechanism accurately over the desired rod to be pulled. The theta drive was the only RRS mechanism not submerged in the water pit. Its secondary function was to provide the rotating link between the upper support structure and the operating mechanism. This function required that the theta drive not only be an integral piece of the support structure but also a precision positioning mechanism.

Figure 7 is a schematic of the theta drive system. The theta drive consisted of an inner and outer housing. The outer housing provided the primary support to the theta drive by being directly mounted to the upper support structure; the inner housing rotated while resting on two large-diameter radial thrust bearings. The inner housing, linked to a large, 114-tooth silent drive chain sprocket by a shear pin, provided the only connecting link between the remainder of the rod removal system and the rotational drive system. The inner housing was bolted to the support tube. The support tube (described above in Section 2.1) provided the mounting locations for the cantilevered radial arms (see Figure 5) as well as the axis of rotation for the entire system.

The theta drive was rotated by a d-c servomotor geared down by a reduction of 1800:1, thus providing the increased sensitivity to accurately position the rod pulling mechanisms over the proper rod location. The gearing included a standard worm gear reducer and a silent drive chain reduction as the final drive.

Rotational positioning of the rod removal system was monitored by an independent encoding device which was coupled directly to the inner housing of

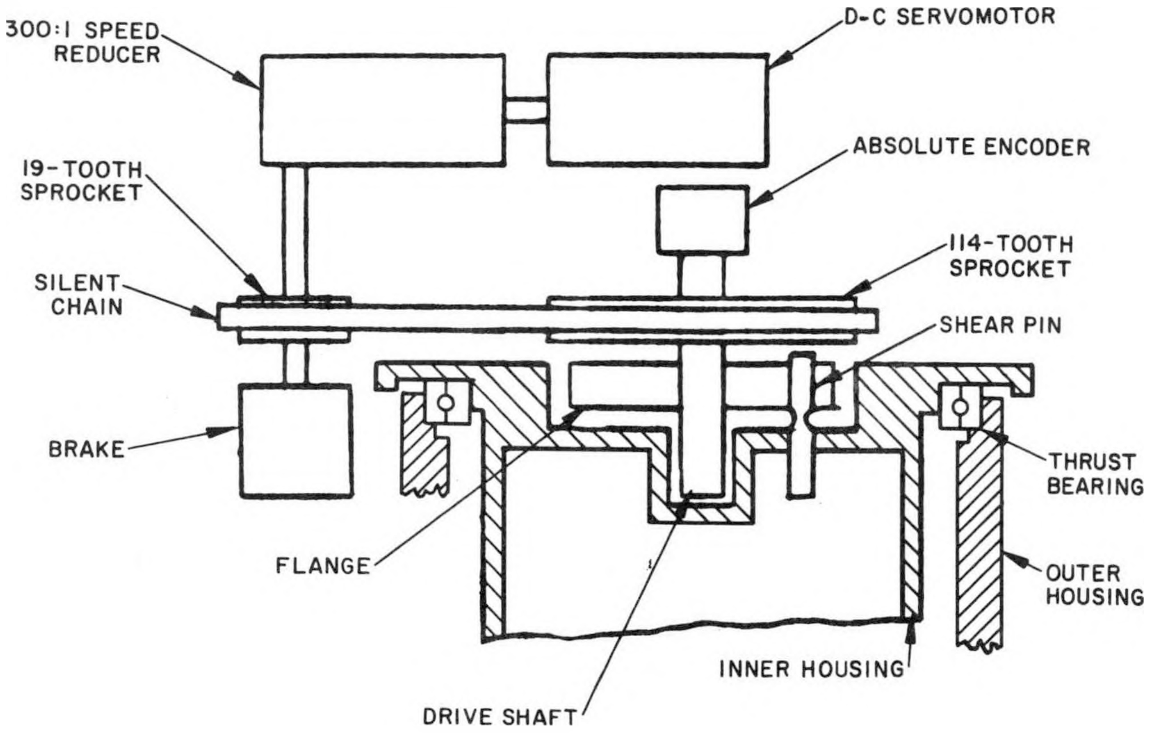


Figure 7. Schematic of RRS Theta Drive

the theta drive. With an encoder linked directly to the housing, rather than relying on counting motor pulses, a positioning system with near-zero backlash was obtained. In this manner, encoding served as a feedback circuit to control the drive motor until properly positioned. The encoded position was displayed to inform the operator of the progress of the events, and the encoder position was recorded by the microcomputer when required. The encoder was an absolute positioning type which provided immediate position location. The actual position was displayed, even if the theta drive was moved manually when power was unavailable to the encoder. The data furnished by the absolute encoder provided the means of positioning the theta drive accurately at a particular address and computing motion travel limits on the theta drive to prevent damage from overtravel.

By monitoring the absolute encoder and providing feedback information to the d-c servomotor, the theta drive was capable of positioning the rod pulling mechanism to within 0.003 degree. This enabled the rod pulling mechanism to be within 0.010 inch of the ideal location of the rod to be pulled when it was at the extreme radial position. The design maximum allowable limit was 0.03 inch which was one-half of the nominal rod-to-rod spacing in a module. This limit was set to prevent the collet bottom lip from catching the edge of a neighboring fuel rod when the fitting was lowered over the end of the rod.

2.3 - RADIAL ARMS

The 17-4 PH stainless steel radial arms provided the radial component of position to perform rod pulling operations on the cut off modules. Two 76-inch long rectangular cross section arms were fabricated from hollowed-out forgings to reduce weight while maintaining structural integrity (see Figure 8). The upper arm was cantilevered on the support column 30 inches below the water surface, while the lower arm was mounted 190 inches below the upper arm. A bronze water bearing carriage was positioned along each arm by an Acme lead screw driven by a d-c servomotor (see Figure 9). An absolute encoder, connected to each lead screw, encoded the position of the water bearing along each arm.

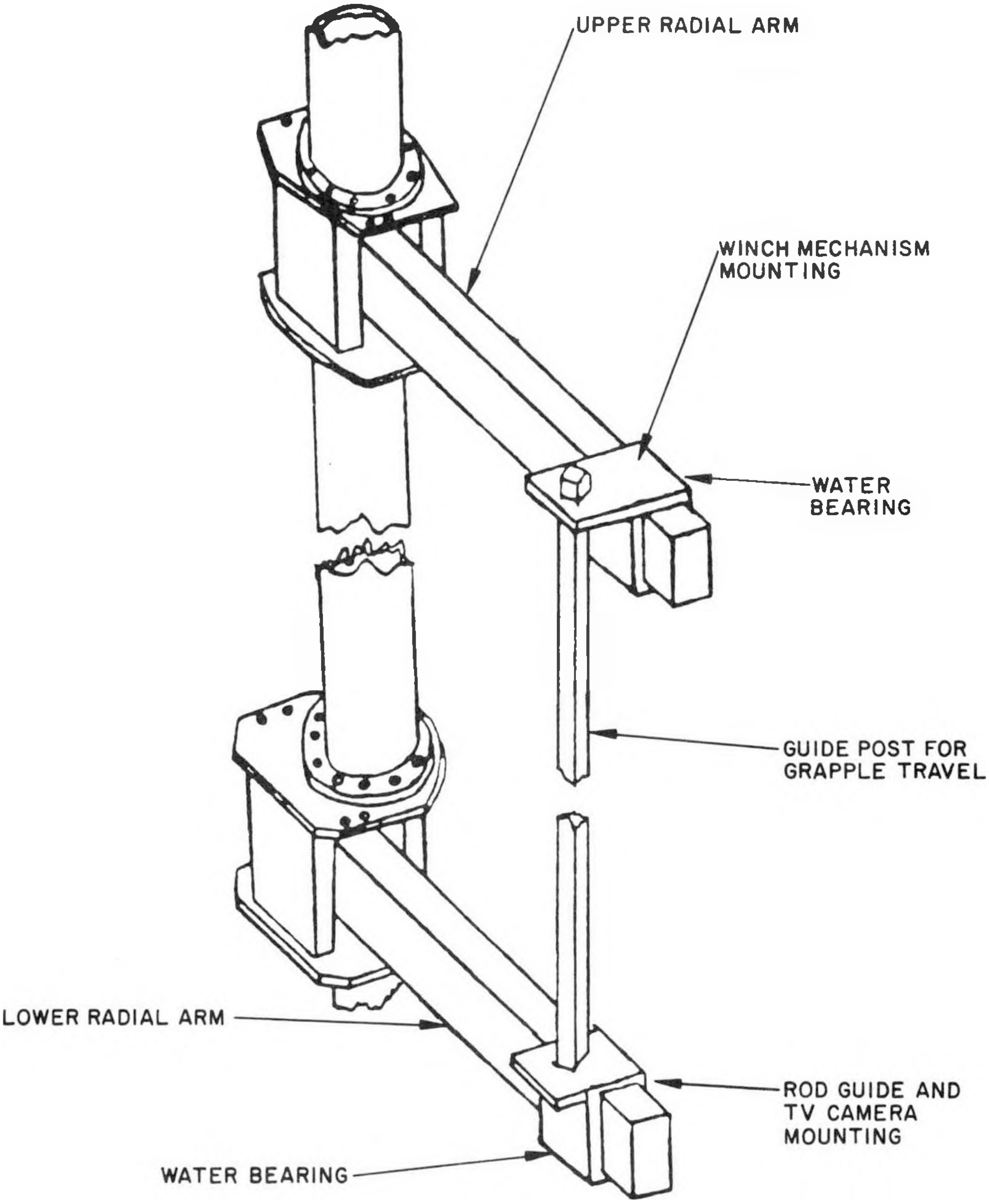


Figure 8. Trimetric of RRS Radial Arms Assembly

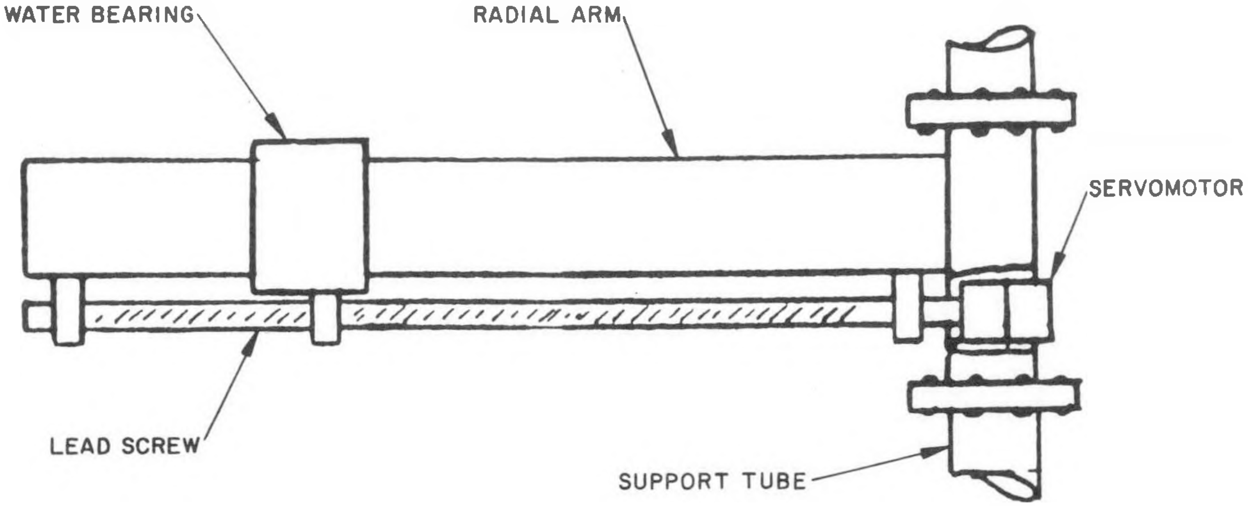


Figure 9. Schematic of RRS Radial Arm Bearing Assembly

Each arm had a particular assignment. The upper arm carriage transported the winch mechanism, while the lower arm carriage transported the rod-locating closed circuit television (CCTV) target camera, the lower rod guide mechanism, and the grapple guide bracket. A square guide post, that provided constraint for vertical motion of the grapple, was attached between the carriages on each arm. The horizontal travel of the two transport carriages was synchronized by the control motor electronics to maintain the guide post in a vertical position. Synchronization of the carriage motors was necessary to ensure that (1) a rod was not pulled at an angle and (2) after a rod had been removed from a module and suspended between the upper and lower arms, it would remain vertical during a radial move to a new location.

The water bearing was employed as the mechanism carrier due to its low coefficient of friction while pressurized with water. The reduced friction greatly reduced the force required by the 1 1/2-inch diameter Acme screw to position the bearing and enhanced its accuracy as well as its design life. Another benefit of the water bearing was that, after it had been positioned and the pressurized water had been shut off, it maintained its position as if a brake had been applied.

Watertight carriage motor housings were pressurized with air to prevent water leaks around the seals on the rotating Acme screws.

2.4 - WINCH

The vertical force necessary to extract a fuel rod from a module was supplied by the winch which was mounted on the upper radial arm water bearing carriage (see Figure 5). The winch supported the fuel rod grapple by means of two roller chains. When the grapple established a grip on the fuel rod, the winch lifted both the grapple and the fuel rod. The winch had the capacity to exert a pull force of approximately 3500 pounds which greatly exceeded any of the pull forces required during rod pulling operations.

The winch was powered by a d-c servomotor and was linked to an absolute encoder. While extreme accuracy in the winch's vertical travel was not necessary, the absolute encoder provided vertical position to within ±0.06 inch. Through a 460:3 gear reduction, the d-c motor drove a pair of roller chain sprockets which raised or lowered the grapple mechanism at a variable speed ranging from 0 to 6 ft/min. This maximum speed was specified for lowering rods based on the response time of the equipment to detect weight offloading (i.e., the time needed to stop the winch before rod bending stress limits were exceeded after a rod had been landed on a solid surface). The maximum lifting speed was limited to the response time for recording rod pull forces every 1/4 inch of travel. Both maximum speeds were 6 ft/min.

To prevent the free-hanging winch roller chains from becoming twisted or snagged during winch operation or during a radial move, a chain take-up system was installed on the upper radial arm. This system can be seen as a weight hanging from the chains near the support tube shown in Figure 5.

The watertight motor housing was pressurized with air to prevent water leaks around the rotating seals.

2.5 - COLLET/GRAPPLE ASSEMBLY

The collet/grapple assembly was the primary component in the process of pulling rods from the Light Water Breeder Reactor (LWBR) fuel modules. The collet/grapple assembly performed four specific functions during operation: (1) it provided the capability to grip and pull rods from LWBR modules (this also included the requirement of handling rod shrouds which were Zircaloy tubes used as individual rod transfer containers); (2) it provided a motor drive to actuate the rod gripping collets; (3) it rotated a rod to preserve grid wear marks during rod pulling; and (4) it monitored the torque, angular position, pull forces, rod engagement, and the degree of tightening required to grip a rod sufficiently to prevent rod slippage. Figure 10 shows a typical collet, and Figure 11 depicts a grapple motor assembly.

2.5.1 - Collet

The element of the collet/grapple assembly that directly contacted the rod was the collet (Figure 12 shows a schematic drawing of a collet). It consisted of an inner and an outer sleeve. As the outer sleeve was raised relative to the inner sleeve (which contains gripping fingers), the outer sleeve diameter decreased at the collet tip causing the inner sleeve fingers to

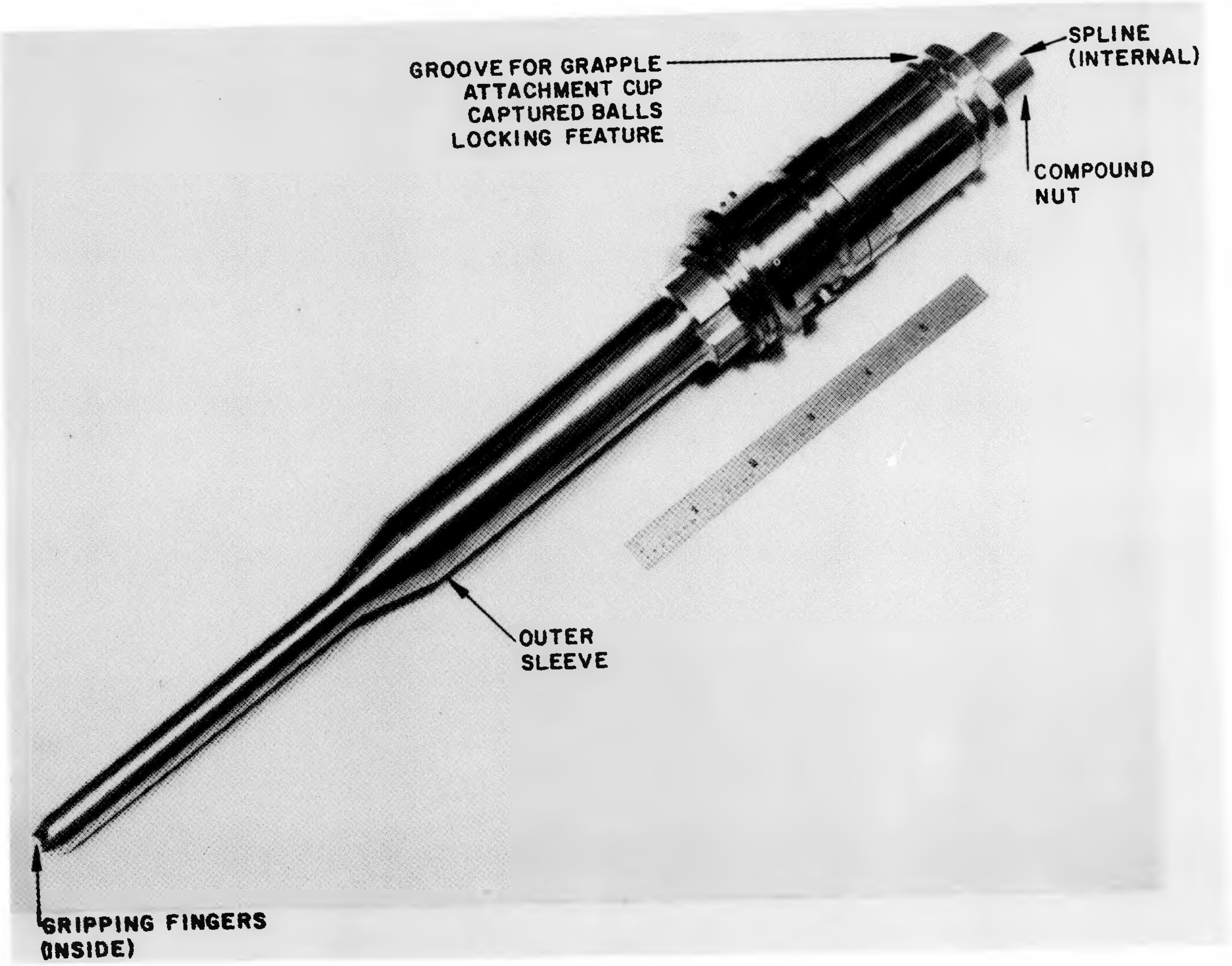


Figure 10. Typical RRS Collet

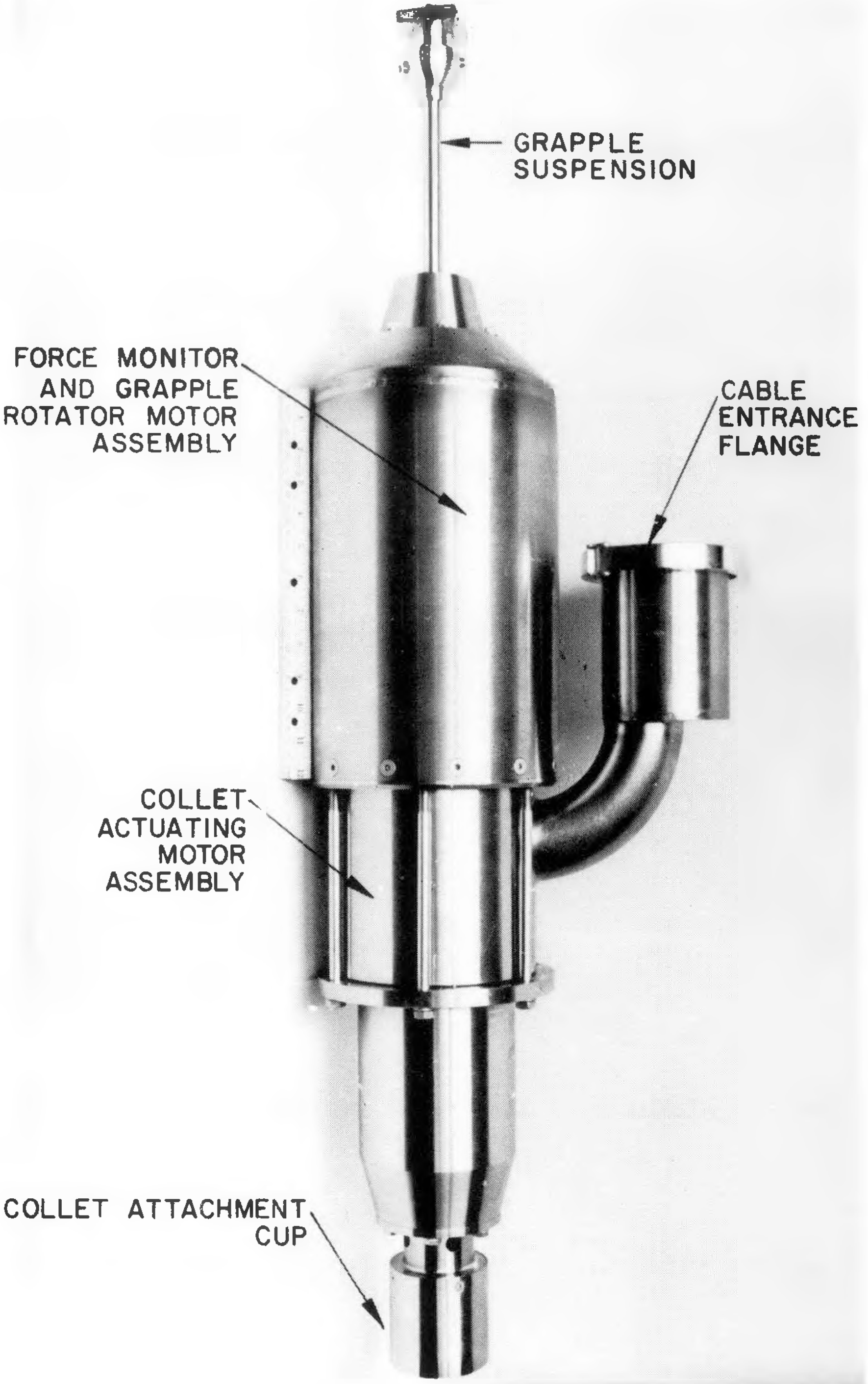


Figure 11. RRS Grapple Motor Assembly (Collet Not Shown)

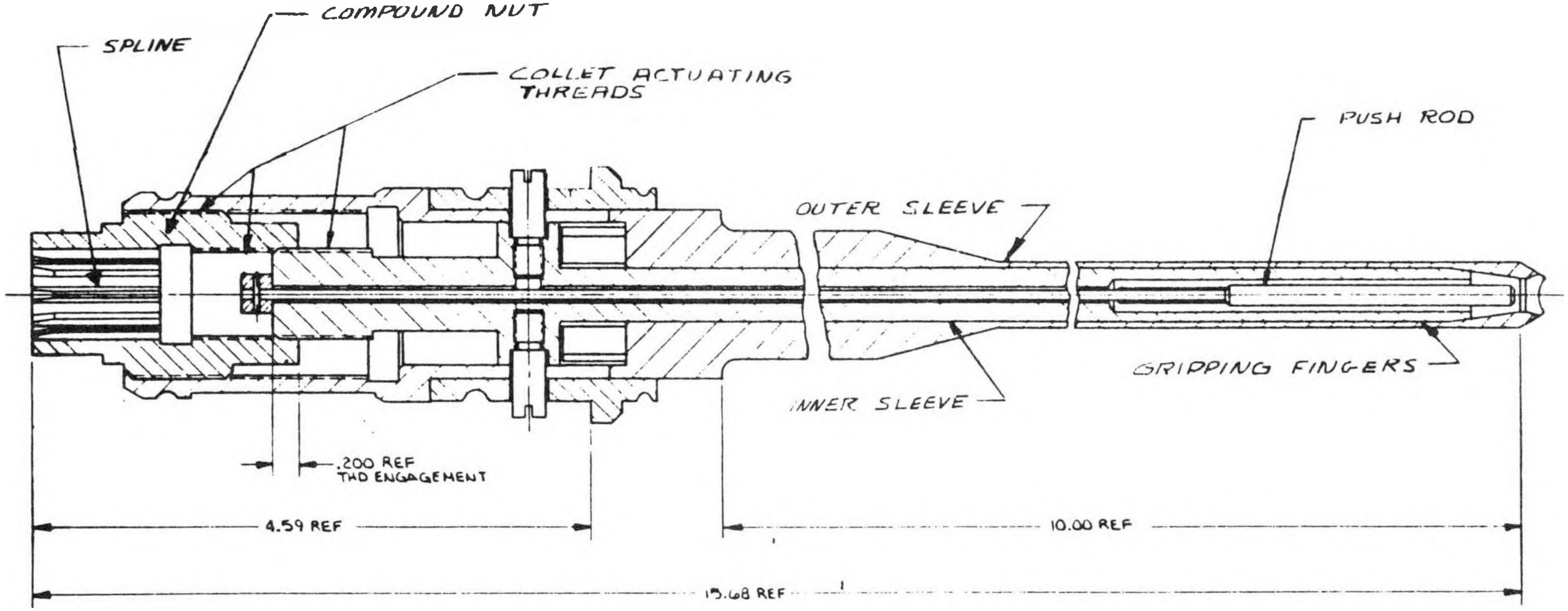


Figure 12. Schematic of RRS Collet Assembly

contract and grip the rod. Because of the type of gripping action, no axial or rotational loads were imposed on the rods. Due to the various rod diameters and the geometry difference for removing top and bottom mounted rods (e.g., top mounted rods were gripped by their end stems), several collet sizes were required. Collets for handling rod shrouds were unlike rod-gripping collets. Shroud collets gripped the shrouds internally at the top open end by axially compressing a rubber sleeve, causing it to expand against the internal surface of the shroud tube. Thus, gripping was effected by rubber-to-metal friction versus metal-to-metal friction as was the case for the rod collets.

The relative motions of the inner and outer collet sleeves were achieved by converting rotary motion from the grapple (described in Section 2.5.2) to axial motion by rotating a compound nut which was fabricated as part of each collet (see Figure 12). This compound nut engaged two different thread pitches in the collet at the same time. One, on the outside diameter, had six threads per inch and was permitted to translate along its axis. The other, on the inside diameter of the nut, had a thread pitch of 10 threads per inch and was fixed in position. As the compound nut was rotated clockwise, it would translate along the fixed thread at a rate of 0.100 inch per revolution while the movable thread translated in the opposing direction at a rate of 0.167 inch per revolution. The movable thread was an integral feature of the outer sleeve, causing relative motion between the inner and outer sleeves at a rate of 0.067 inch per revolution of the grapple's spline drive.

Interchangeability of the collets was necessary to ensure that they all performed when installed. Consequently, the upper drive section was identical for all collet types.

Control of the torque used to tighten the collets was accomplished by limiting the current to the grapple drive motor. This method of tightening was used in lieu of specifying discrete numbers of spline revolution because of the uncertainty for ensuring that a rod was sufficiently gripped to preclude slippage.

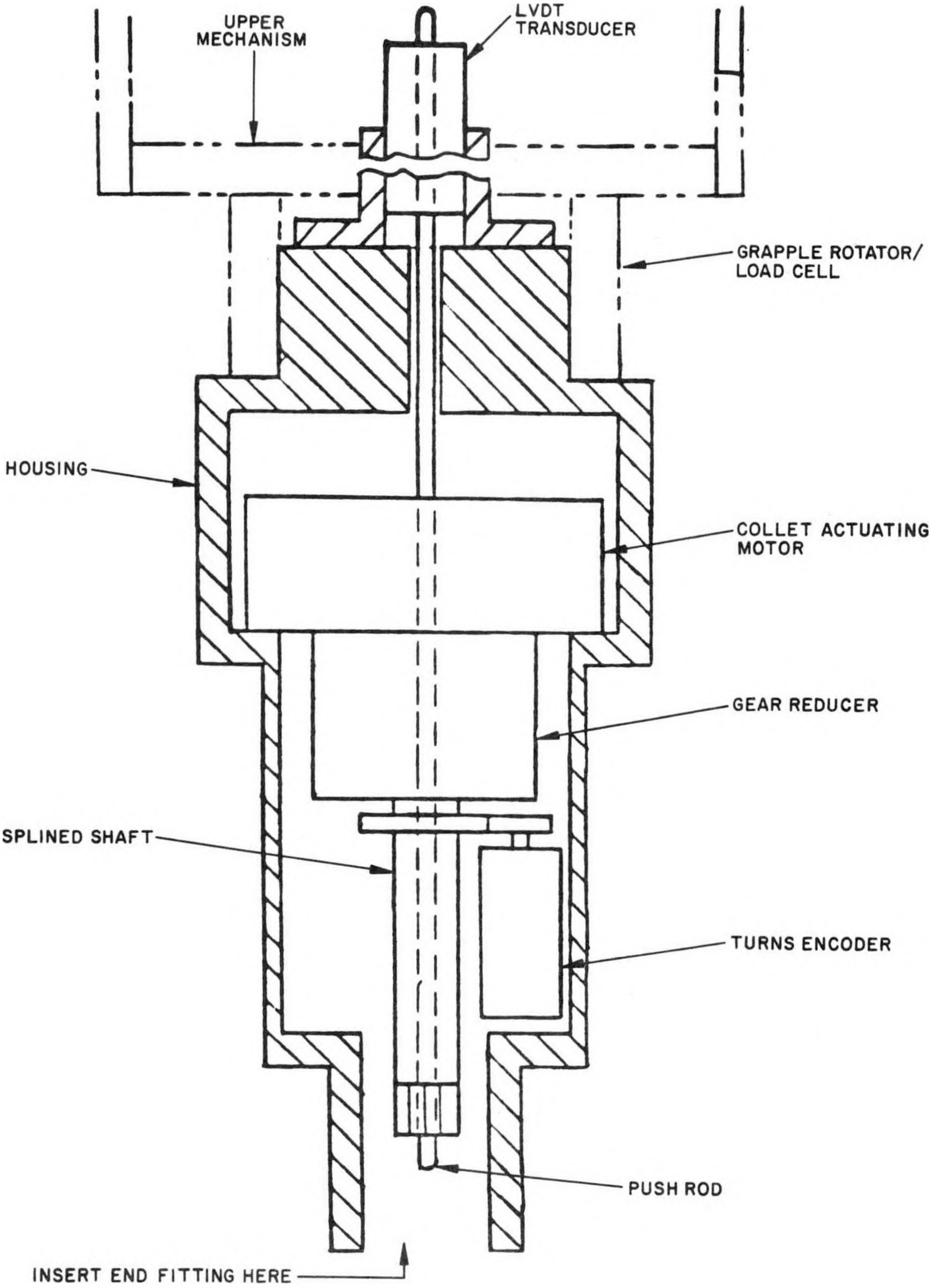


Figure 13. Schematic of RRS Grapple Lower Mechanism for Collet Actuating Components

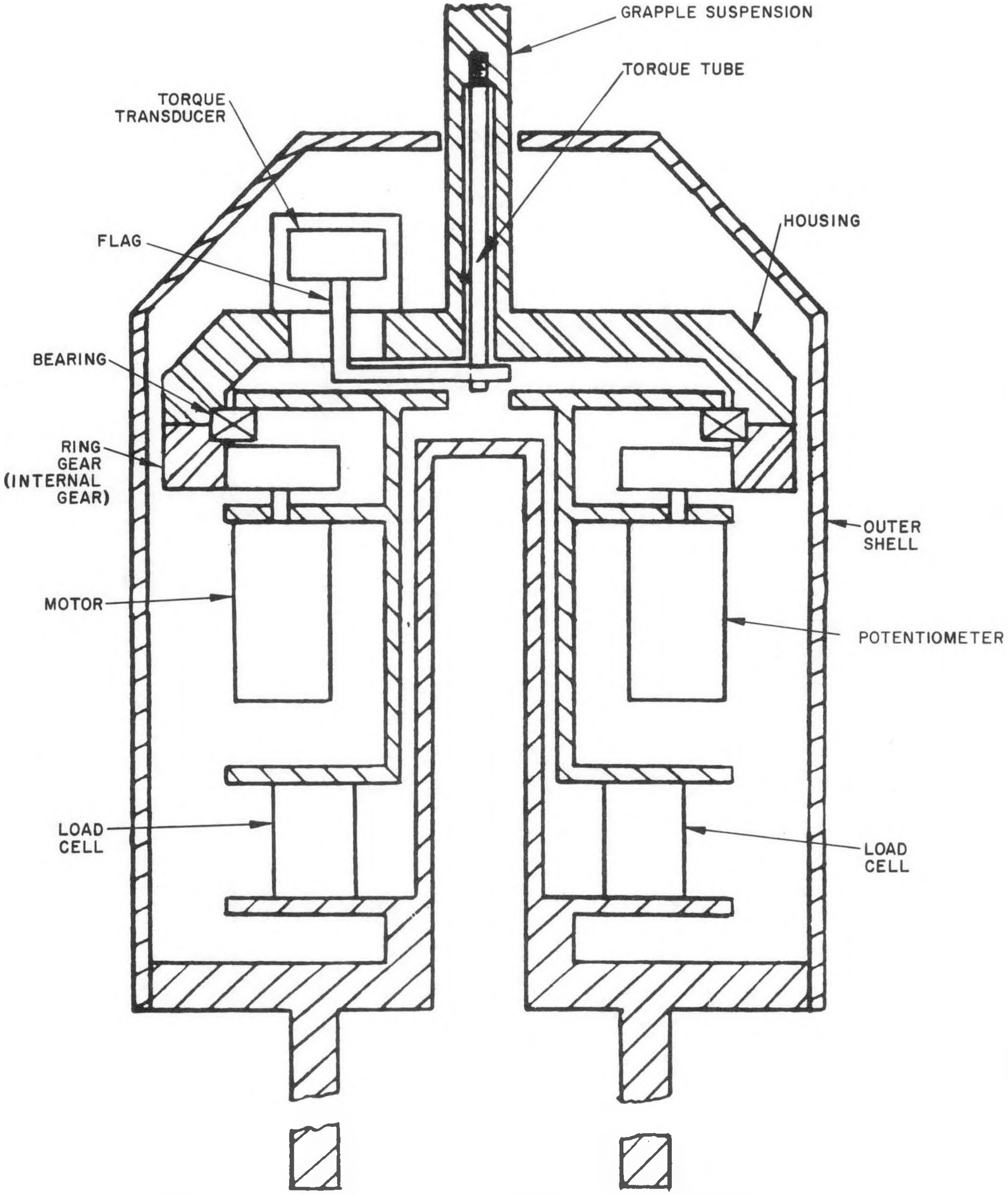


Figure 14. Schematic of RRS Grapple Upper Mechanism for Rotating and Force Monitoring Components

Although not used as a measure of collet tightness, the number of drive spline revolutions was measured by an absolute encoder. This allowed all collet tightening operations to be measured from the same reference value and provided empirical data to judge collet tightening performance. For instance, in the case of blanket rods where there were two different size rods, if the standard blanket rod collet was mistakenly used to grip a power-flattening blanket rod, the motor controller would determine that the expected encoder limit for tightening a standard blanket rod collet had been exceeded and would automatically stop the operation. By using the information provided by the absolute encoder, the operation was double checked by the programmable logic controller (PLC).

During engagement of a collet on a rod, it was necessary to ensure the rod was fully inserted into the collet. Once the collet had gripped the rod, it was necessary to determine if any slippage was occurring during any portion of a rod handling operation. To provide this type of monitoring, each collet (except for the shroud collets) had a free-hanging push rod through its center which was actuated by the end of the rod being engaged (see Figure 12). The push rod actuated a linear variable differential transducer (LVDT) in the grapple which indicated the amount of rod insertion in the collet. This enabled the operator to know when the collet had fully engaged the rod. Once the rod end had been gripped, the LVDT position was monitored by the PLC. If this value changed, indicating rod slippage in the collet fingers, the rod pull or transfer operations automatically stopped.

2.5.2 - Grapple

The grapple was a drive motor mechanism assembled in a watertight housing. The lower portion housed a pancake motor, gear reducer, and spline (see Figure 13) to provide rotary motion to the collet to drive the compound nut for tightening on a fuel rod end.

The grapple's ability to rotate a rod was provided by a small, d-c motor driving a ring gear up to a maximum of 270 degrees. This was mounted in the upper section of the grapple (see Figure 14). During normal operations it was used to rotate rods 60 degrees to preserve the dimple and spring wear marks on the rod surface caused by the fuel module grids. Other functions of grapple rotation were: (1) to rotate the rod to a position which enabled the serial number to be read by CCTV cameras mounted on the support column or on the VDS; (2) to measure and limit torque on the rod if it were not free to move; and (3) to enable remote changeout of the collets at the collet changeout station. Grapple rotation at the collet changeout station allowed the captured balls in the grapple collet attachment cup to be retracted, thus allowing the collet to be released. It could then be replaced with another collet. By rotating the grapple in the opposite direction, the captured balls were returned to the locked position, thus holding the replaced collet in the grapple.

The angular position of the grapple was determined by measuring the resistance of a multiple-turn, high-precision potentiometer which was geared to the rotating ring gear. As the ring gear rotated, the resistance of the potentiometer was directly proportional to the grapple's angular position.

The torque was monitored by measuring the rotational displacement of a calibrated torque tube relative to a fixed position at the grapple suspension point (see Figure 14). This measurement was done by a miniature LVDT capable of linear measurements over a range of ±0.050 inch, which was equivalent to a maximum linear capacity of 400 lb-in of measurable torque. Figure 15 shows the upper mechanisms with two views of the unit without the watertight enclosure.

In order to prevent rod failures resulting from overtorquing, frequent calibrations were performed to ensure the proper relationship between applied torque and angular displacement. Figure 16 shows the torque calibration fixtures (and load test fixture) for all fuel rod types. The angular scales were read directly from overhead as the grapple torque was applied.

Another important feature of the grapple was its ability to measure the pull forces accurately as the rod was removed from the module. A pull force measurement capacity ranging from 0 to 1000 pounds was achieved by mounting two 500-pound load cells in parallel to ensure symmetrical loading of each cell. The cells were connected via a pivoting beam which compensated for any differences in load cell lengths as well as any tolerance stackups resulting

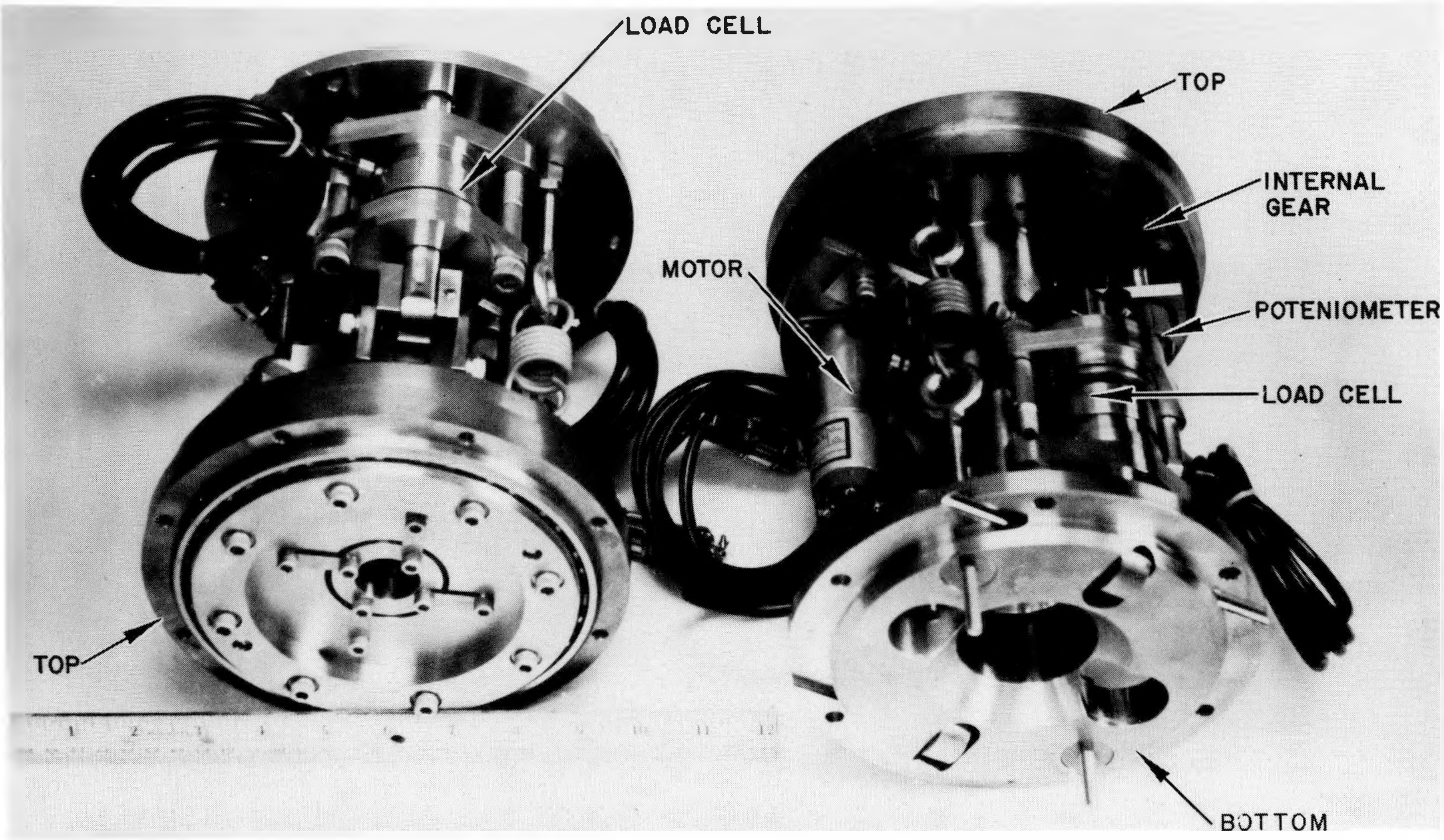


Figure 15. RRS Grapple Upper Mechanisms for Rotating and Force Monitoring Components (Two Views)

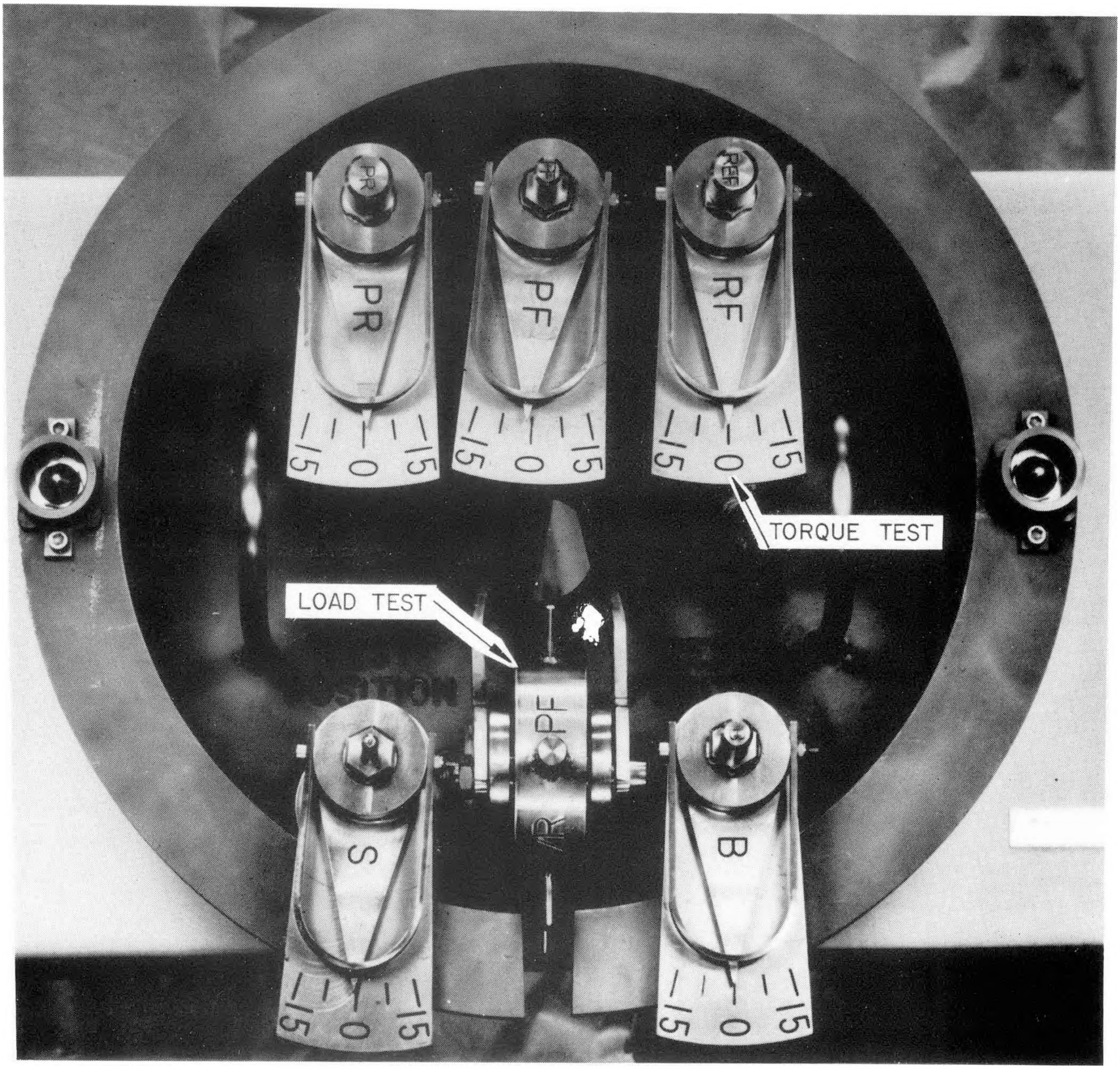


Figure 16. RRS Grapple Torque Calibration and Load Test Fixtures

from fabrication of the grapple. The load cells were calibrated monthly or when a module type was changed. The fixture shown in Figure 16 includes an adjustable load test weight assembly that was set up to match the collet size being tested. The pull force load test for the seed collets was 200 pounds, and the reflector and blanket collets were tested to 500 pounds.

To compensate for the effect of atmospheric pressure changes within the grapple housing due to changes in the water pit depth as a rod was being pulled, information from an air pressure monitor and the encoder readout for the winch position were combined to compensate the load cell readout meter.

2.6 - ROD GUIDE

The three functions of the rod guide were: (1) to surround the grapple collet to ensure that the rod was captured as it was withdrawn from the module or a storage location; (2) to restrain the lower end of the rod, thus preventing it from swinging freely in the water during a transfer (this function of the rod guide was most essential because the bending stresses on the rod resulting from the hydraulic drag were significantly reduced); and (3) to position accurately the bottom of a rod or shroud over any of the various ports within the VDS into which the rod was to be placed.

The principle feature of the rod guide mechanism was its two motor-driven arms which operated in a scissorlike fashion. In order to accommodate the various rod, shroud, and collet diameters, the ends of the arms were designed with a slot so that the arms converged on the same point as they were driven together. To position the arms properly for a specific rod or shroud diameter being handled, an absolute encoder was linked to the d-c motor driving the arms. An encoder reading was assigned to each specific diameter, enabling the rod guide to capture a rod, shroud, or collet in a controlled fashion. Figure 17 displays the rod guide with the rod capturing arms in the open position.

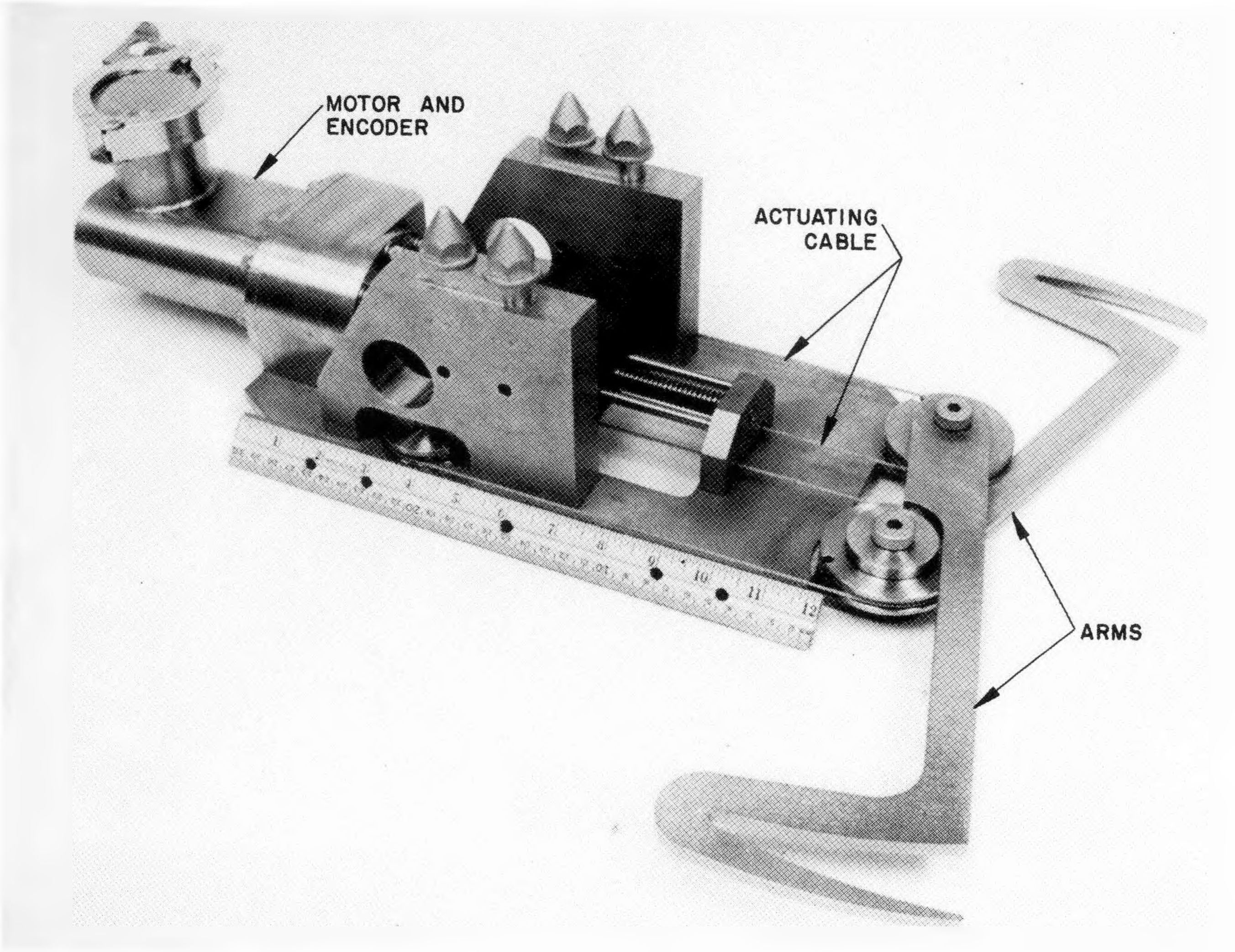


Figure 17. RRS Rod Guide

SECTION 3 - ELECTRICAL SYSTEMS AND INSTRUMENTATION

3.1 - OPERATOR'S PANEL - GENERAL

The operator's panel was located at the edge of the water pit. The operator could not directly observe the operations from overhead because of the depth of water and the Rod Removal System (RRS) components blocking the view. Therefore, underwater closed circuit television (CCTV) cameras were employed around the top of the vertical display stand (VDS) to assist in equipment alignment, fuel rod serial number recognition, and general area viewing. The monitors and controls for these cameras were installed in the operator's panel along with an operator's touch-sensitive display (TSD) for activating the RRS stored sequences. Figure 18 is a sketch of the engineer's and operator's control panels.

3.1.1 - Operational Viewing Systems

Television cameras used for the RRS had an image or picture resolution of 800 or more horizontal TV lines at 525 lines per frame. They were capable of resolving all 10 Electronic Industries Association (EIA) test pattern gray shades with only 1 footcandle faceplate highlight illumination. The cameras were equipped with a stainless steel underwater housing and were capable of operating at depths of 100 feet. They were certified to withstand accumulated radiation up to 10^8 R. Three cameras were used on the RRS. The target camera was fixed in a vertical position on the lower radial arm, and the two other cameras, one on the support tube and one on the edge of the VDS top plate, were mounted on remotely controlled pan and tilt systems (see Figure 5). Each camera location had variable intensity underwater lights.

All TV monitors were solid state designs and had a center screen resolution of 800 TV lines minimum.

A video cassette recorder was integrated with the viewing system and provided complete visual records of all rod surface conditions.

The viewing system also included a character generator for displaying messages or data on the video screens through a video mixer. The generator,

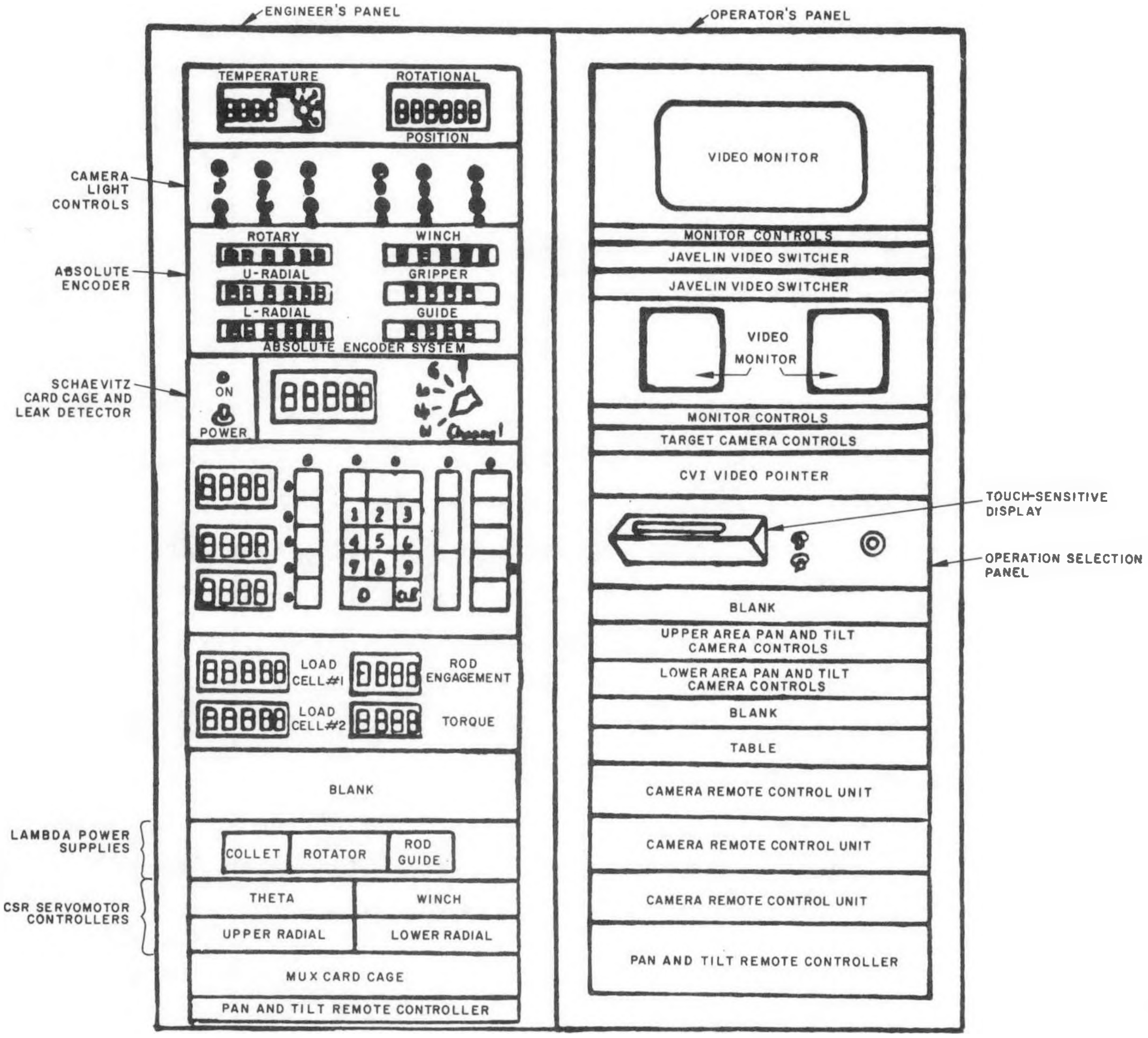


Figure 18. RRS Control Console

installed in the control panel described in Section 3.1.2, was equipped with a keyboard so the operator could enter pertinent examination information.

3.1.2 - Operation Selection Touch Control Panel

The operation selection panel (OSP), which was the operator interface with RRS computer programs, was located on the operator's console (see Figure 18). During RRS operation, sequences of screens were presented to the operator on the OSP display. The operator responded to each screen by touching the OSP screen to select options required to perform a desired sequence of operations.

The OSP was a cathode ray tube (CRT) used for alphanumeric display. A transparent switch matrix overlaying the CRT provided a programmable soft keyboard which served as an operator keyboard. The transparent switch matrix was positioned directly over the CRT display and, through programming, provided an array of touch-sensitive areas. CRT screen messages to the operator identified which keys were active and labeled the keys according to function. The operator read the display screen and responded by touching the appropriate keys offered on the screen. The OSP offered 60 different touch-activated areas on the display screen. Figure 19 illustrates two typical operations screens that were presented to the operators. Only a few controls needed to perform an operation were actually presented to the operator. Unused areas of the display were programmed to provide additional instructions, safety warnings, and measurement data. Each time the operator touched the key, the operation advanced to the next phase in the operational sequence. With "on-line prompting," the RRS was handled by operators with minimal training and without relying on human memory. The OSP was connected to the central electronic control system which interpreted operator commands and converted them into operations.

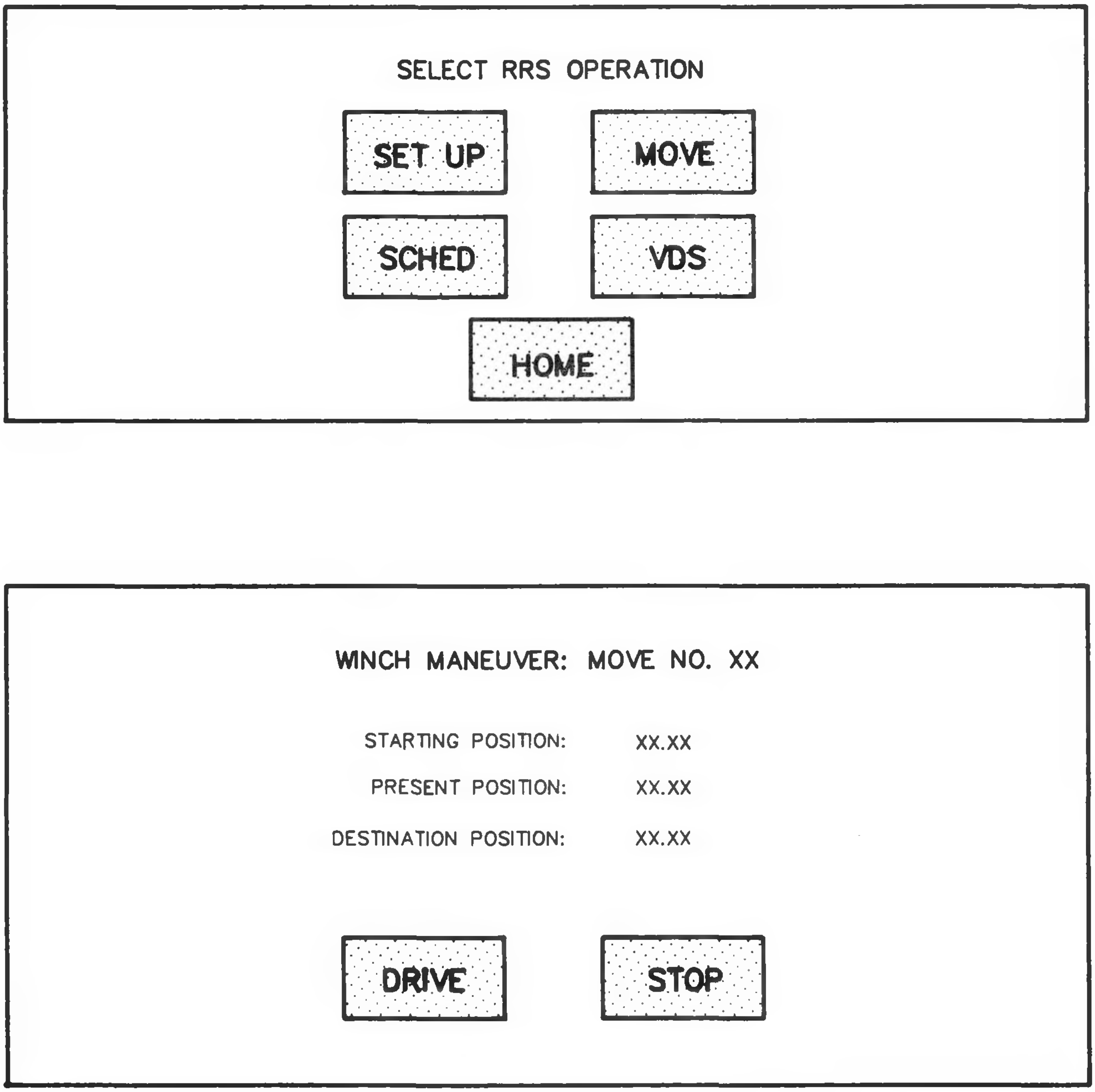
3.2 - ELECTRICAL CONTROL SYSTEM

The operator's panel was connected to the programmable logic controller (PLC) so the operator's actions or commands would effect the operation (see Figure 4). The central control system was a single package of electronicallyintegrated circuit logic which provided all of the logic needed to operate the RRS. All electrical units had access to the logic circuit for instructions and commands needed to perform the given task. The collection of logic circuits were contained in the PLC, which was programmed in the way the equipment was to perform.

3.2.1 - Programmable Logic Controller

The PLC was of standard manufacture and could be replaced easily in the event of system failure. The application logic was programmed into the PLC to define the absolute manner in which the system would operate for each given situation. The PLC was a Gould Industries Modicon 584. The commercially available PLC was tested and refined into an extremely reliable unit with a built-in error checking system to ensure continuous, reliable operation and safe shutdown in the event of failure or malfunction. If the PLC required replacement, the control program could be reloaded into a replacement unit and the system put back in operation with minimal down time.

The PLC was an industrial form of computer incorporating a complementary metal oxide semiconductor (CMOS) memory with a lithium battery backup. The memory contained instructions to implement a specific sequence of operations and functions. These functions included Boolean algebra, sequencing, tabulating, timing, counting, and arithmetic computation to control mechanisms, processes, or operations. The PLC considered the whole sequence of the operations and interacted continually with external devices or the operator to correct or modify an operation as required. Additionally, the PLC was designed to operate in an industrial environment, unaffected by radio frequency interference, dust, dirt, extremes in temperature and humidity, and power line voltage fluctuations. (It is used in the automobile industry to control welding processes, paint lines, and body assembly operations. It is also used in metal stamping operations, sheet metal rolling, chemical processing, water processing, and many other applications.)



SELECT RRS OPERATION

WINCH MANEUVER: MOVE NO. XX

STARTING POSITION: XX.XX

PRESENT POSITION: XX.XX

DESTINATION POSITION: XX.XX

Figure 19. Two Examples of RRS Operation Selection Touch Control Panel Screens

A typical PLC system can be divided into three major components. These components are the mainframe, power supply, and input/output (I/O) section. Both the processor and the power supply were contained within the same cabinet. The processor was a solid state device on large printed circuit boards. The electronic logic circuits continually scanned the entire system of controls, inputs, outputs, and prestored instructions to formulate a decision for each output. The PLC decisions were the result of previous logic conditions, mathematical calculations, or new input information from the operator's keyboard. The arrangement of circuits to form the output decisions were programmed through a keyboard terminal programmer. By using a set of standard logic boards, the logic system could be configured to a particular application with unique circuits solving the control equations. The controller, once programmed for the application, was locked to perform the programmed routine continually. As the operational requirements changed by system revisions during installation, checkout, and upgrading, the circuits were unlocked and reconfigured to the new situation. The standard logic boards in the PLC configuration were off-the-shelf products of the controller company such that replacements were readily available.

3.2.2 - Input/Output Section

The input/output (I/O) section was the main interface between the PLC and the "real world" of switches; d-c servomotors; absolute encoders; temperature, pressure, flow, and humidity sensors; and the operator's panel. The system utilized the industrial Modicon 200 Series I/O plug-in modules, which contained 16 input or output circuits per module. Complete error checking by redundant transmission and echo checking offered maximum system integrity from mainframe-to-I/O modules. The I/O modules were installed into heavy-duty housings where all wiring connections from input and output devices were made. To simplify maintenance and minimize down time, the modules could be removed and replaced without interrupting field power or the controller's scan.

All input and output circuits were individually isolated with photo diodes to prevent transients in the field wiring from affecting the internal logic. Indicators were provided on each module to show the operational status and fuse condition on the outputs.

3.2.3 - Circuit Programming

Operational sequences of the RRS were programmed into memory in common ladder logic on a standard keyboard (P190 programmer). A CRT displayed the circuit diagram during programming and indicated the flow of completed circuit paths as various switches or sequences were executed. Circuit designs, tests, and operations were immediately able to be performed without hand-wiring circuit boards. After programming was completed, the P190 terminal was used as a tool for diagnosing and troubleshooting overall system operations by allowing follow, via a video display, of the operation of switches and valves of any system as an RRS operation was being performed.

3.3 - MECHANISM DRIVE SYSTEMS

3.3.1 - Servomotors

Servomotors supplied power for operation of each of the RRS mechanisms. The servomotor operated from a control chassis which furnished d-c power, speed control, speed sequencing, data storage, and position monitoring. The servomotor controller received digital information from the PLC to indicate the magnitude and direction the motor was to turn to reach the desired position. The control chassis converted the information into motor pulses to rotate the motor shaft accurately to the precise point. The controller required 2500 pulses for the motor to make one revolution. The pulse width of the power drives was modulated to provide the torque limit requirements of the load. Additionally, for high inertial loads, as in the case of the theta drive, the motor was started at a slow pulsing rate until the desired running speed was achieved. As the motor accomplished the required travel, the motor pulses were slowed to bring the load to a smooth stop. The revolution rate was maintained at the required limit by means of tachometer feedback. Motion response of the motor was monitored by a resolver attached to the motor shaft.

Thus, the commands from the PLC were properly interpreted by the motor control chassis. The control chassis, in turn, monitored the response of the motor to ensure that the commands were carried out accurately.

3.3.2 - Direct-Current Motors

The grapple assembly used two d-c motors to tighten the collet and to rotate the grapple for rod manipulation. The collet tightening motor was a 40 volt dc, 5-ampere "pancake" motor which was attached to a gear reducer. The grapple rotator motor was a 12 volt dc, 4-ampere motor with a gear reducer incorporated in the motor frame. Direct-current motors were used because precision positioning was not required for tightening and rotating collets. These motors were powered from d-c power supplies controlled directly by the PLC. Position feedback controlled the limit of the grapple rotator and the collet tightening mechanism. In addition, current-limiting circuits ensured the limitation of torque to the mechanisms.

3.4 - POSITION ENCODING SYSTEMS

Each mechanism used in the RRS was equipped with an independent encoding device to inform the control system of its position. In this manner, encoding served as feedback to the PLC for any command given to a motor. The encoded position also served to inform the operator of the progress of the event and to furnish data to the microcomputer when required for record purposes (see Figure 4).

3.4.1 - Absolute Encoder System

The major mechanisms (rotator, winch, radial motion drives, and the grapple collet) each had a position resolver on the turning shafts to translate the shaft movement into the proper distance units. The encoders were of the absolute position type, which retained the absolute position of each d-c, motor-driven axis during any power interruption or motor control malfunction, thus allowing continuation of operating processes after repairs were completed. The data furnished by the absolute encoder provided the means of positioning the mechanisms at particular addresses and computing operating limits on the mechanisms.

3.4.2 - Displacement Transducers

Linear displacement transducers were used in the RRS for measuring short linear distances of mechanical motion. These transducers were used in the grapple assembly for fuel rod engagement into the grapple collet, for force measurement on the fuel rods during pulling, and for torque measurements during fuel rod rotation. Signals from the transducer were processed by a phase-sensitive bridge circuit and were digitized and sent to the PLC for incorporation into circuits for motion information and control. Signals from the grapple load cells were also sent directly to an analog strip chart recorder for data collection during rod pull operations.

3.4.3 - Position Potentiometer

A position potentiometer was used to transmit the rotation of the grapple as it rotated a rod or imparted a rotating action to a grapple tool. Because the required accuracy in rotational precision did not exceed several degrees, this form of simple transducer was cost-effective.

(Intentionally Blank)

SECTION 4 - CONTROL SYSTEM COMMUNICATIONS

4.1 - MICROCOMPUTER

An on-line microcomputer was interfaced to the programmable logic controller (PLC) to provide an interactive system for data transfer (see Figure 4). The microcomputer was utilized to perform data computations and information manipulations, both prior to Rod Removal System (RRS) operations and during rod pulling and transfer operations. Throughout all fuel rod activities, the microcomputer maintained a record of rods removed, stored, shrouded, and scrapped. By means of a unified data base, production, criticality, and accountability records were generated to ensure an orderly rod removal process. The RRS microcomputer was a MINC-11 (Modular Instrument Computer) from Digital Equipment Corporation.

4.2 - SYSTEM ARRANGEMENT

The communications between the touch-sensitive display (TSD) through the PLC to the microcomputer provided the data exchanges needed by the PLC to operate the RRS coherently and efficiently.

The PLC, using a RS-232-C serial bit interface, transmitted the ANSI standard control and ASCII character sequences to the TSD to produce the display control features such as highlighting, blinking, reverse image, underlining, and messages. The PLC received one of 60 ASCII codes from the TSD corresponding to one of the 60 touch-sensitive areas touched. Transmissions between the RRS control components occurred at the rate of 1200 baud (bits/sec) with an information configuration of no parity, two stop bits, and eight data bits.

The microcomputer and PLC communicated to exchange the addressing information needed for rod removal. The transmission consisted of a code identifying the nature of the transmission plus the address or message data required. No direct communication line existed between the TSD and the microcomputer.

4.3 - OPERATIONAL INTERACTION

Appendix A1 contains flowcharts of all the operation selection panel (touch panel) operations, detailing the control path required to operate the

RRS. As an example of the interaction of the RRS control components, a description of a segment of events typical of the operation of the RRS follows, with emphasis on the information exchanges.

1. The TSD displayed a selection of RRS operations that the operator was required to execute to position the grapple over a rod or storage container port.
2. Upon a signal from the operator to proceed with the scheduled operation, the microcomputer transmitted the radial and rotator (theta) RRS coordinates of the starting and destination locations to the PLC.
3. The PLC mechanisms automatically positioned the fuel rod target camera over the designated destination location to permit operator verification of the accuracy of the radial and theta coordinates and to ensure the destination was empty and available to receive a fuel rod. Figure 6 is an example of the view from the target camera. The operation was initiated by using the mechanism drive TSD. During the operation, the operator observed the encoder readouts of the starting, destination, and current positions in progress.

   Although the operation alleviated the operator of most of the decision-making processes, the operator still retained control to stop the maneuvers if a problem developed during the operation. An example of the sequence to halt operations would be as follows:

   If the operator touched a stop switch on the TSD, the panel displayed a screen allowing for the choice of the operation to proceed or be aborted. If an abort was necessary, a list of possible abort justifications appeared on the TSD. When the operator touched the appropriate justification message, the PLC transmitted a code to the microcomputer informing the control program OVERCR of details of the situation. The microcomputer then transmitted to the PLC either the corrective action to continue this operation or the radial and theta coordinates of the next scheduled fuel rod destination.
4. During the automatic radial and theta positioning of the target camera, the operator observed the positioning of the destination location within the cross hairs incorporated in the camera. The operator

then jogged the radial and theta drives as necessary to align the cross hairs above the destination. Limits programmed in the PLC prevented the operator from jogging an excessive distance to an adjacent location.

5. After positioning the target camera cross hairs, the operator touched the "in-position" switch to call up the next screen on the panel which displayed the radial and theta shift switches needed to position the grapple over the destination location sighted by the target camera. With the grapple positioned over the destination location, the operator touched a "PLC send" switch to transmit the radial and theta encoder data to the OVERCR Program. The OVERCR program then determined if the coordinates corresponded to the calculated position of the destination location for the operation. If an ambiguity existed or if the operator was unable to visually verify that the location was the desired destination, an abort may have been necessary to allow correction of the problem.
6. Following the verification of the fuel rod destination, the touch-sensitive panel displayed screens for operator execution of the automatic theta and radial alignment positioning operations to situate the target camera over the location for extracting the rod.
7. The operation continued with displayed screens on the touch-sensitive panel similar to the previous sequences to enable the operator to continue the operation of grappling and pulling the fuel rod.

4.4 - CIRCUITS DESCRIPTION

4.4.1 - General

The control system circuits, described in Sections 4.1, 4.2, and 4.3, used all of the instrumentation available to perform the work in a safe and efficient manner. In addition to the internal self-checking of the PLC, the circuitry continually monitored all position-indicator systems for abnormal or undesired situations. The general circuit design allowed only one mechanism at a time to be in motion while ensuring the lock-up of the other mechanisms. Additionally, while the grapple assembly was engaged to a rod, lateral motion was not allowed, except at specific winch heights, to ensure that no rods were damaged.

4.4.2 - Engineer's Panel

The engineer's panel provided a means of controlling the RRS in other than the programmed sequenced and addressed mode (see Figure 18). Access to this panel was limited to authorized persons skilled in its use. The panel had features which allowed individual addresses to be programmed directly into the controller, thereby permitting mechanisms to be moved to locations not routinely scheduled by the operating system. The engineer's panel provided a means of performing a recovery or extra move that was not anticipated at the time the schedule was loaded by the OVERCR program.

In the event of power or equipment failure, several default systems were available to operate the RRS manually to complete a fuel rod move. Such default systems included hand crank capabilities on the theta drive, radial arm drive shafts, and grapple winch mechanism.

4.4.3 - Data Collection System

During rod removal operations, pull forces and rotational torques were of interest for later consideration in the analysis of the fuel rods. The nature of the PLC circuitry allowed for the collection of such data and the ultimate storage of the information on magnetic disks.

Because of the inherent nature of PLC control using arithmetic calculations, the encoder and transducer data, needed to limit positioning and forces of the mechanisms, were entered into the PLC in digital form. The digital information was used in limit equations to stop or reduce the operational event in progress. The PLC control circuitry monitored the digital form of the data and would stop the operation should it determine that a pull force limit had been violated. Pull force data and position encoding data collected by the PLC was sent to a microcomputer data collection routine to locate the source of the pulling resistance. This same data was transmitted to the microcomputer for storage on magnetic disks which were available for later analysis.

SECTION 5 - COMPUTER SOFTWARE DESIGN

To assist in automating fuel movement schedules, locating ports in storage containers, collecting rod pull force data, and maintaining fuel movement records, a computerized system called OVERCR was developed. The OVERCR program was a system of MINC 11 BASIC programs which collected, saved, and reported Rod Removal System (RRS) data. The MINC 11 BASIC was a computer language developed by Digital Equipment Corporation for their Modular Instrument Computer (MINC). The MINC provided the operator with displays of data and information collected during the operations. The programmable logic controller (PLC) communicated to the MINC when particular steps of the RRS operations had been completed. Additionally, the MINC provided the PLC with operational data and addresses as determined by the particular production schedule entered into the MINC. The OVERCR program was developed as an interactive computer system to assist the operator in scheduling RRS fuel rod movements and to identify empty fuel rod locations in a Light Water Breeder Reactor (LWBR) module or in a rod storage liner while the module or liner was in the vertical disassembly stand (VDS). Once a fuel rod location was calculated, the coordinates were sent from the MINC to the PLC. The PLC caused the RRS mechanisms to execute a fuel move. When the fuel move was completed, the PLC sent a signal to the MINC to save the date, time, and other pertinent information related to this fuel move in computer data files. The data files provided the status of all fuel storage locations and the location of all fuel rods. The program used these files to check if the next scheduled fuel rod move was reasonable. See Appendix A2 for brief descriptions of the OVERCR program and subprograms and how they inter-related during LWBR rod removal operations.

(Intentionally Blank)

SECTION 6 - SUMMARY AND CONCLUSIONS

The Rod Removal System (RRS) mechanisms and support structure pulled approximately 1100 rods from Light Water Breeder Reactor (LWBR) modules in a highly-controlled, reliable manner without rod damage or a major shutdown due to equipment failure. The system was constructed and assembled in sections, each of which had design features that permitted their remote replacement without the need for removing the entire system from the water or isolating and draining the water pit to permit access. Each section, except for the winch and theta drive, was fabricated with a complete duplicate which served as a spare. Thus, if required, spares could be used to continue the system operations while repairs were made on the inoperable mechanism. Due to their accessibility, the winch and the theta drive did not have complete spares but only replacement parts which permitted quick repair and return to service. During the rod removal program, there was no requirement to replace any major section such as the theta drive or radial arms. The grapple and rod guide were removed from the water pit for maintenance to replace water seals, then returned to service.

The support structure, which enabled the RRS to be mounted to the wall of the water pit, also provided the pivotal link between all the mechanisms during their operations. It was also capable of withstanding an earthquake while maintaining the integrity of the entire system.

Safeguards on all aspects of the RRS provided an automatic system shutdown in the event a problem was detected. Operations could not continue until the problem was solved and appropriate system checks were made.

Some of the reasons to automate rod pull rather than using a simple system, like hand pulling rods from overhead walkways, were: (1) to limit rod pull force and to obtain accurate rod pull-force data; (2) to minimize the chance for dropped rods in the water pit by monitoring successful engagement of the rod pull tool on the rod end; (3) to pull rods out of the modules vertically to prevent rod bending or unnecessary scratching on the rod cladding; and (4) to confidently locate the correct rod in the module through 20 feet of water.

Once the water pit technicians experienced hands-on training on dummy rod modules, they had very few problems with the controls. The fuel rod removal involved basic "cook book" operations, with the menu of sequential events displayed to the operator on the touch sensitive display panels. The RRS was handled by operators with minimal training and without relying on human memory.

SECTION 7 - REFERENCES

1. D. R. Connors, S. Milani, J. A. Fest, R. Atherton, Editors, "Design of the Shippingport LWBR," WAPD-TM-1208, January 1979.

2. J. T. Williams, "LWBR Core Evaluation Operations at ECF," WAPD-TM-1611, October 1987.

3. W. S. Bacvinskas, G. Fodor, T. J. Kikta, R. L. Matchett, "LWBR Module and Rod Examination System," WAPD-TM-1610, October 1987.

(Intentionally Blank)

APPENDIX A1 - FLOWCHARTS FOR OPERATION SELECTION PANEL ("TOUCH PANEL")

(Intentionally Blank)

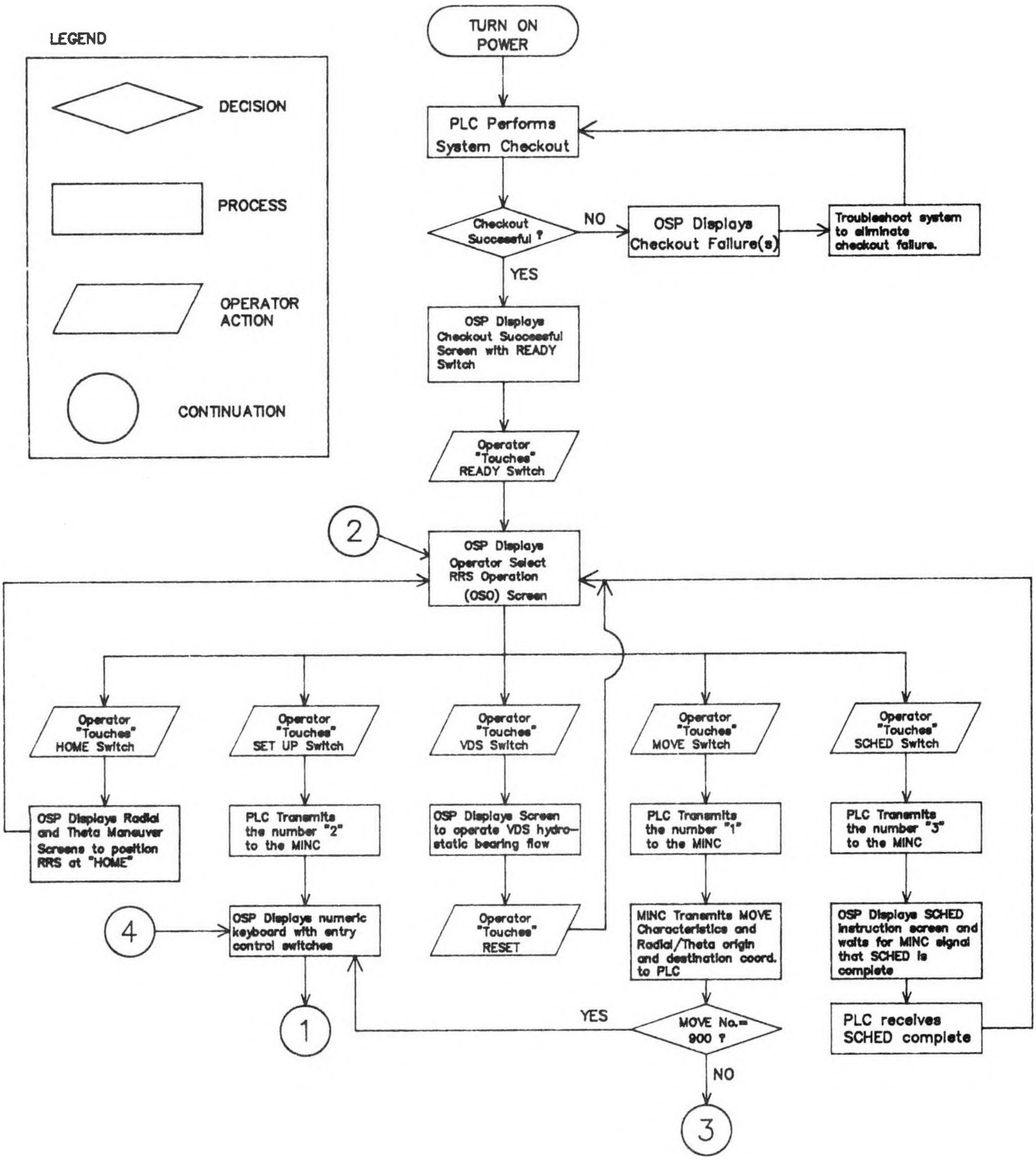


Figure A1-1. Flowchart for Operation Selection Panel (OSP) Selection of RRS Operations
(NOTE: The 900 code selected on this chart will determine "Next Screen" sequences on subsequent charts)

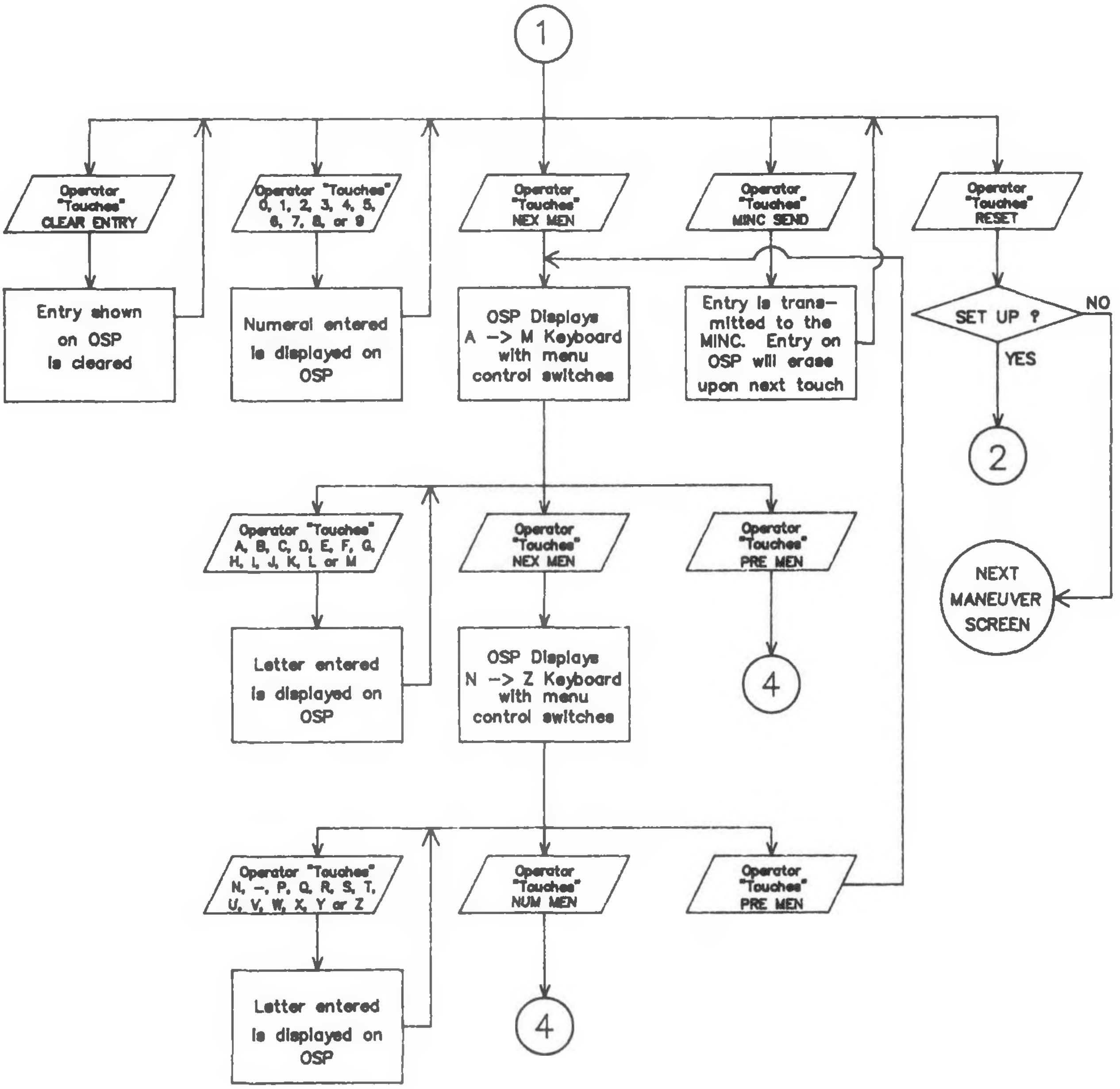


Figure A1-2. Flowchart for Operation Selection Panel (OSP) Alphanumeric Keyboards

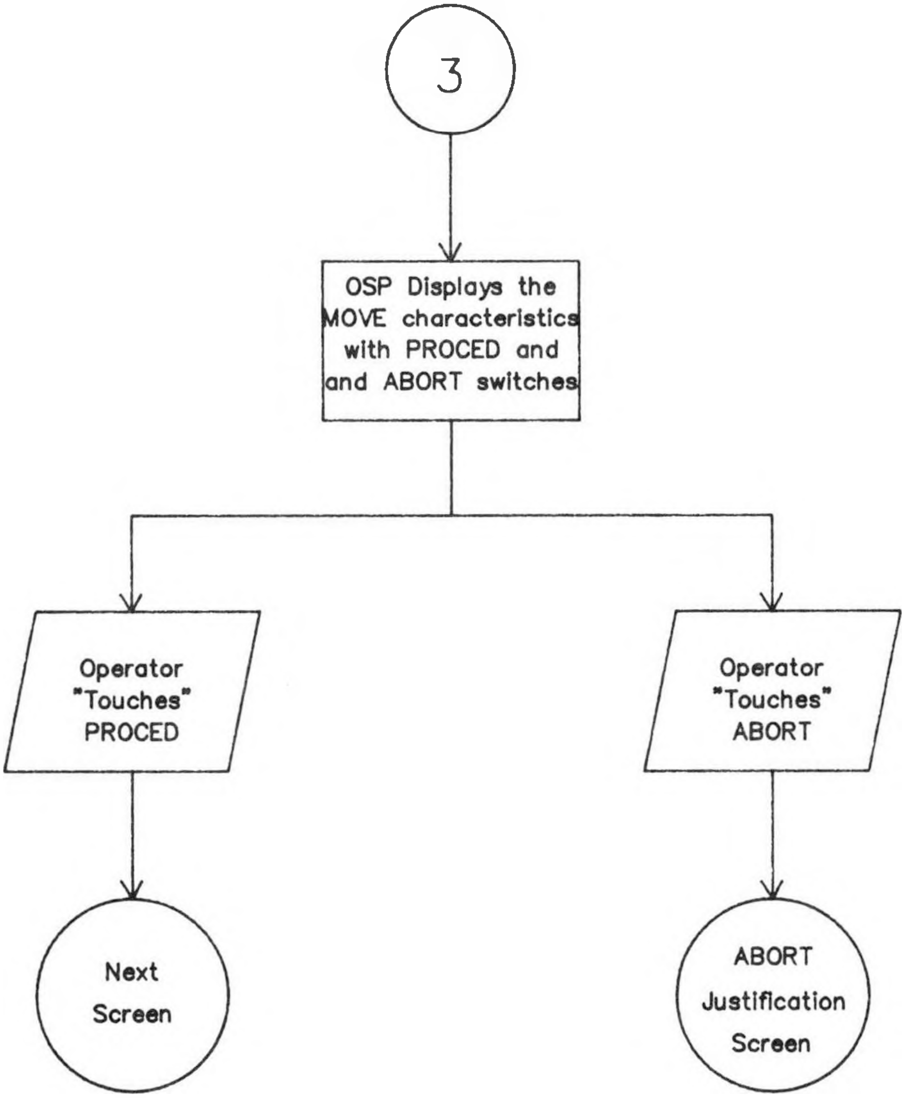


Figure A1-3. Flowchart for Operational Selection Panel (OSP) Move Description Screens

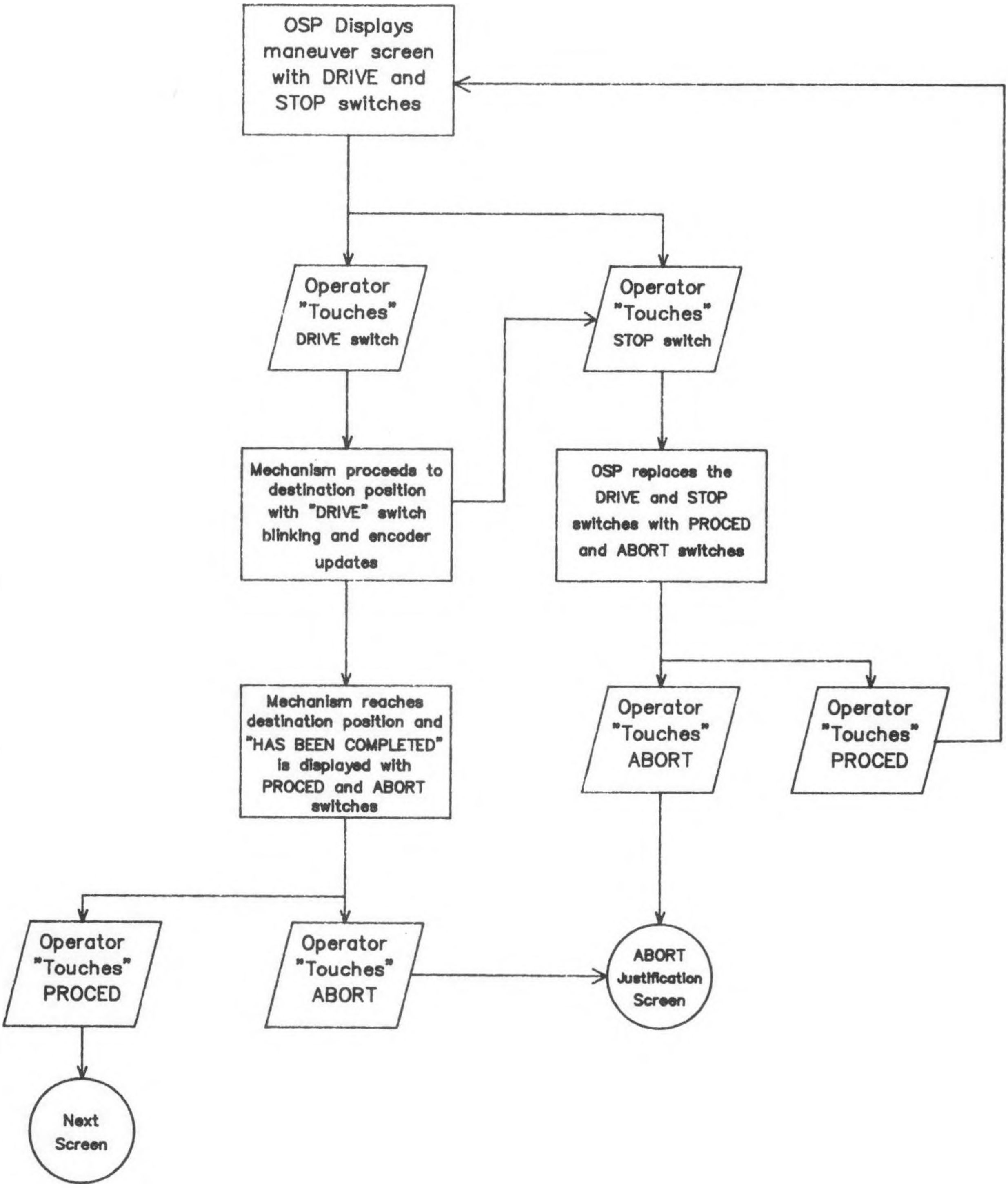


Figure A1-4. Flowchart for Operational Selection Panel (OSP) Mechanism Maneuver Screens

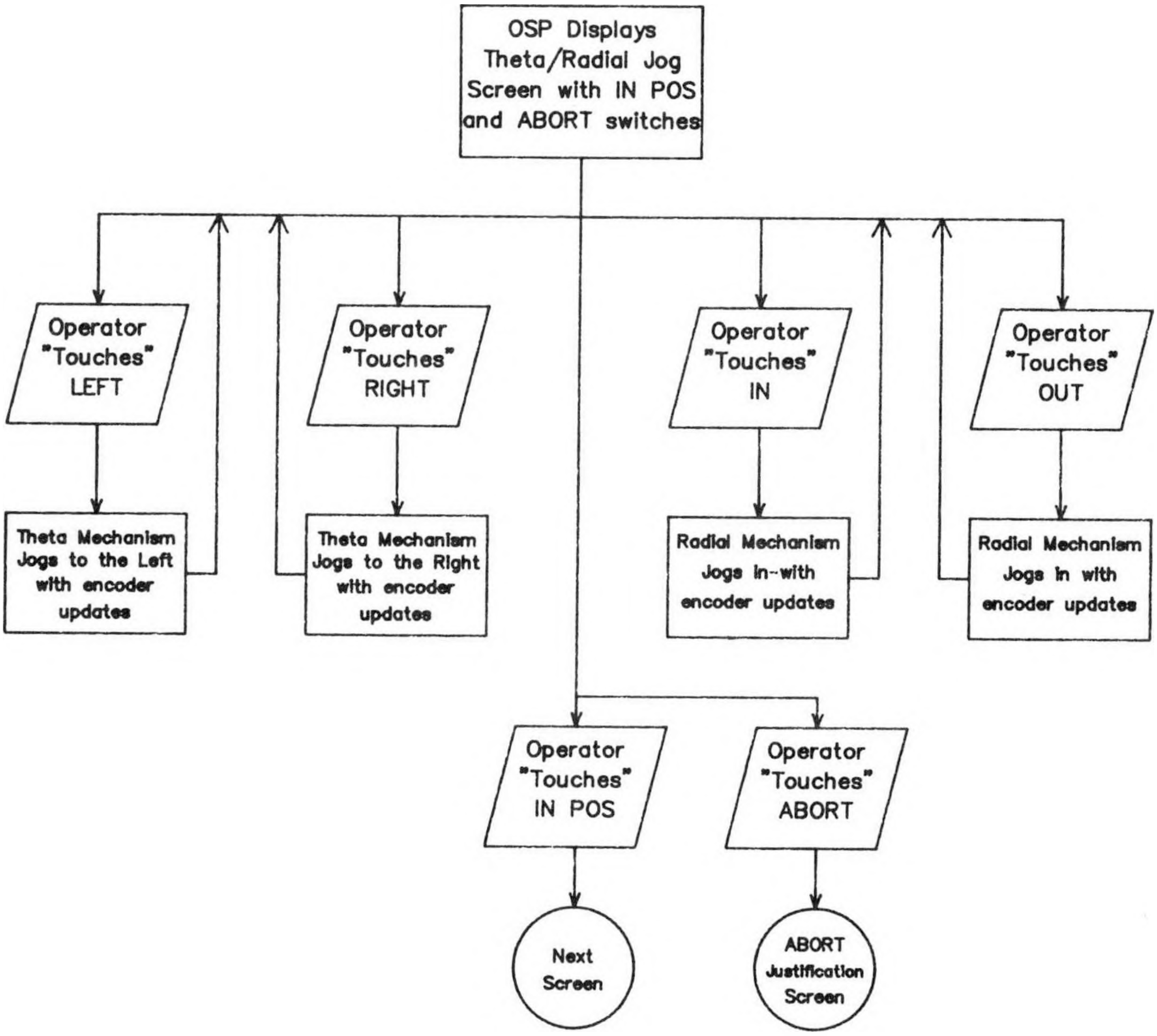


Figure A1-5. Flowchart for Operation Selection Panel (OSP) Theta/Radial Jog Screen

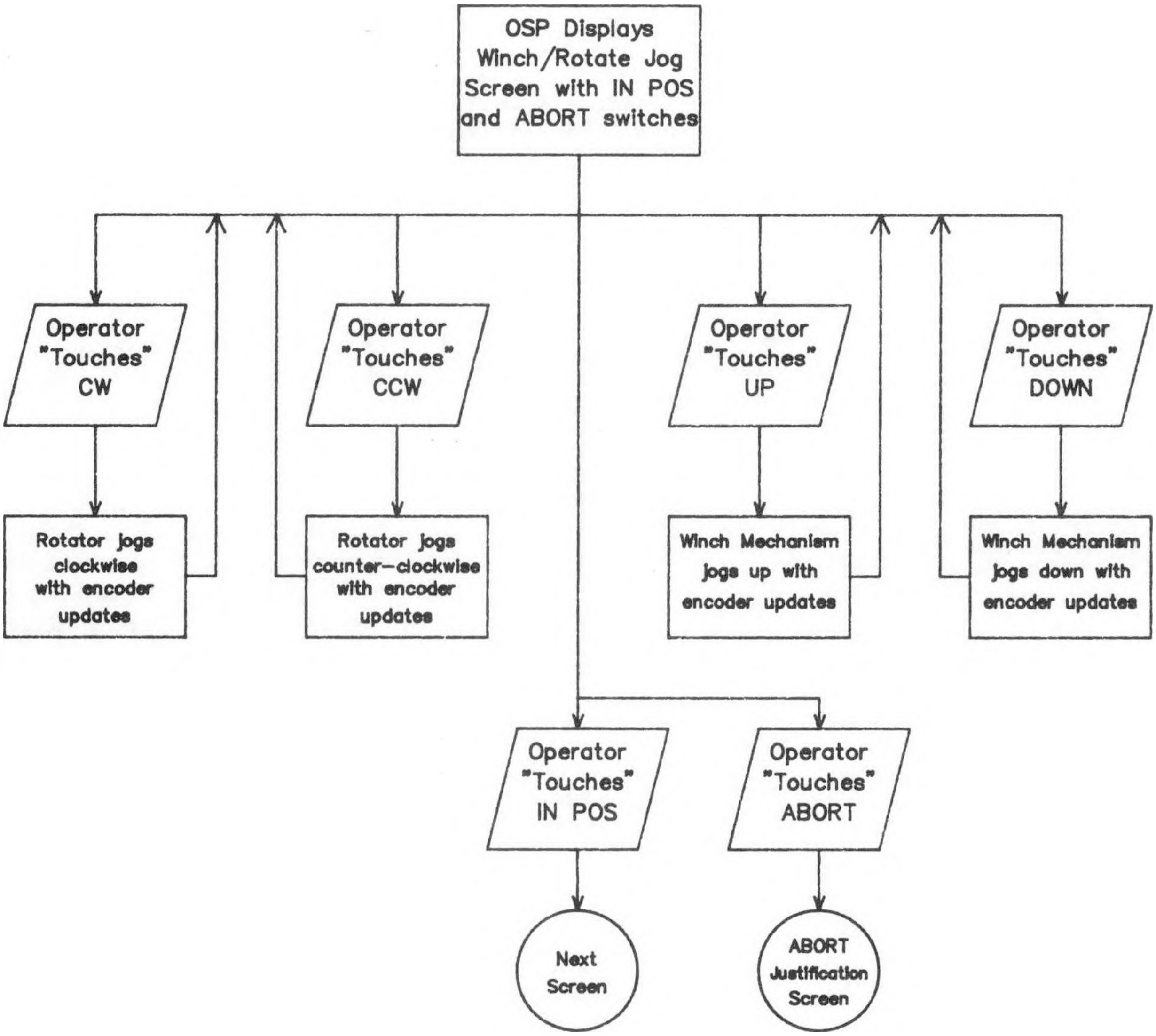


Figure A1-6. Flowchart for Operation Selection Panel (OSP) Winch/Rotate Jog Screen

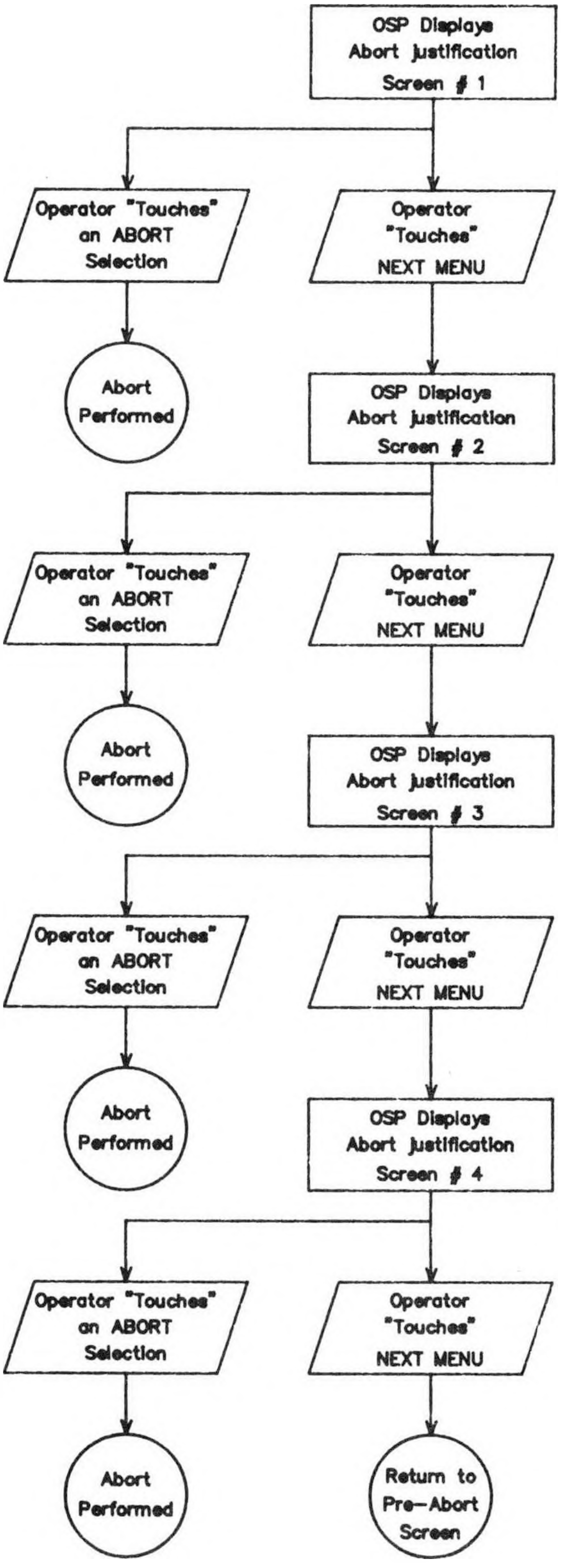


Figure A1-7. Flowchart for Operation Selection Panel (OSP) Abort Justification Screens

(Intentionally Blank)

APPENDIX A2 - DESCRIPTION OF THE OVERCR COMPUTER SYSTEM

A2.1 - GENERAL

The OVERCR computer system consisted of a number of computer programs designed to interact with the Rod Removal System (RRS) operators and the programmable logic controller (PLC) to schedule fuel movement, locate container cells, collect rod pull force data, and maintain LWBR fuel movement records. The following brief descriptions of the programs outline how OVERCR was used during LWBR rod removal and provide an overview of the OVERCR computer system. Figure A2-1 is a flowchart describing how the programs interact. The remainder of the programs listed in this appendix stand alone and are marked with an asterisk (*).

A2.1.1 - The INICHK Program (Store VDS Port Coordinates*)

The RRS operator used the operator's control panel and the system alignment camera to locate each module support stand port, and INICHK saved these coordinates in the STATON.DAT data file.

A2.1.2 - The INITIA Program (Maintain VDS Container Serial Numbers*)

The RRS operator used INITIA, with the two subprograms INICAS and INIMOL, to update the RECPSN.DAT data file when a container or a collet was moved into or out of the module support stand.

A2.1.3 - The OVERCR Program (Initiate the OVERCR System)

The system control program was OVERCR. It used SCHED and SETUP as subprograms, monitored collet changeout, and was "transfer controlled" (chained) to subprograms that monitored rod/shroud moves within the module support stand.

A2.1.4 - The SCHED Program (Schedule Fuel Movement within the Module Support Stand)

The RRS operator used SCHED to define a set of fuel rod/shroud moves which determined what was to be moved, from where, and to where within the module support stand. The SCHED program automatically interjected a collet changeout move, when needed, and stored all move data in the PATH.DAT data file.

A2.1.5 - The SETUP Program (Access ORIENT, RRSTAT, and COLTST)

The SETUP program used ORIENT to calculate container cell coordinates, used RRSTAT as a subprogram to report the status of the module support stand, and used the subprogram COLTST to attach, detach, or test collets.

A2.1.6 - The ORIENT Program (Calculate Module and Rod Storage Liner Cell Coordinates)

When a module or rod storage liner was transferred into the module support stand, an RRS operator used the operator's control panel and the alignment camera to locate three preassigned benchmarks. The ORIENT program accessed the appropriate MCORX.BET or RCORX.BET data file, used it with benchmark data and the GENECF subprogram to calculate machine coordinates for each cell in the container, and saved this data in the appropriate MCORX.ECF or RCORX.ECF data file.

A2.1.7 - The RRSTAT Program (Report VDS Status)

The RRS operator used RRSTAT to report which container was in which module support stand port and which fuel rod or shroud was in which container cell.

A2.1.8 - The COLTST Program (Test Collets)

The RRS operator used SETUP to access COLTST to send collet storage and test station coordinates to the PLC during collet testing.

A2.1.9 - The CHECKR and CHECKS Programs (Check Rod and Shroud Existence)

When an LWBR fuel rod was being moved in the module support stand, OVERCR chained to CHECKR to determine if the fuel rod was still in a module. If a shroud was being moved, OVERCR chained to CHECKS to locate the shroud and to determine if the shroud contained an LWBR fuel rod.

A2.1.10 - The CHFROC, CHFROR, and CHFROS Programs (Check a "From" Move)

The CHECKR and CHECKS programs chained to these subprograms to determine if the data files and the procedure agreed on the location of the rod or shroud being moved. The CHFROC, CHFROR, and CHFROS programs accessed the ORTIC.DAT and DATIM.DAT data files to locate the rod or shroud, then calculated the location in machine coordinates. The CHFROC program monitored a move from a rod cassette or a rod box, accessed the RECPSN.DAT data file to locate the container within the module support stand, then retrieved location coordinates from the STATON.DAT data file. The CHFROR program monitored a move from a rod storage liner and accessed the appropriate RCORX.ECF data file for cell location coordinates, which CHFROR converted into machine coordinates. The CHFROS program monitored a move from a rod caddy or the decrud brush station and retrieved location coordinates from the STATON.DAT data file.

A2.1.11 - The CHTOC, CHTOR, and CHTOS Programs (Check a "To" Move)

After one of the CHFRO subprograms verified the "from" move, it chained to the appropriate CHTO subprogram to determine if the data files and the procedure agreed that the location to which a rod or shroud was scheduled to be moved was available. The CHFROC program monitored a move to a rod cassette or a rod box, accessed the RECPSN.DAT data file to locate the container within the module support stand, then retrieved location coordinates from the STATON.DAT data file. The CHFROR program monitored a move to a rod storage liner, accessed the appropriate RCORX.ECF data file to determine the next available empty cell, then it accessed the appropriate RCORX.ECF data file for cell location coordinates, which it converted into machine coordinates. The CHFROS program monitored a move to a rod caddy or the decrud station and retrieved location coordinates from the STATON.DAT data file.

A2.1.12 - The WTFRO Program (Communicate With the PLC)

After one of the CHTO subprograms verified the "to" move, it chained to WTFRO to send data for the move to the PLC. The WTFRO program also waited for a "from move has been completed" signal from the PLC. If a rod was being moved from a module, WTFRO saved rod pull force data on a magnetic disk and chained to subprogram RODSN to verify the rod serial number.

A2.1.13 - The RODSN Program (Verify Rod Serial Number)

After a rod was pulled from a module and before it was moved anywhere, RODSN directed the RRS operator (through the TSD) to use a general utility closed circuit television (CCTV) camera to read the rod serial number and verify that the correct rod was pulled. The RRS operator entered the number into the MINC for final verification.

A2.1.14 - The ORFRO Program (Store "From" Move Data)

The WTFRO and RODSN programs chained to ORFRO to store data associated with a "from" move in the ORTIC.DAT, DATIM.DAT, RECPSN.DAT, and CASERB.DAT data files. When data was saved, ORFRO printed a summary of the move, then chained to WTORTO.

A2.1.15 - The WTORTO Program (Communicate With PLC, and Store "To" Move Data)

The WTORTO program waited for a "to move has been completed" signal from the PLC, then it stored data associated with the "to move" in the ORTIC.DAT, DATIM.DAT, RECPSN.DAT, and CASERB.DAT data files. When data was saved, WTORTO printed a summary of the move then chained back to OVERCR for the next action.

A2.1.16 - The BYHAND and BY2 Programs (Record Operator's Control Panel Fuel Move)

The RRS operator used BYHAND to store data associated with a fuel move in the module support stand when data communications between the PLC and MINC were interrupted during a fuel move, or when the operator's panel, not OVERCR, was used to direct a fuel move. The BYHAND and BY2 programs were similar to SCHED because they asked what was moved, from where, and to where. The BYHAND program chained to BY2, then BY2 chained to BYCHKR, if a rod was moved, or to BYCHKS if a shroud or shrouded rod was moved.

A2.1.17 - The BYCHKR and BYCHKS Programs (Check Rod and Shroud Existence)

The BYHAND subprograms BYCHKR and BYCHKS performed the same function as CHECKR and CHECKS.

A2.1.18 - The BYFROM Program (Verify and Record "From" Move Data)

The BYCHKR and BYCHKS programs chained to subprogram BYFROM to verify data entered for a "from" move, and, if data was correct, BYFROM updated appropriate data files for OVERCR.

A2.1.19 - The BYTO Program (Verify and Record "To" Move Data)

The BYCHKR and BYCHKS programs chained to subprogram BYTO to verify data entered for a "to" move, and, if data was correct, BYTO updated appropriate data files for OVERCR.

A2.1.20 - The MODSUM Program (Generate Module Status*)

The RRS operator used MODSUM to generate a summary listing of the location of each LWBR fuel rod that was pulled from a specified module.

A2.1.21 - The RSLSUM Program (Generate Rod Storage Liner Status*)

The RRS operator used RSLSUM to generate a listing of which LWBR fuel rod, shroud, or shrouded fuel rod was in each cell in a specified rod storage liner.

A2.1.22 - The RODHIS Program (Generate LWBR Fuel Rod Status*)

The RRS operator used RODHIS to generate a chronological listing of all moves that a specified LWBR fuel rod made in the module support stand.

A2.1.23 - The LASMOV Program (Report Last Move Made in Module Support Stand*)

The operator used LASMOV to list information related to the last move made in the module support stand, as recorded by OVERCR or BYHAND.

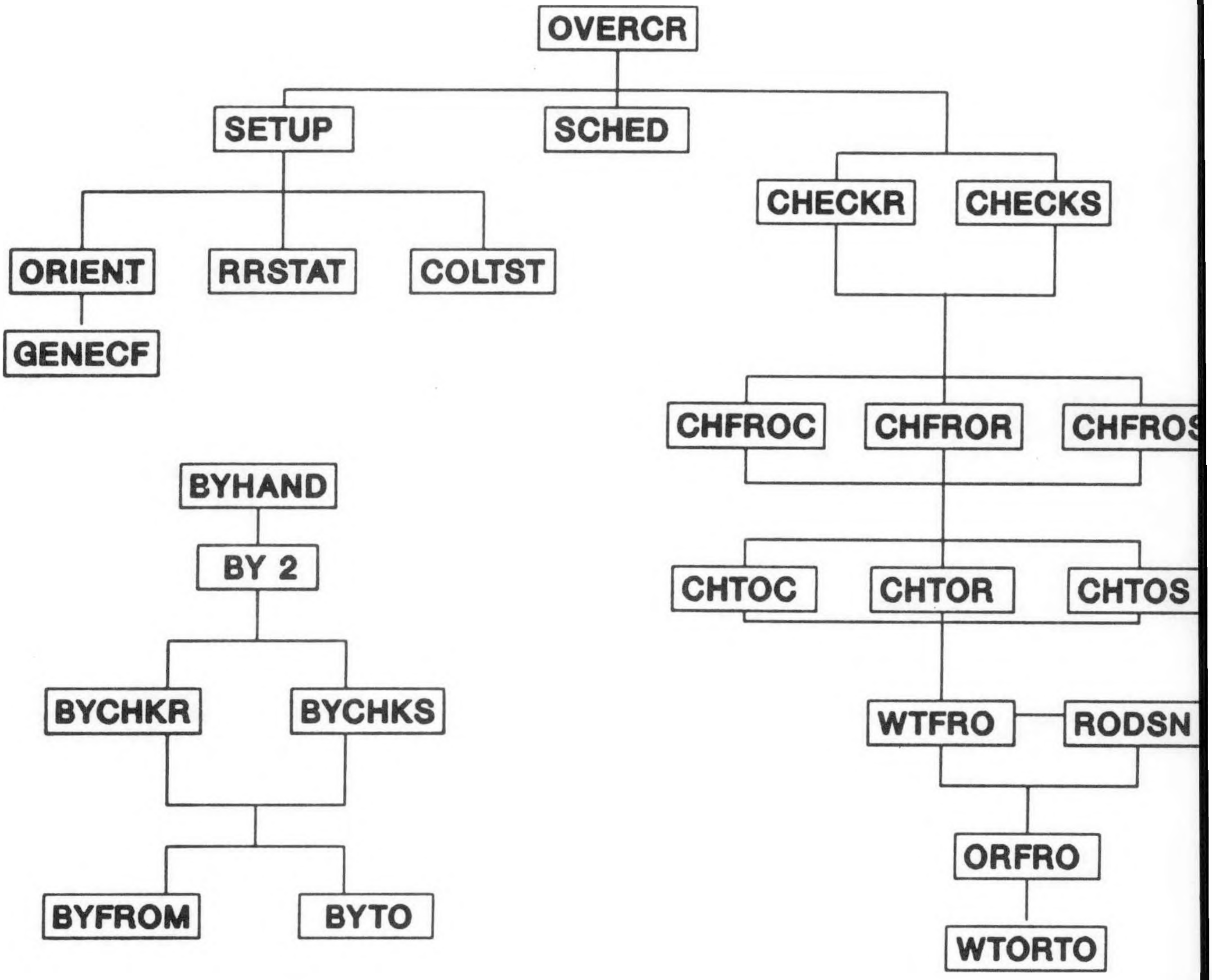


Figure A2-1. Flowchart for OVERCR Computer System used with the RRS

☆U.S. GOVERNMENT PRINTING OFFICE: 1987-505-000-60762