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DESIGN AND DEVELOPMENT OF THE CRBRP EX-VESSEL TRANSFER MACHINE*

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ABSTRACT

The Reactor Refueling System[1] (RRS) for the Clinch River Breeder Reactor Project (CRBRP) uses the Ex-Vessel Transfer Machine (EVTM) for transferring core assemblies outside the reactor vessel. The design of the Ex-Vessel Transfer Machine (EVTM) and its gantry-trolley for the CRBRP is discussed. The development tests required for the design are presented, in conjunction with the impact of the test results on the design. The impact of the increased seismic requirements on the design are also presented.

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INTRODUCTION

The Reactor Refueling System[1] (RRS) for the Clinch River Breeder Reactor Project (CRBRP) uses the Ex-Vessel Transfer Machine (EVTM) for transferring core assemblies outside the reactor vessel. The EVTM and its gantry-trolley (G-T) are located in the reactor containment building (RCB) and reactor service building (RSB), shown in Figure 1. The EVTM, in conjunction with the G-T, transfers new core assemblies from the new fuel unloading station (NFUS), following examination, to the preheat thimbles in the ex-vessel storage tank (EVST). After preheating, the EVTM moves the core assemblies from the preheat thimbles into core component pots (CCP's) in the EVST in preparation for refueling. Following reactor shutdown and preparation for fueling, which includes removal of the hatch between the RCB and RSB and installation of the gantry rail bridges between the RCB and RSB, the EVTM moves between the EVST and the reactor.

At the reactor, for refueling, a reactor fuel transfer port (RFTP) adapter is placed over the RFTP nozzle. A floor valve (FV) is bolted to the RFTP adapter. The EVTM may then remove and store the RFTP plug in a plug storage facility (PS) in the RSB. The EVTM removes plugs from, and replaces plugs into, the various facilities through FV's, and stores the plugs in PS. The reactor contains five transfer positions accessible to the EVTM. Any two adjacent transfer positions may be accessed by the EVTM, without decoupling from the reactor, via an offset rotating guide tube (RGT). Transfer of the core assemblies, from and to the reactor transfer positions, into and out of the reactor core, is accomplished by the in-vessel transfer machine (IVTM) in conjunction with the three rotating plugs, which form the reactor head.

To refuel the reactor, the EVTM transports new core assemblies in sodium-filled CCP's from the EVST to a reactor transfer position, and returns irradiated core assemblies in sodium-filled CCP's from a reactor transfer position to the EVST.

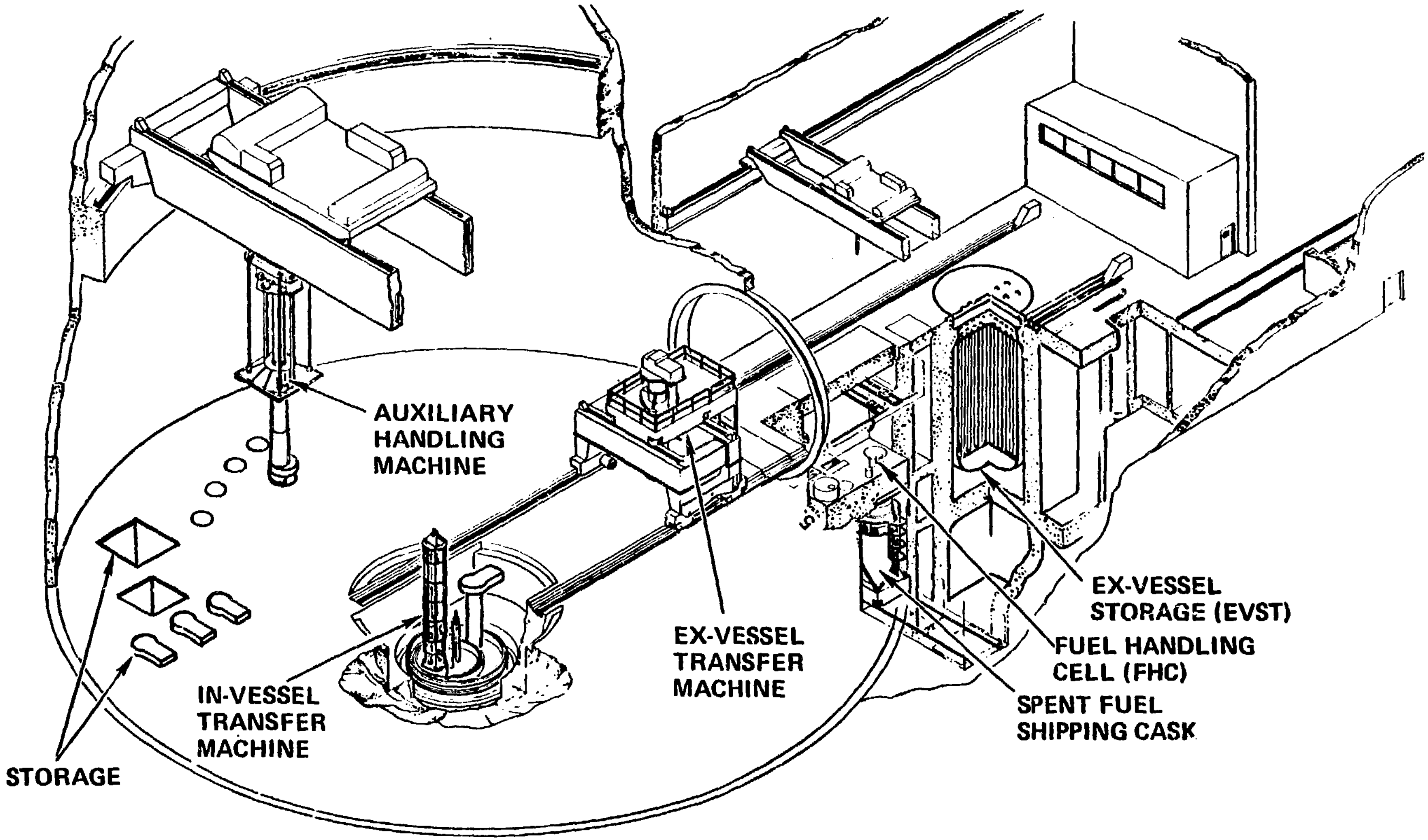

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Figure 1. CRBRP Reactor Refueling

Following refueling and during reactor operation, the EVTM transfers irradiated core assemblies from the EVST to the fuel handling cell (FHC) for examination and shipment. The EVTM then returns the empty CCP's to the EVST.

SYSTEM DESCRIPTION

The EVTM is a single-barrel, shielded, sealed transfer machine which is mounted on the G-T, as shown in Figure 2 . The gantry and trolley are basically components of a gantry crane. The gantry moves on rails located in trenches in the RCB and RSB floor. Seismic locks, which serve as seismic restraints, are located between the wheels of each gantry truck. The flat pads of the locks contact tapered protrusions extending from the sides of the trench. These caliper-type locks react loads in three planes, thereby precluding excessive wheel-to-rail loadings. Pneumatic cylinders are used to actuate the locks.

The gantry span is 9.14 m (30 ft), and the gantry beams are 1.52 m (5 ft) high by 1.22 m (4 ft) wide. The trolley, which is mounted on top of the gantry, has a span of 3.96 m (13 ft) and supports the EVTM. The control cab is mounted on the side of the trolley. Trolley seismic locks are located on both sides, outside of the rails, and on the control cab at the bottom of the gantry beam. Seismic locks are also attached to the EVTM near the bottom of the gantry beam. The gantry and trolley weigh 113,400 kg (125 tons).

The EVTM is basically a cylindrical structure about 9.75 m (32 ft) long, and varies between 1.02 to 2.03 m (40 to 80 in.) in diameter and weighs approximately 127,000 kg (140 tons), as shown in Figure 3. The basis for the EVTM design is the Fast Flux Test Facility (FFTF) closed loop ex-vessel machine (CLEM). The EVTM consists of fourteen major components, which are:

1) The grapple drive system

2) The core assembly grapple

3) The CCP grapple

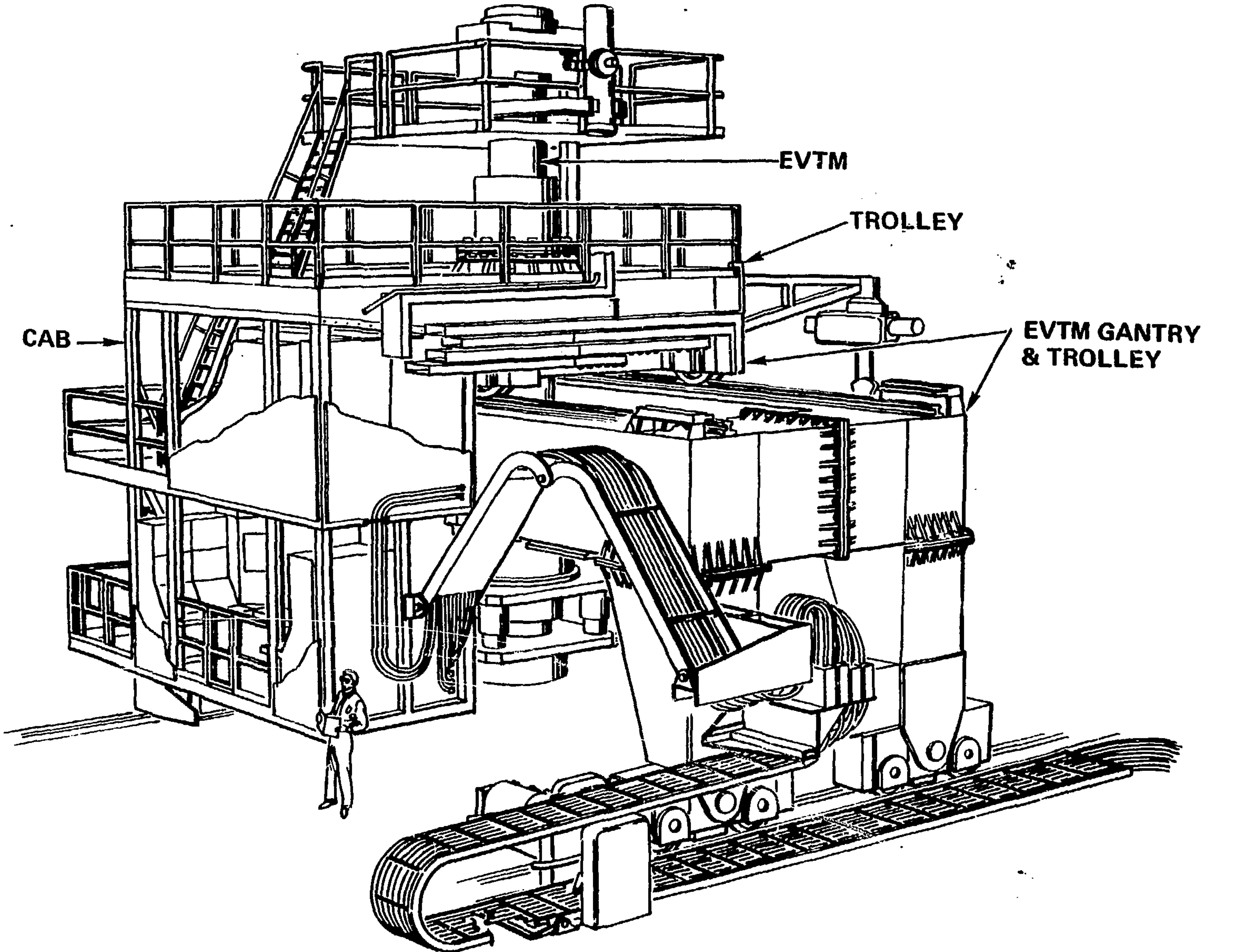

Figure 2. EVTM Gantry-Trolley

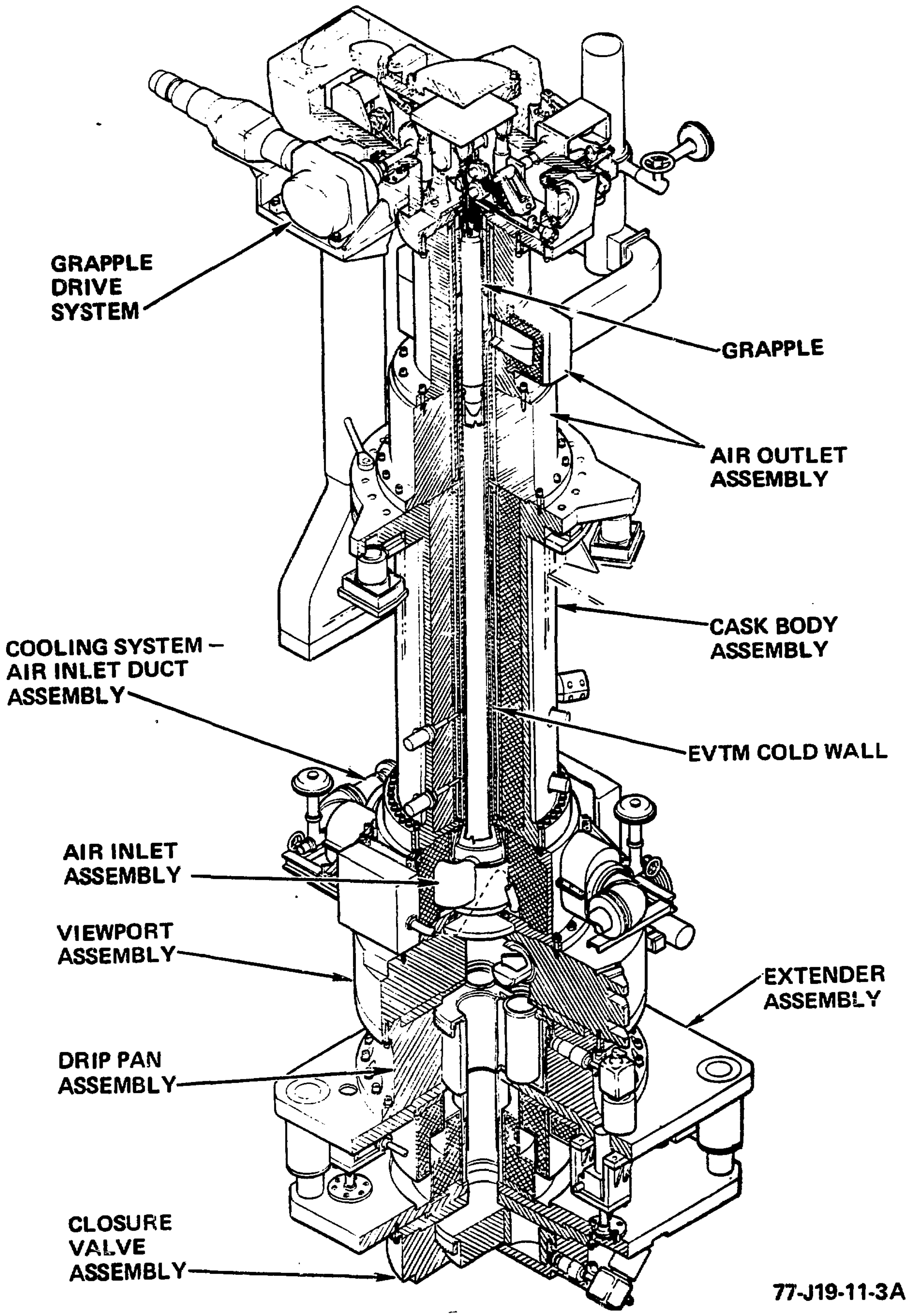

Figure 3. EVTM

4) The cold wall

5) The cooling system

6) The air outlet module

7) The cask body module

8) The air inlet module

9) The viewport

10) The drip pan module

11) The extender

12) The closure valve

13) Platforms and ladders

14) Instrumentation and control.

The grapple drive system uses redundant load chains and a grapple release chain, as shown in Figure 4. The three chains are carbon steel crane-type chain. The core assembly grapple and CCP grapple are interchangeable on a common grapple upper assembly. Grapple exchange is accomplished in the FHC.

The EVTM cooling system, shown in Figure 5, uses one blower to force cooling air into the air inlet module, up between the cask body module and the cold wall, out the air outlet module, and up the exhaust duct. The backup cooling system utilizes natural convection of air through the same flow path.

Decay heat from irradiated core assemblies is transferred to the CCP by convection and conduction of the sodium in the CCP. The heat is hence transferred by radiation and conduction across the argon-filled gap between the CCP and the cold wall. The exterior of the cold wall is finned to improve heat transfer to the cooling air. Heaters are attached to the outside of the cold wall to maintain preheat of new core assemblies. The inside of the cold wall is coated to enhance the emissivity.

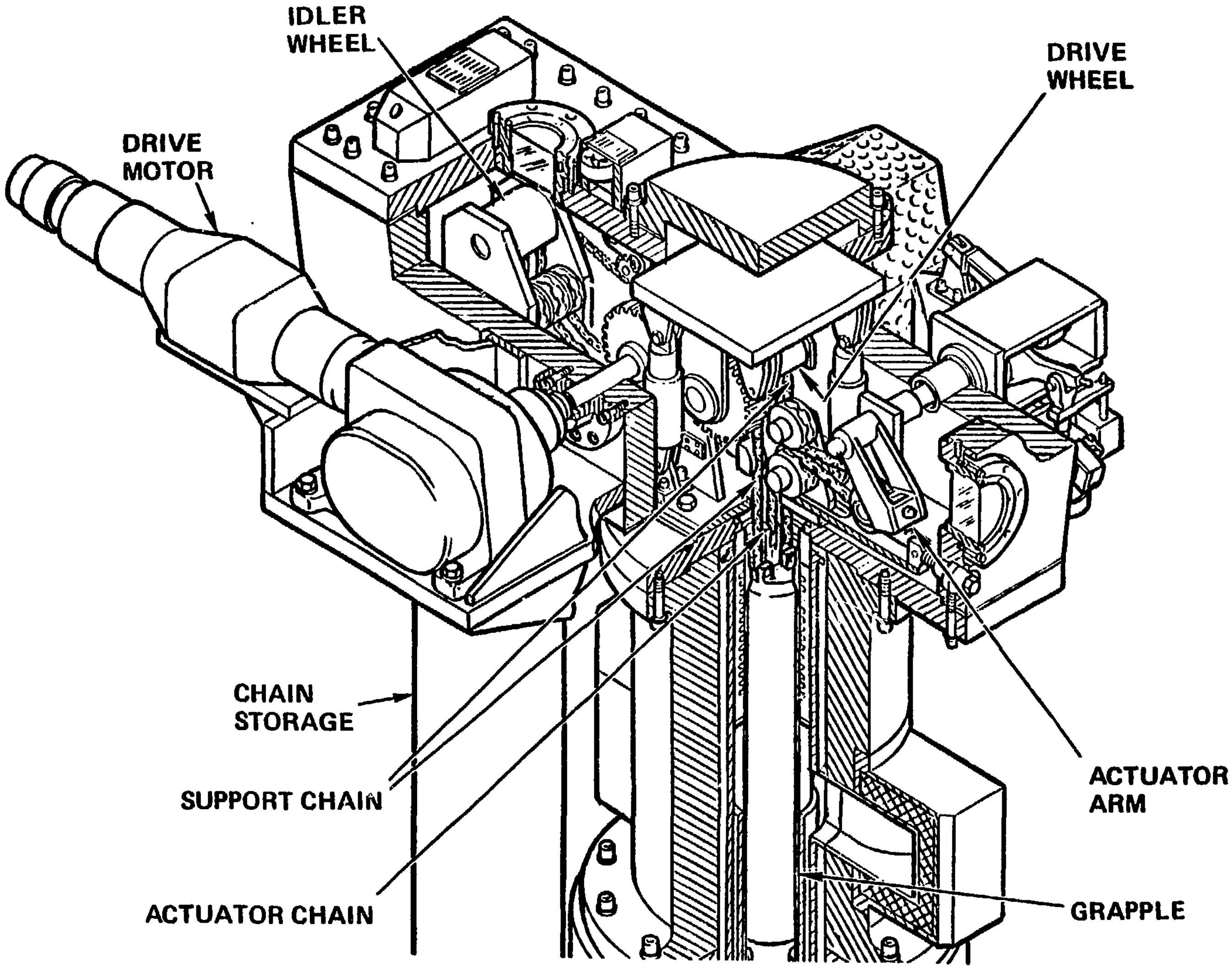

Figure 4. Grapple Drive System

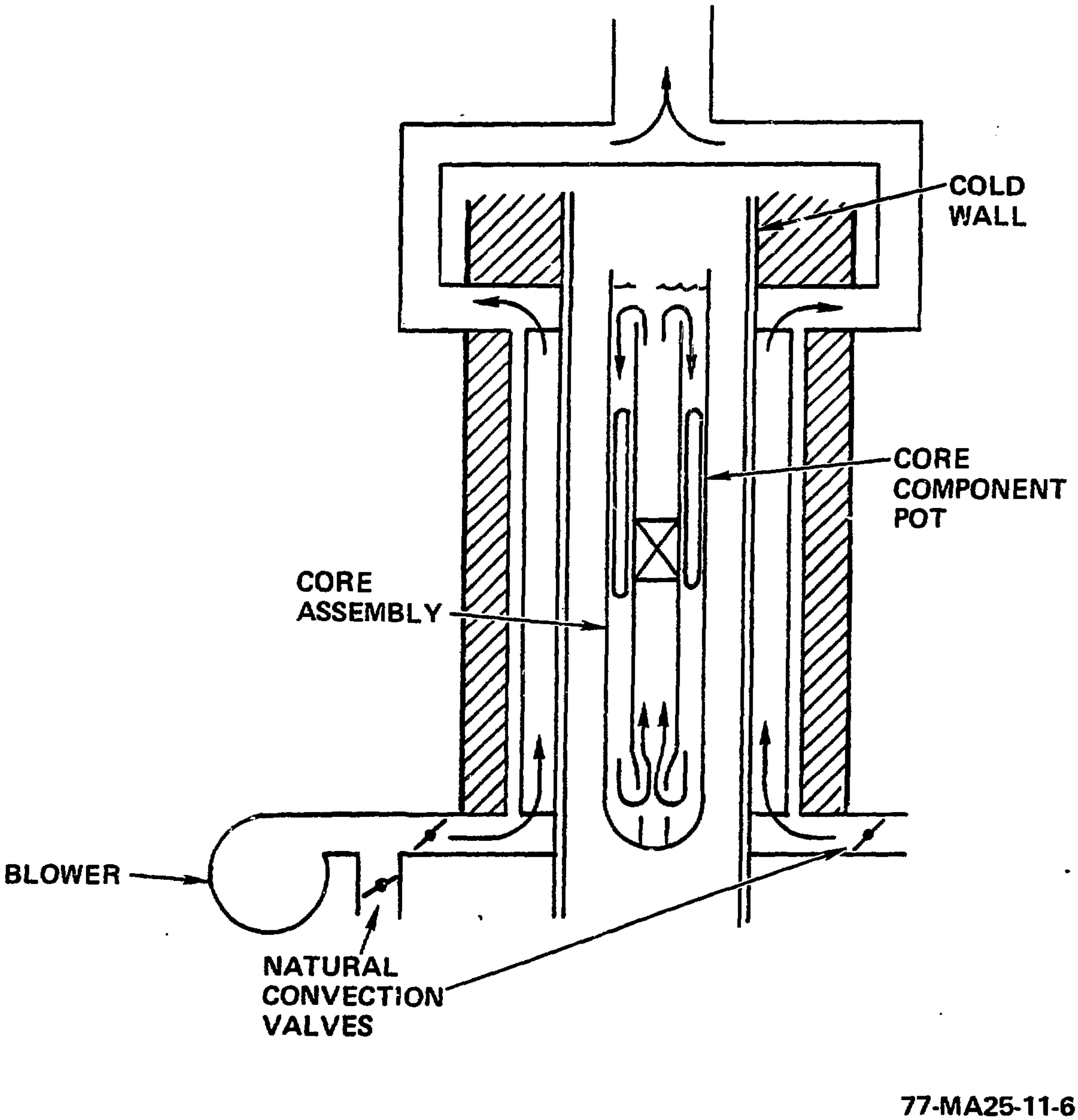

Figure 5. EVTM Cooling System

The viewport assembly is a stainless steel forging which contains an offset video camera and mirror assembly. The camera and mirror assembly rotates to view either a drip pan or the side of components passing through.

The drip pan module contains a rotor in which three drip pans are mounted. The rotor is sized to contain the sodium from a CCP in the unlikely event a CCP would leak. Each drip pan contains 18.75 liters (1144 $in.^3$). The rotor through-port allows removal and replacement of the drip pans. Sodium level in the drip pans is monitored by the viewport camera. Heaters are provided to melt sodium in the drip pans, if required, to facilitate grappling.

Development of a CCP syphon, shown in Figure 6, resulted in a design which empties the upper portion of sodium in the CCP to allow for thermal expansion of the sodium without overflow during normal transfers from the reactor to the EVST. Minimizing sodium overflow reduces the time required for sodium evaporization, and thereby enhances the overall heat transfer.

The extender assembly elevates and lowers the closure valve to mate with the floor valves. Redundant bellows form the pressure boundary. Screw jacks, which have a nominal 22.9 cm (9 in.) stroke, lower and elevate the closure valve. Guide posts are used to maintain alignment during extender operation.

The closure valve is a rotating disk-type valve. Inflatable seals are used above and below the disk. The closure valve sockets into a floor valve. O-rings seal the two valves outside the through-port to minimize the volume of trapped gases. A pair of inflatable seals on the closure valve seal to the outside of the socket on the floor valve, and act as a backup set of seals in case of a seismic event. Vertical motion between the two valves is allowed without leakage of gas from the EVTM. Horizontal motion between the bottom of the EVTM and the ground is accommodated by

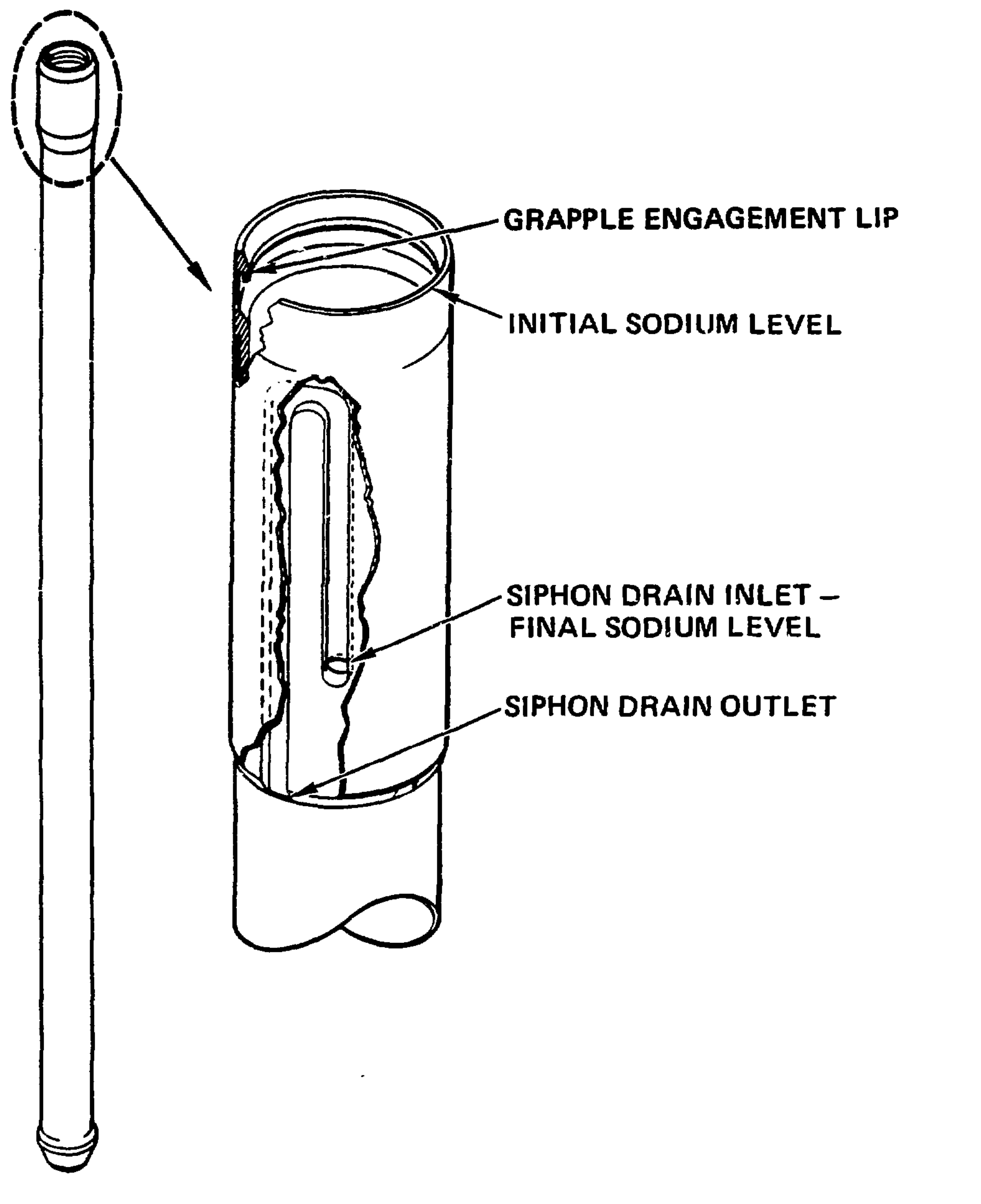

Figure 6. Core Component Pot (Containment for Transfer and Storage of Fuel Assembly in Sodium)

a slip joint between the closure valve and the extender, as shown in Figure 7. Shear pins provide normal restraint, but would allow horizontal motion in case of a seismic event to limit loads to the mated facility.

In operation, the closure valve and the lower half of the extender are lowered and rest on the floor valve. The slip joint "uncouples" the EVTM from the floor, thereby minimizing the loads from the EVTM to the floor valve.

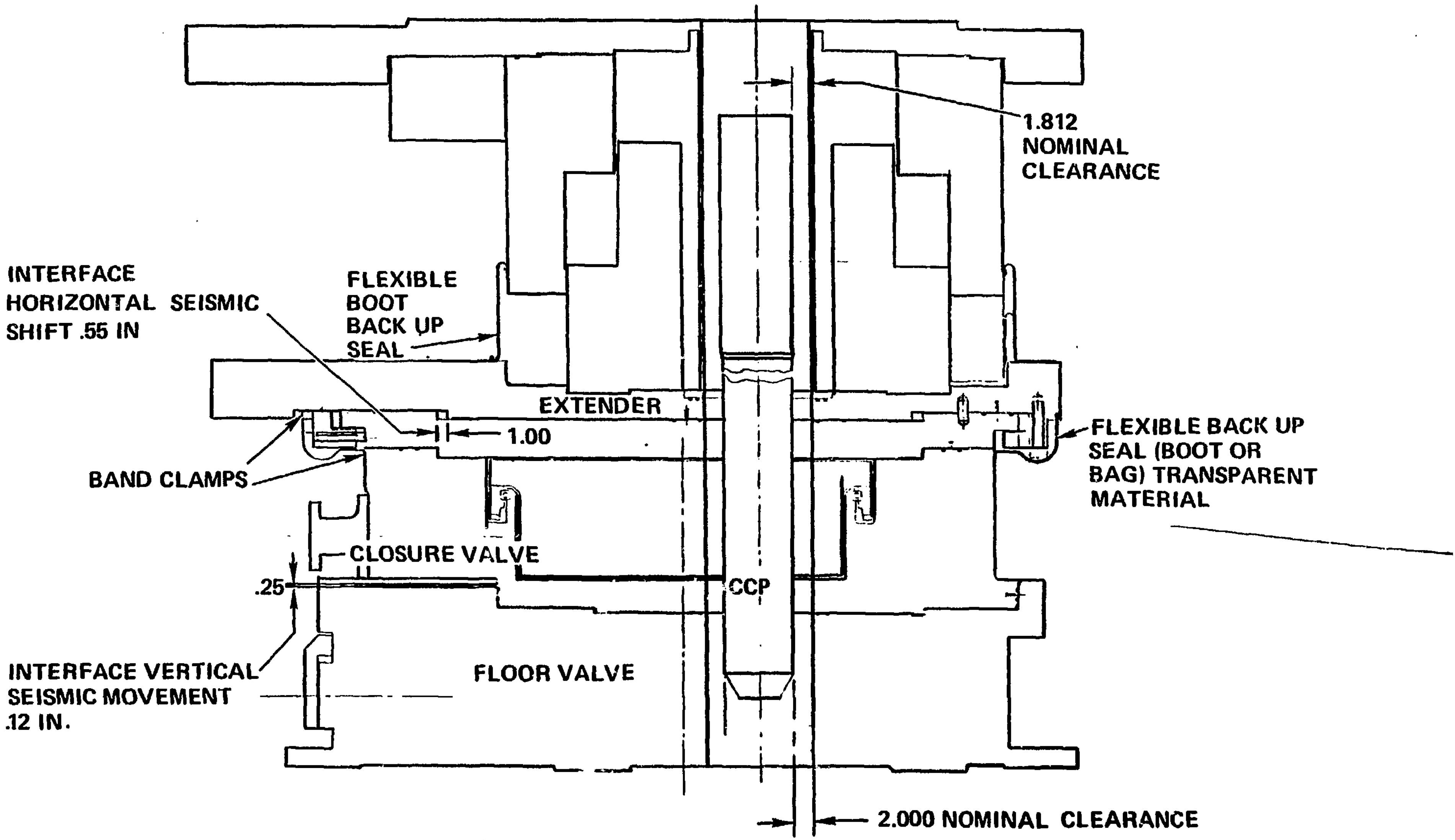

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Figure 7. EVTM Slip Joint

BACKGROUND

The initial building arrangement designs kept the entire RRS in the containment building. The EVTM concept was a tall machine of about 17.98 m (59 ft). A long grapple was used to reach the CCP's in the reactor transfer position so that the top of the grapple and the grapple chains remained out of sodium. This is the CLEM design. The gantry size varied, depending on the building arrangement. Two EVST's were under consideration, resulting in a gantry span of up to 21.34 m (70 ft), as shown in Figure 8. Initially, the auxiliary handling machine (AHM), which is used to install and remove the IVTM from the reactor, was also mounted on the gantry. Conflicting operational requirements necessitated the removal of the AHM from the gantry. The AHM is now handled by the RCB polar crane.

Means to shorten the EVTM were initially investigated as potential cost savings. Evolution of the building arrangements indicated the majority of the refueling equipment should be in a separate building, so that normal fuel handling would not be affected by reactor operation and vice versa. The smallest possible EVTM was required to minimize the size of the hatch between the two buildings. The result was a gantry with a 9.14 m (30 ft) span and 10.30 m (33.8 ft) high EVTM.

To accomplish this EVTM shortening, the grapples were shortened as much as possible. The grapple support members must be immersed in sodium, the deepest sodium depth being 5.49 m (18 ft) at the reactor. The grapple support members that are immersed in sodium will traverse through the grapple drive system. The reference grapple support member chosen was crane chain. The backup was tape. Testing of the reference chain and backup tape was required.

The chain and tape test, shown in Figure 9, was initially conceived as a confirmation of the adaption of commercial hardware to sodium - sodium vapor application; initial results were not

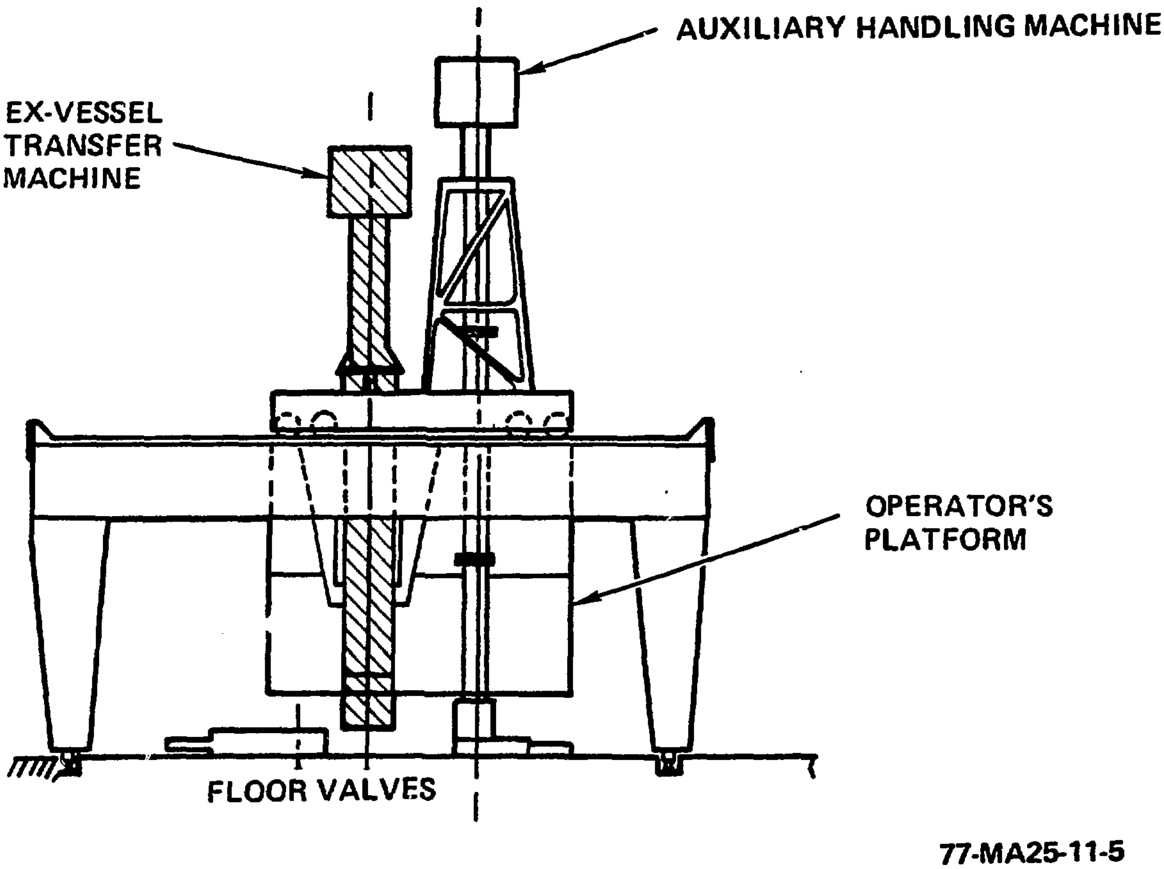

Figure 8. Fuel Handling Arrangement

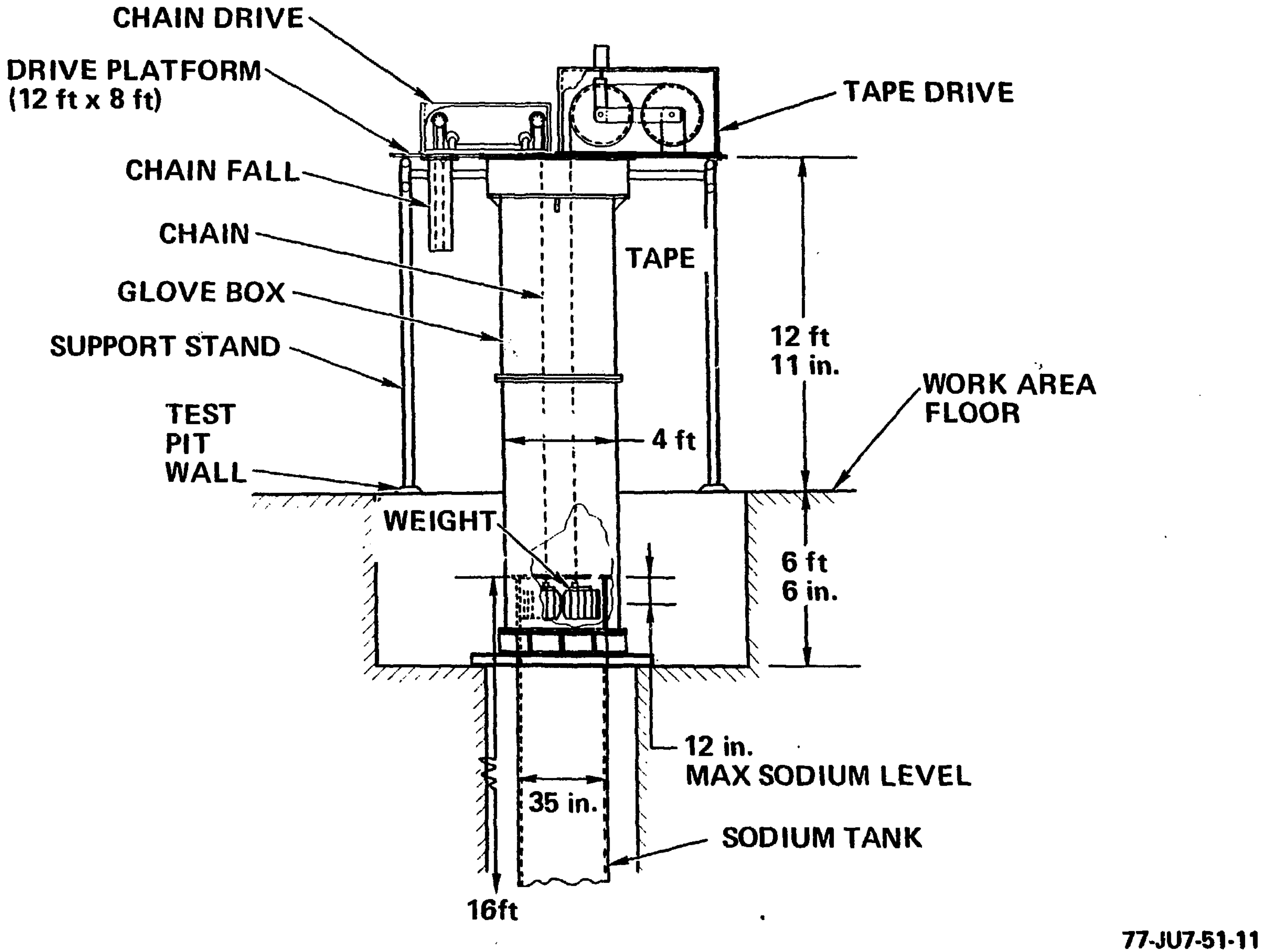

Figure 9. EVTM Grapple Chain Tape Test Fixture Layout

promising. Chains would survive several reactor refueling cycles, but would not survive one year operation in the RSB without lubrication. RSB operating lives on the order of two to four months were experienced. Sodium - sodium oxide buildup on the drive system was large, as shown in Figure 10 and 11. Testing indicated that the chains must be lubricated for extended "dry" operation as in pre-operational testing. The main contributor to chain wear was the number of loaded articulations. The design, originally a rear drive wheel with seven loaded articulations, was changed to a front drive wheel with one loaded articulation. Chain traverse through the drive train with liquid sodium exhibited about the same wear as dry-unlubricated chain. Solid sodium acted as wear inhibitor, or semi-lubricant. It reduced chain wear by an order of magnitude.

Chains, under load, operated in and out of 204°C (400°F) sodium became "wetted" with sodium in ten to twenty traverses through the drive system, as shown in Figure 12. Solid sodium mechanically transferred to the entire chain. Chain life is now in excess of ten years, provided the chains are operated in sodium prior to being operated "dry."

To deposit new core assemblies in the reactor and remove irradiated core assemblies, the EVTM would couple to the reactor, deposit the CCP, decouple and move away, rotate the reactor head, recouple to the reactor, remove the CCP, decouple and move to the EVST. Elimination of the decoupling and recoupling at the reactor could reduce reactor refueling by several days. A rotating guide tube (RGT) design was developed, as shown in Figure 13 which allows the EVTM to deposit a CCP at the reactor and to remove another CCP without decoupling. The RGT has an offset lower end which, by RGT rotation, guides a CCP or grapple to either of two adjacent reactor transfer positions.

Adoption of the RGT design necessitated the selection of the crane chain grapple support member. The grapple supports rub the sides of the RGT and must deflect in more than one plane. Tape

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Figure 10. Sodium – Sodium-Oxide Buildup on Grapple Chain

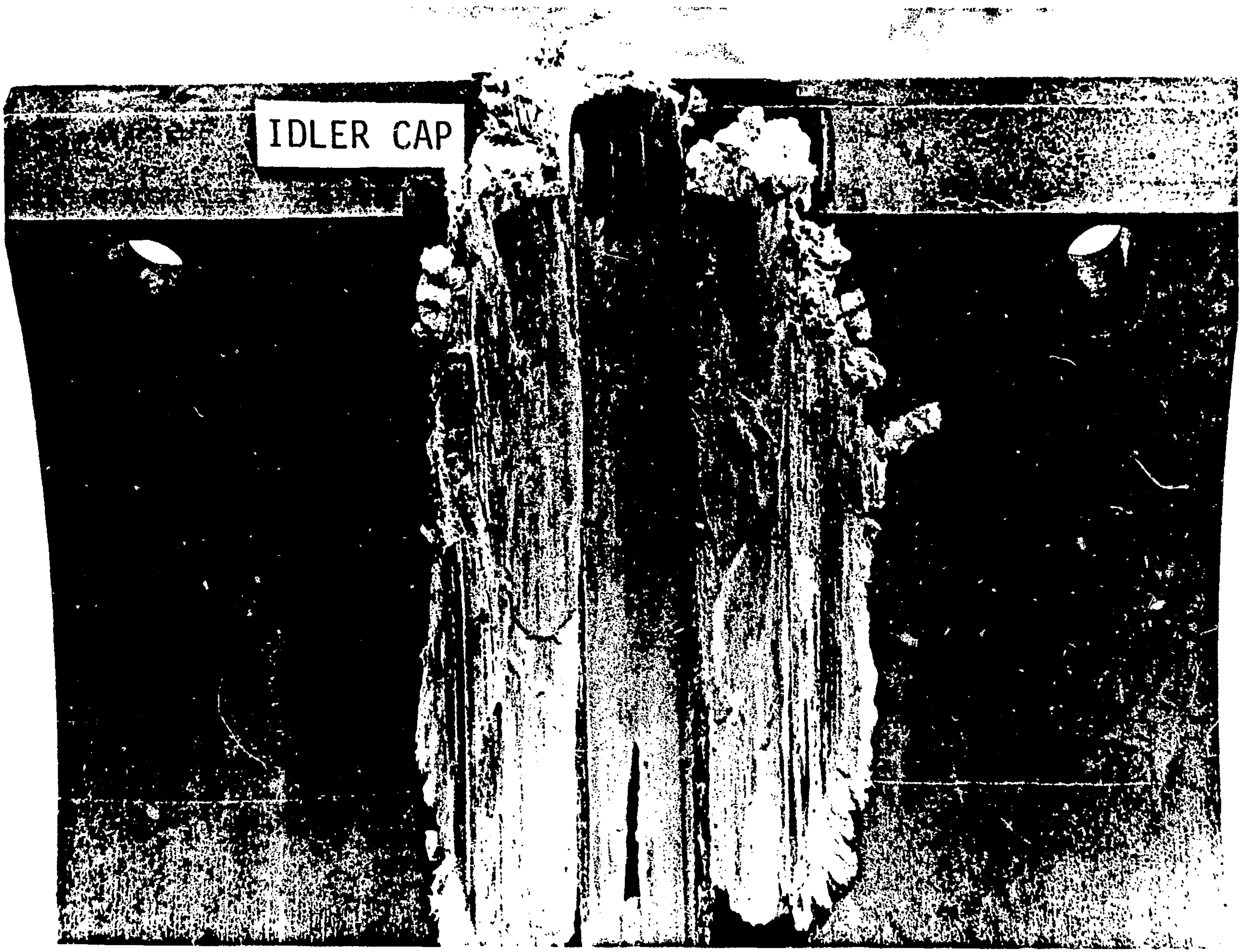

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Figure 11. Sodium Buildup on Grapple Drive Idler Cap

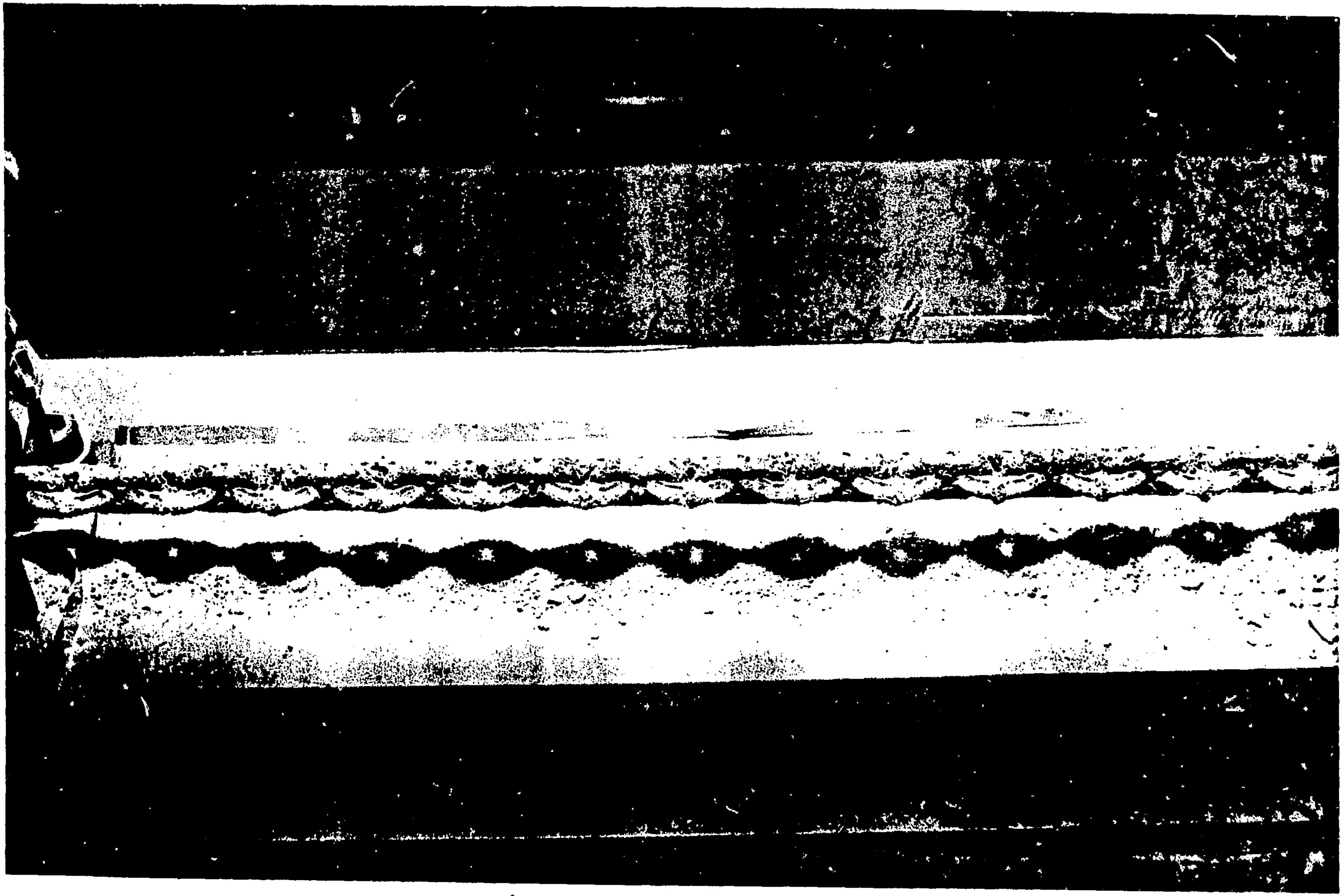

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Figure 12. Sodium Wetted Grapple Chain

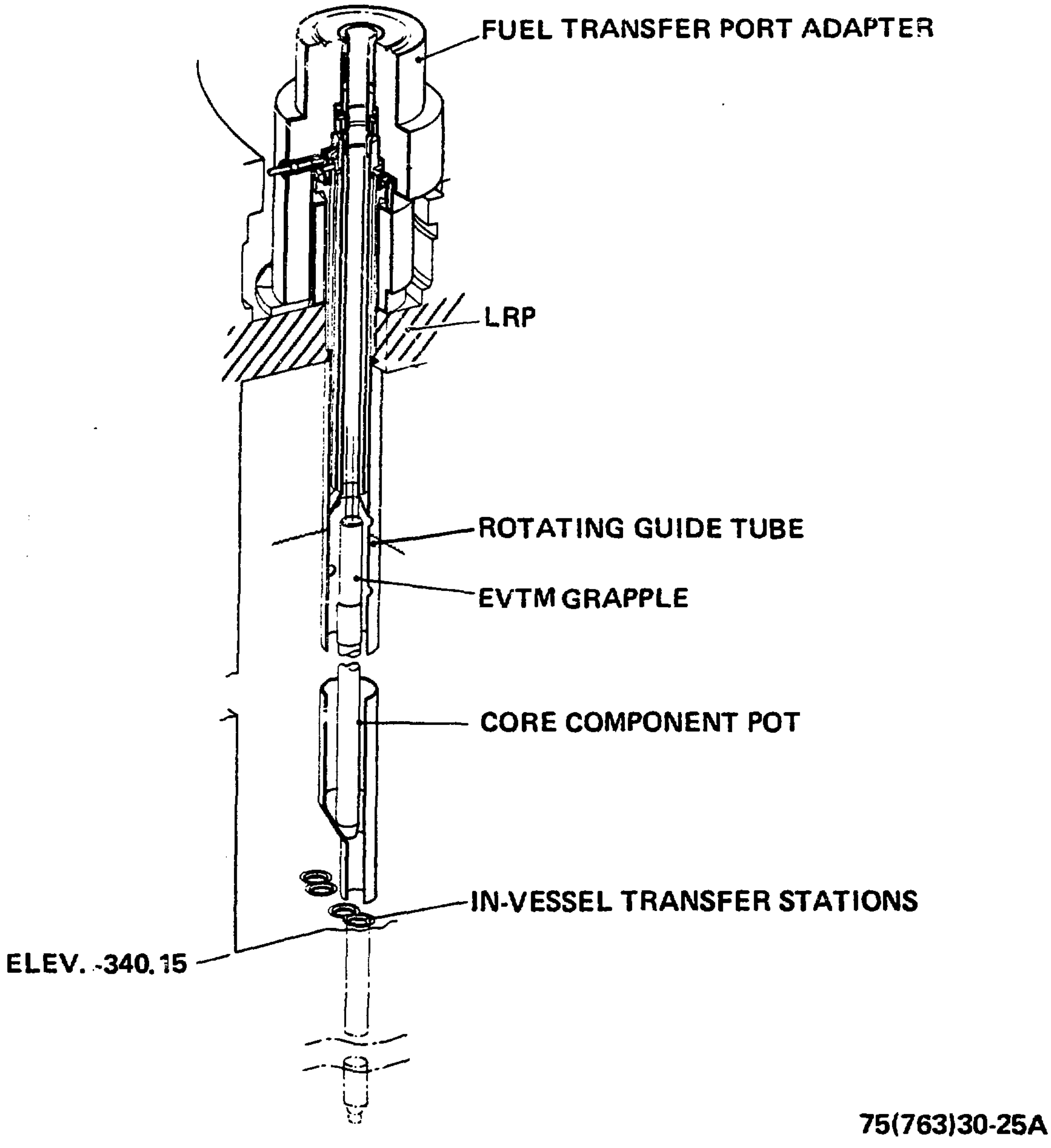

Figure 13. Rotating Guide Tube

flexes easily in one plane, but tends to buckle in other directions. Rubbing of the tapes against the RGT was questionable. Finally, a tape drive requires large diameter drums which could increase the height of the EVTM and require a larger containment building hatch size. The grapple chain-type test, therefore, concentrated on development of a chain drive.

Seismic response spectra have increased in magnitude during the conceptual and preliminary design phases. Initially, the G-T utilized the CLEM transporter seismic lock design of serrated pads which contacted serrations in the trench at the various indexing locations. The G-T wheel loads became very high during the sesmic event, resulting in rail-wheel damage or possible wheel failure. The caliper brake-type seismic lock design, shown in Figure 14 was developed to react the high loads and reduce the seismic wheel loads. These locks also serve as overturning restraints. In addition, the locks may be actuated at any location during EVTM travel. The loads on the control cab structure necessitated the addition of a similar lock between the control cab and the bottom of the gantry beam. To minimize the relative motion between the EVTM closure valve and the floor valve, locks were also required from the lower end of the EVTM (the viewport area) and the bottom of the gantry beams. With this rigidity, the slip joint became practical.

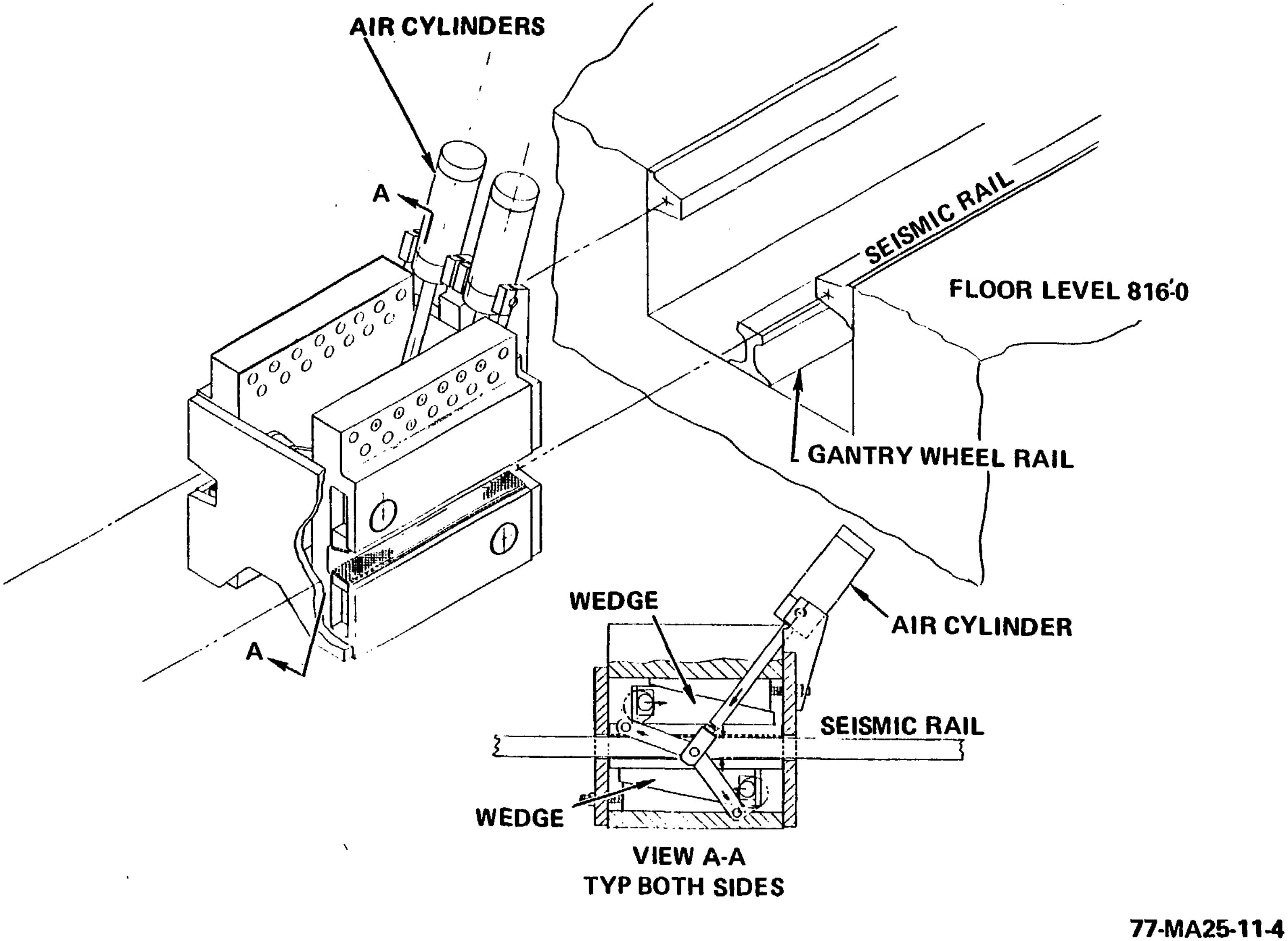

Figure 14. Gantry Seismic Clamp

THERMAL TESTING

Initial testing results have been presented in a previous paper.[2] The series of thermal tests confirmed the 20 kW decay heat dissipation capability of the EVTM without exceeding maximum cladding temperatures of 676.7°C (1250°F) during normal transfers, or 815.6°C (1500°F) for off normal (natural convection cooling). The principal uncertainties in the thermal analyses were the mode of core assembly cooling in the CCP, and the effects of sodium - sodium oxide deposits on the emissivity of the CCP and cold wall.

The subscale parametric heat transfer test indicated a weak convective loop through the fuel assembly and many strong convective loops between the outside of the fuel assembly and the CCP. This test allowed development and verification of the analytical model used during the initial phases of the design. The predictions indicated that an FFTF-sized CCP was marginal, and that a larger diameter CCP would enhance the overall thermal performance of the system. The CCP tubing was increased from 16.83 cm (6-5/8 in.) to 18.42 cm (7-1/4 in.).

The full-scale test was a combined test of the EVTM and CLEM designs. The test results confirmed the EVTM design. Results indicated that core assemblies below 4 kW may freeze sodium at the bottom of the CCP if handling times exceed normal transfer times.

The coupon emissivity and subscale emissivity tests investigated the emissivity of the CCP and cold wall, and the possible changes in emissivity due to the deposition of sodium and sodium oxide deposits. The results indicated that, during normal transfer times, the sodium would evaporate off of the CCP. In addition, the sodium buildup on the cold wall would not significantly affect the overall conductance over a one- to two-year operating cycle, and that the frost film could be effectively removed by cold wall heat-up with the heaters.

In summary of the thermal tests, specific changes to the EVTM design were not required; the CCP size was increased to enhance thermal performance. A CCP syphon was developed to minimize sodium evaporation and re-deposition. The testing confirmed the thermal models to increase the confidence of the design.

SUMMARY

Changes to the EVTM design were due to increased seismic loads and grapple support chain tests. The problems encountered have been resolved by modifications to the design to provide an EVTM design capable of meeting its initial operating and maintenance goals.

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