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Consolidated Fuel Reprocessing Program

REMOTE MAINTENANCE FOR A NEW GENERATION OF HOT CELLS

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ABSTRACT

For several years the Consolidated Fuel Reprocessing Program (CFRP) at Oak Ridge National Laboratory (ORNL) has been developing facility concepts, designing specialized equipment, and testing prototypical hardware for reprocessing spent fuel from fast breeder reactors. The major facility conceptual design, the Hot Experimental Facility, was based on total remote maintenance to increase plant availability and to reduce radiation exposure. This thrust included designing modular equipment to facilitate maintenance and the manipulation necessary to accomplish maintenance. Included in the design repetoire was the development effort in advanced servomanipulator systems, a remote sampling system, television viewing, and a transporter for manipulator positioning. Demonstration of these developed items is currently ongoing, and the technology is available for applications where production operations in highly radioactive environments are required.

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INTRODUCTION

For several years the CFRP at ORNL has been developing facility concepts, designing specialized equipment, and testing prototypical hardware for reprocessing spent fuel from fast breeder reactors. A perceived lack of need for breeder reactors has delayed the construction of a reprocessing plant that would verify the technical and economic advantages of the developments that have evolved. However, many of the research efforts have continued because these development activities had a broad application in areas where hostile environments were encountered. In particular, a comprehensive remote system technology development has produced new concepts and prototypical equipment.[1] Much of the experience gained by the CFRP is applicable to any new large hot-cell production facility and, therefore, should be of interest to any upgrade of an existing large hot cell or for new facility design.

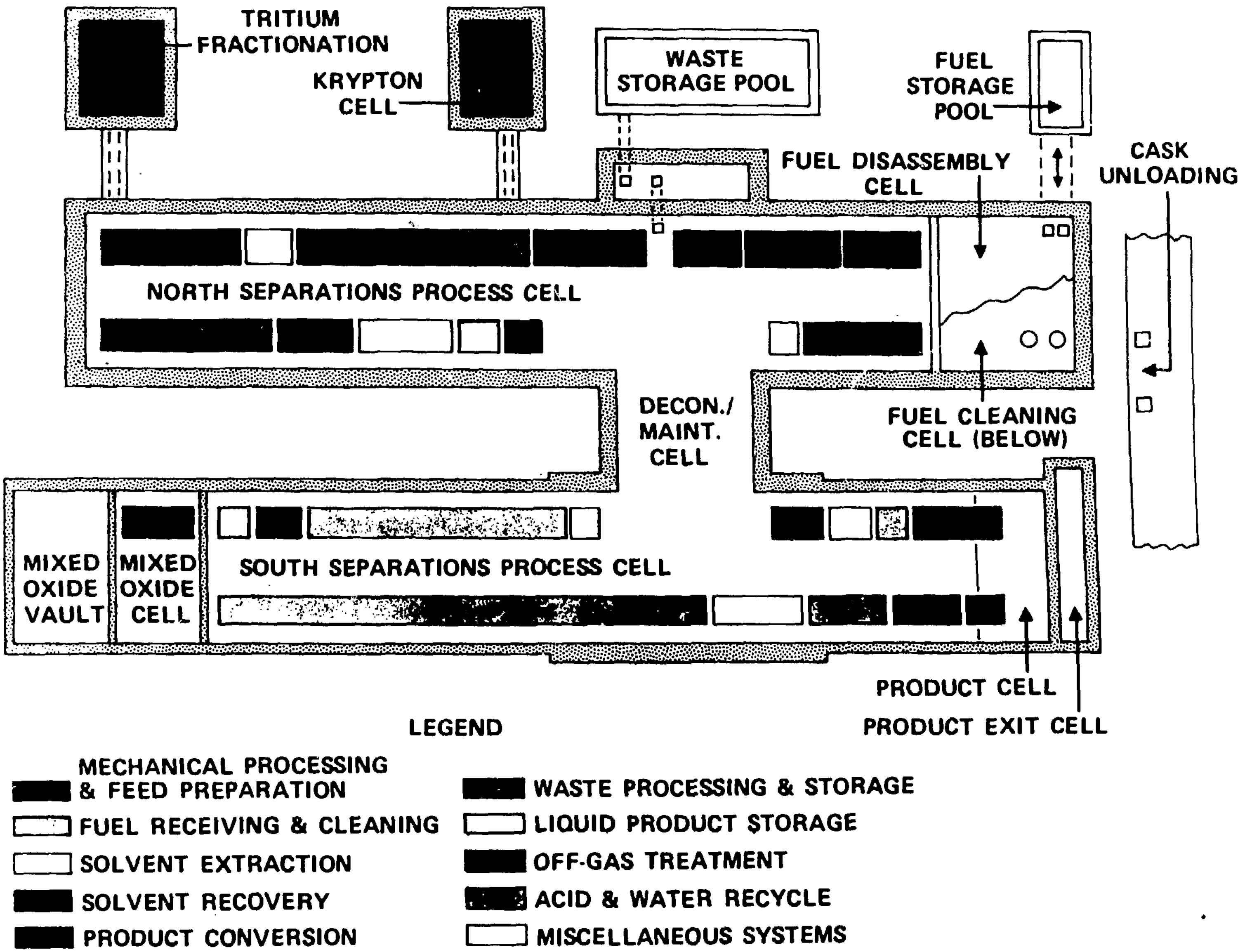
In preparing for a reprocessing facility design, several goals were established. Two of these goals, increased plant availability and reduced radiation exposure, played a major role in the decisions on the approach to remote handling. The major facility design completed by the program was the Hot Experimental Facility (HEF). The HEF was capable of reprocessing 0.5 metric tons of heavy metal per day from any light water reactor or liquid metal fast breeder reactor in existence or under consideration (in 1978). The hot cell was "H" shaped, with each of the "legs" an open cell (no partitions). These cells contained over 100 equipment racks for the chemical processing as well as a mechanical head end for reduction of the fueled portion of fuel assemblies into acceptable feed for dissolution. The use of standardized racks to house chemical and mechanical equipment provided a design basis for a unique maintenance concept and also provided a structure for the introduction of a robotic chemical-sampling system. The design was for a 30-year plant life with no planned human entry. All maintenance was to be accomplished using remotely utilizing overhead cranes along with overhead and floor-mounted transporters carrying servomanipulator systems. All viewing was by closed-circuit television systems.

The concept for HEF required several development efforts. A mockup area to test prototypical HEF equipment was built and is in operation. Existing servomanipulators were tested, and, based on their limitations, a new concept for a servomanipulator that would have greater reliability and that could be remotely maintained was accomplished. The first prototype of this manipulator is currently being tested. State-of-the-art electronics that have increased radiation resistance as well as capabilities for sophisticated computer control programs were applied to this equipment. Other areas of development include radiation-hardened television cameras, wireless signal transmission, and the design of a new concept for an in-cell transporter for the manipulators. The field of ergonomics was utilized to provide the maintenance operators with the best man-machine interface.

FACILITY DESIGN

The reprocessing cell of the HEF was designed to be operated and maintained remotely and, therefore, incorporated many of the remote maintenance features to be discussed.[2] The "H"-shaped hot cell was totally open to allow the overhead bridges and floor transporters to move freely in their individual "legs" (process cells) of the "H" (Fig. 1). Each process cell was about 183 m (600 ft) long, 26 m (84 ft) high, and 12 m (40 ft) wide. The decontamination and maintenance cell (DMC), located in the

Fig. 1 HEF Plan View of Process Cells



crossbar of the "H," was approximately 22 m (72 ft) long between the process cells, 41 m (133 ft) high, and 15 m (50 ft) wide. The extra height of the DMC extended into the process cells to allow the DMC overhead crane bridge to remove trolleys from the process cell bridges for maintenance, remove the process cell bridges, or move a full rack to or from the rack transfer station in the DMC to or from a process cell.

Equipment racks (Fig. 2) were positioned on both sides of the process cells, leaving a center aisle for travel of the manipulator transporters and crane-carried loads. The transporters and the overhead cranes and telescoping tubes provided the remote maintenance capability. Each floor and overhead transporter carried a package consisting of a pair of servomanipulator slave arms, a 455-kg (1000-lb) hoist, and television cameras. Multiple units were located in each process cell to ensure a redundancy of maintenance capability and to provide a means of repairing one unit with one of the other units. In addition, the floor transporters could be moved through the DMC to the other process cell if necessary.

The facility had a 30-year design life, and anything that was estimated not to need maintenance during that period was welded to the rack frame. Everything else was remotely replaceable. For example, the shell of a heat exchanger would be welded to the frame, but the tube bundle would be supported from a flanged head so that it could be removed if any of the tubes developed a leak. All fluid tubing/pipes and electrical/instrument wiring were connected to removable equipment by remotely removable jumpers. All the removable items were located so that the servomanipulator arms could reach them. As a last resort, the entire rack including the permanently placed equipment could be removed with the overhead system and taken to the DMC for repair.

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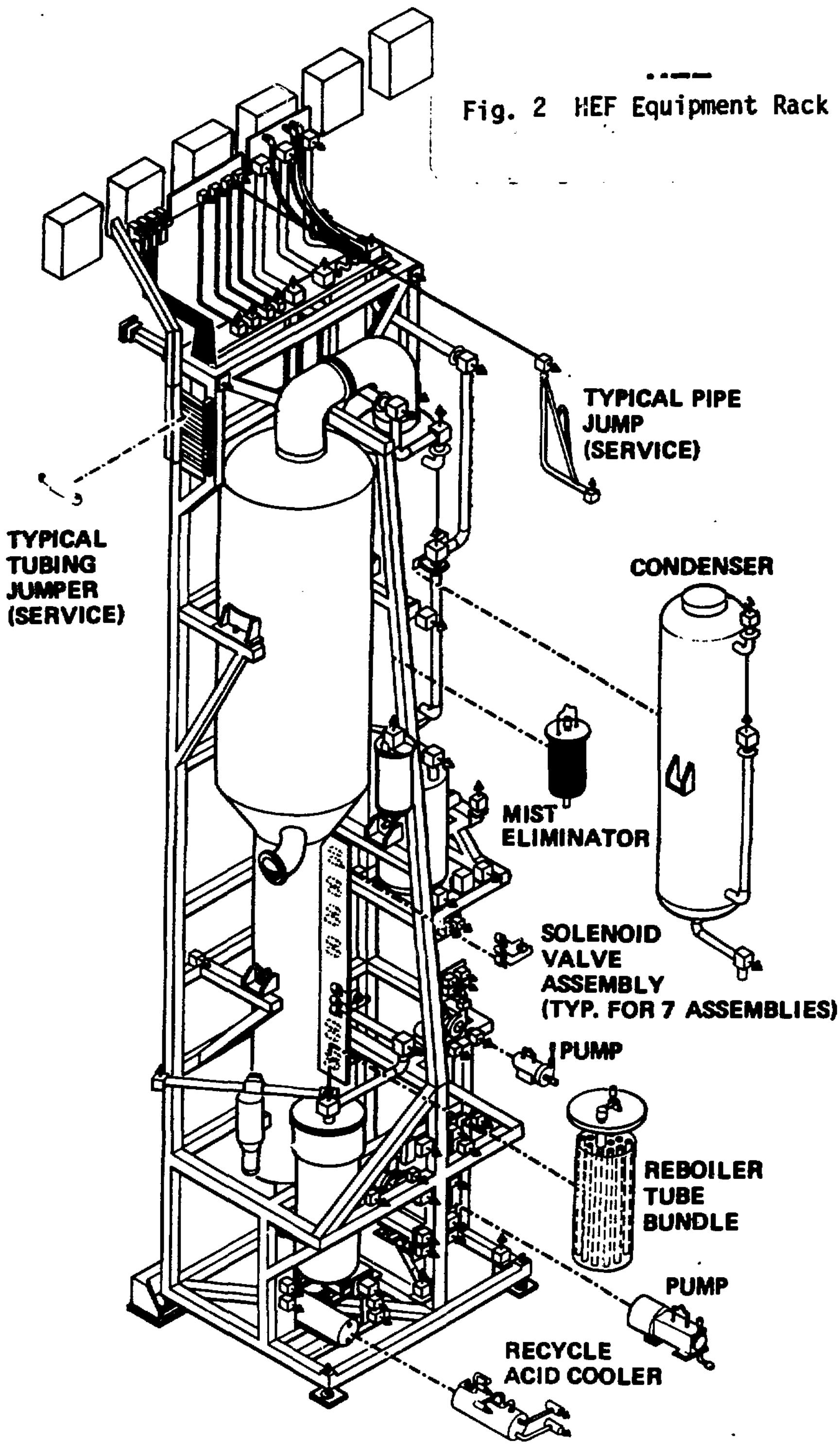

Fig. 2 HEF Equipment Rack

The HEF was designed to reduce personnel exposure levels to as low as reasonably achievable. With the remote handling features incorporated into the design, it was felt that 500 millirem/person/year was an achievable goal. One other benefit provided by this handling system was the ability to ensure remote decontamination and decommissioning at the end of plant life.

SAMPLING SYSTEM

Earlier planned and operating reprocessing facilities have routed sampling lines out of the process cell into glove boxes or shielded cubicles to obtain liquid samples of process systems. This procedure creates two serious problems: increased exposure to personnel obtaining the samples, and a potential route for the surreptitious removal of sensitive (fissionable) material from the process cell. The presence of uniform equipment racks in HEF created the possibility of locating all the sampling points at a common elevation near the top of the rack. What was needed was a robot capable of retrieving the sample bottles from the sampling points.

The advanced technology liquid sampling system is a track-guided, battery-powered, electric vehicle installed on the rack support structure (Fig. 3). The vehicle is 213 cm (84 in.) high, 91 cm (36 in.) wide, 76 cm (30 in.) deep, and weighs approximately 590 kg (1300 lb). It is of modular construction so that failed components can be removed and replaced remotely.

With the vehicle in its base station, the on-board microcomputer receives a series of locations to obtain sample bottles via wireless transmission from the master computer located in the control room. The

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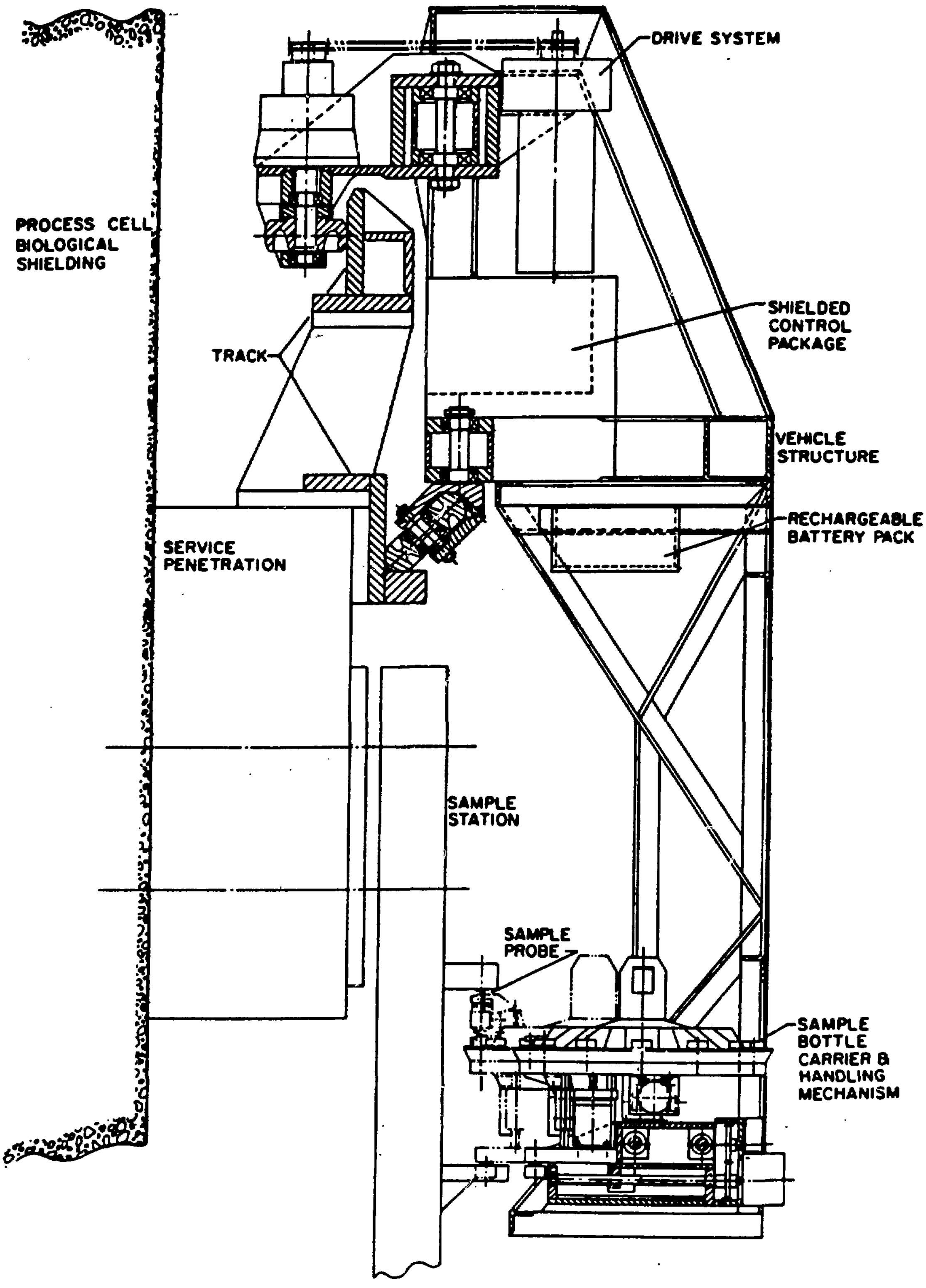

Fig. 3 Advanced Technology Liquid Sampling Vehicle

vehicle moves to the first location, retrieves and identifies the sample bottle, places a fresh bottle on the station, and moves to the next location. The sequence is repeated until the mission is completed, and the vehicle returns to its home base, where the batteries are recharged. The sample bottles are removed by a manipulator and transferred to the analytical cell by pneumatic carrier. A prototype of the sampling system was fabricated and is in operation in the mockup area. The remote maintenance features have been verified.

SERVOMANIPULATORS

Three sets of servomanipulators have been tested at CFRP, two of which were commercial units. The first was a TeleOperator Systems (TOS) Corporation Model SM-229 (Fig. 4).[3] It was used primarily for human factors evaluations of camera viewing issues and to establish the operability of completely remote systems (Fig. 5). In addition, the unit was used to evaluate signal transmission techniques, computerized obstacle avoidance, automated television tracking, and limited robotic slave functions.

The second servomanipulator is the Model M-2 purchased from the Central Research Laboratories (CRL). The M-2 was a joint development between CRL and ORNL in which ORNL developed the all-digital electronics control system.[4] The M-2 was the first successful demonstration of an all-digital bilateral servomanipulator (Fig. 6).[5] The system comprises a pair of force-reflecting servomanipulator arms, three television cameras, lighting, an auxiliary hoist, the control system, and a pair of master arms (Fig. 7).[6] The M-2 system has been operated very successfully for three years, demonstrating maintenance capability on prototype reprocessing equipment.

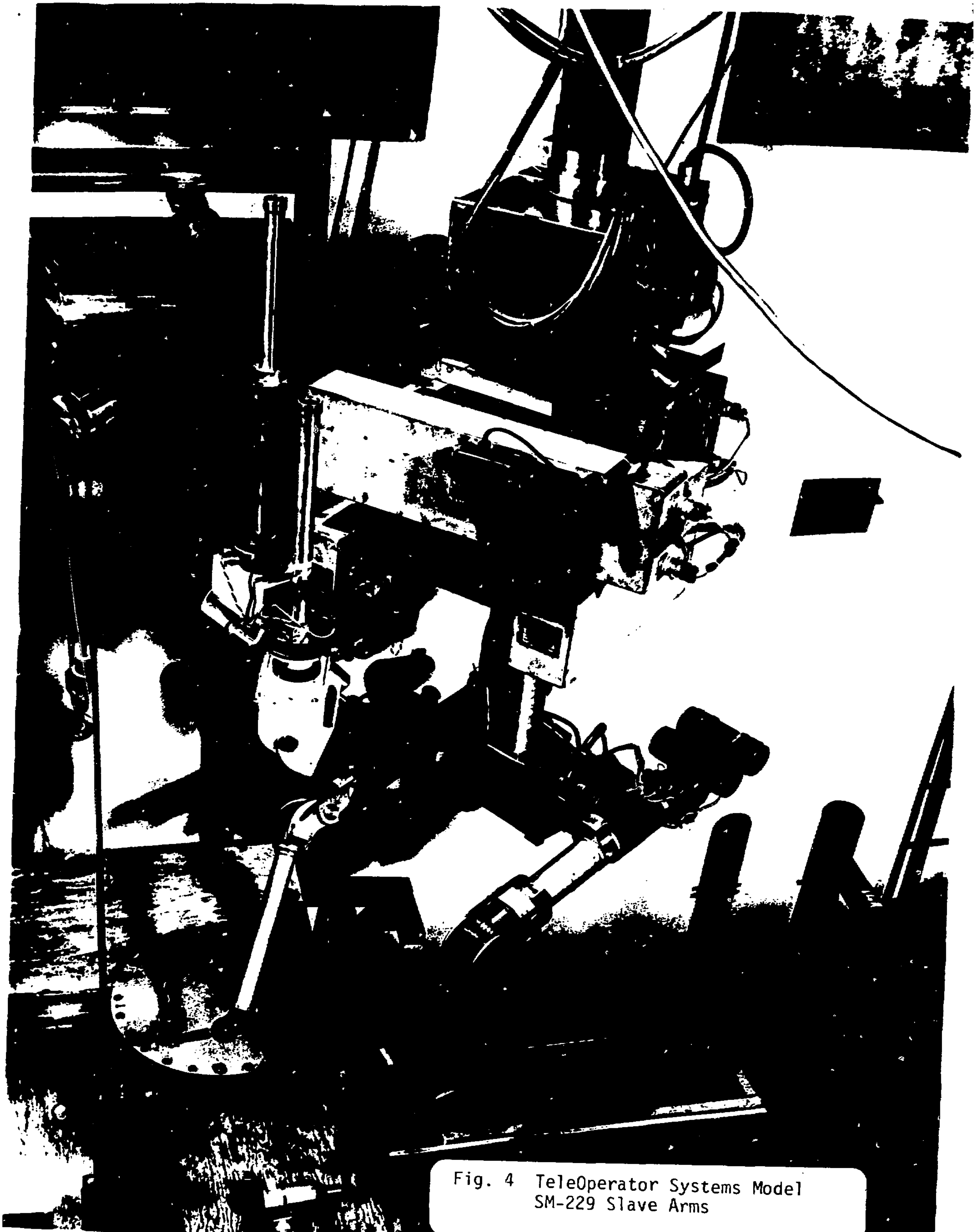

Fig. 4 TeleOperator Systems Model SM-229 Slave Arms

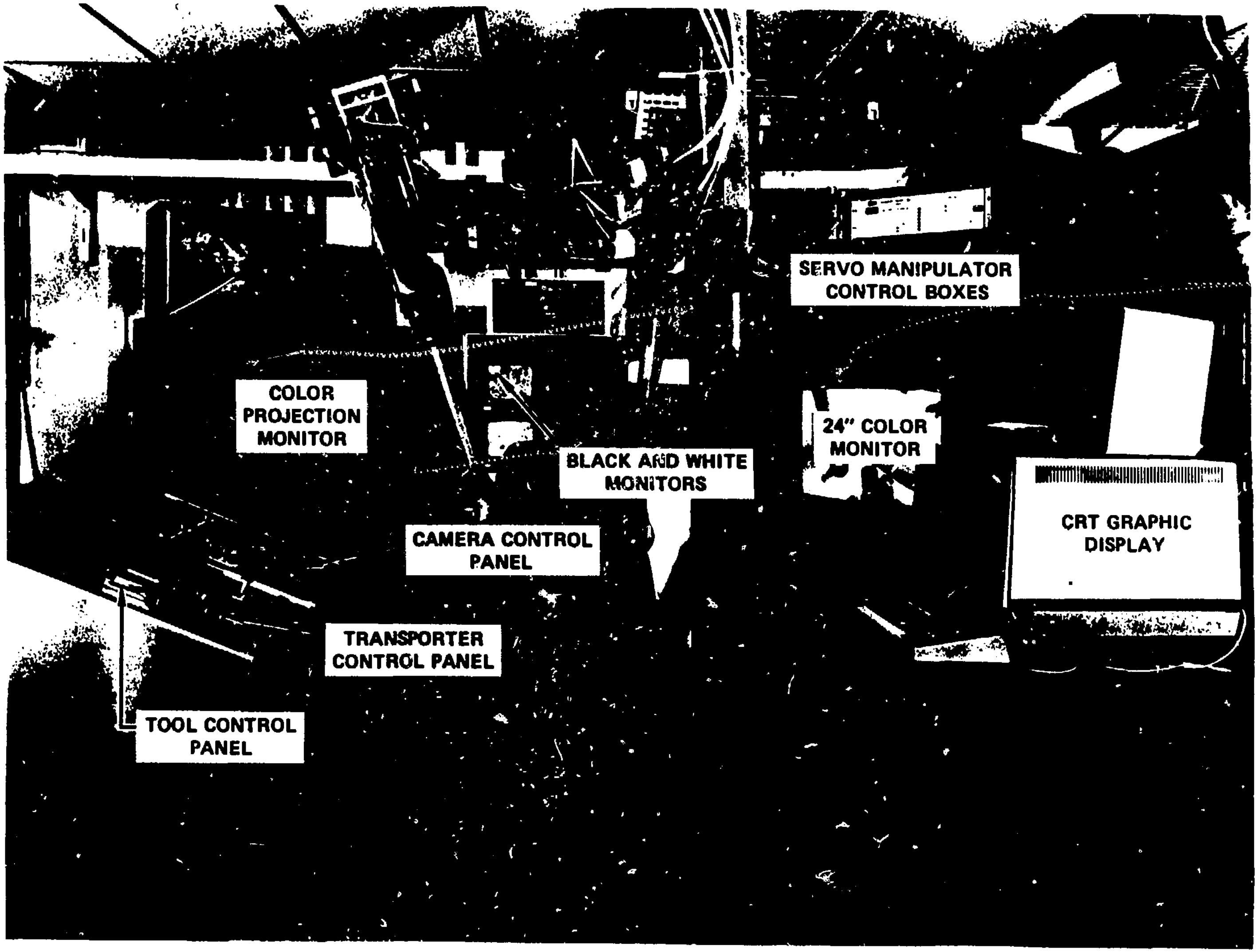

Fig. 5 Operator Control Station for SM-229 Master Arms

Fig. 6 Central Research Laboratories
Model M-2 Slave Arms

Fig. 7 Operator Control Station for M-2 Master Arms

The third unit is the Advanced Servomanipulator System (ASM). The design for the ASM slave arms is based on the use of gears and torque tubes to replace the more normally used tendons of metal tapes and cables in the drive train and is in the elbows-down configuration.[7] This geared approach facilitates modularity so that the slave arms can be repaired in situ by another ASM via spare module replacement (Figs. 8 and 9). The geared approach also increases reliability, but at the expense of increased inertia, friction, and backlash. To help compensate for these negative factors, the replica master arms are extremely light weight and are cable driven (Fig. 10).[8] In addition, digital control algorithms are used to moderate the effects of the negative factors. The control system also provides electronic counterbalance for the slave arms.[9] The system has been in operation for over one year and has performed without problems.

TRANSPORTER

For many years the typical stiff-arm transporter for hot cells has consisted of a series of internally nested concentric tubes, the largest tube at the top, and the smallest tube at the bottom supporting the manipulator. As the weight of manipulator arms has been increased, the tubes have been made larger, thus making it more difficult to maintain rigidity. In addition, the highest reach is limited by the length of the top tube. The CFRP investigated the stacker/retriever crane concept for use as a transporter for the ASM. The design had to be modified so that the transporter would be remotely maintainable, and an interface package was added to support the television systems and the hoist (Fig. 11).[10] With this design, rigidity is excellent, and the ASM can reach from the floor to the bottom of the overhead bridge. The negative aspects of the

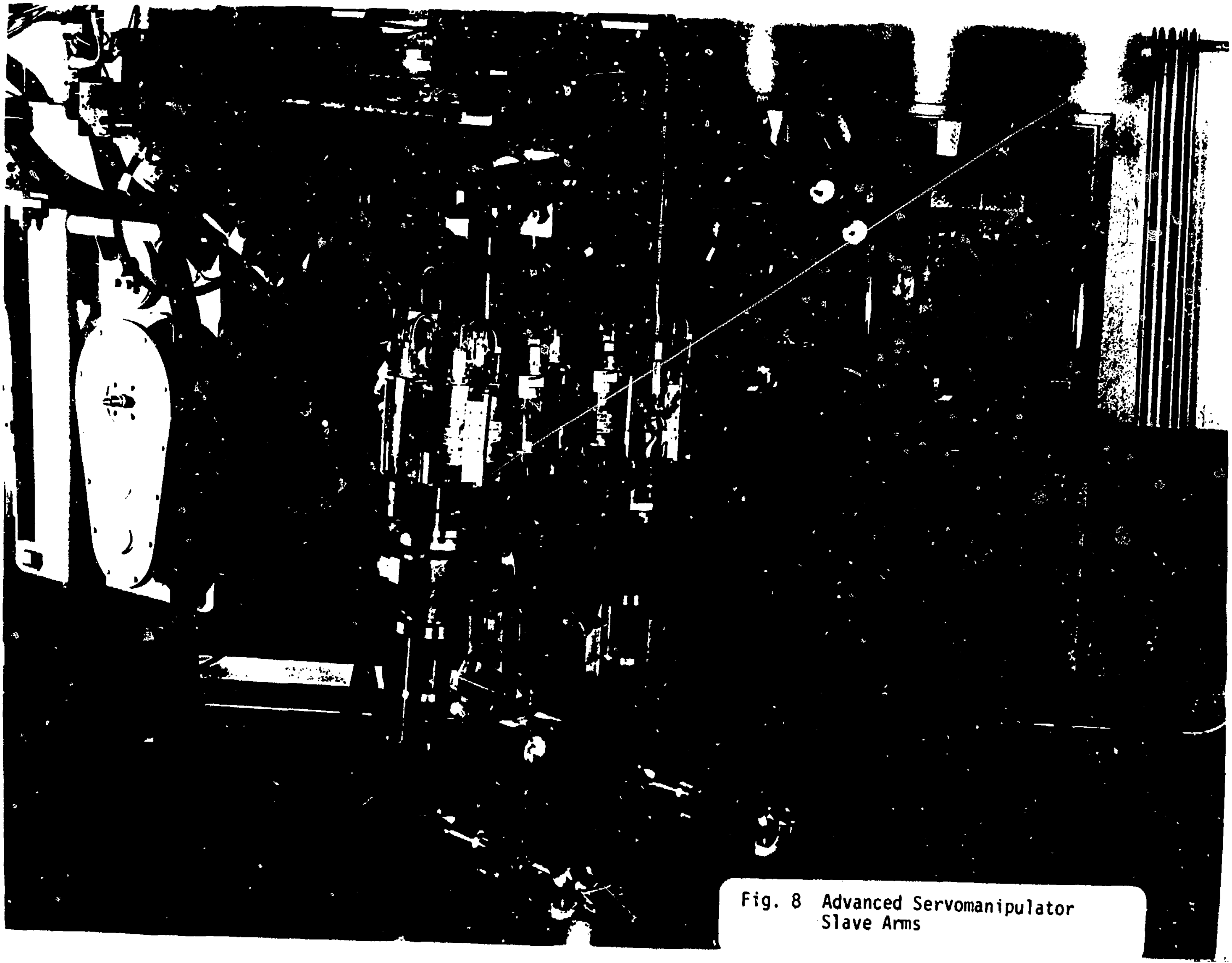

Fig. 8 Advanced Servomanipulator Slave Arms

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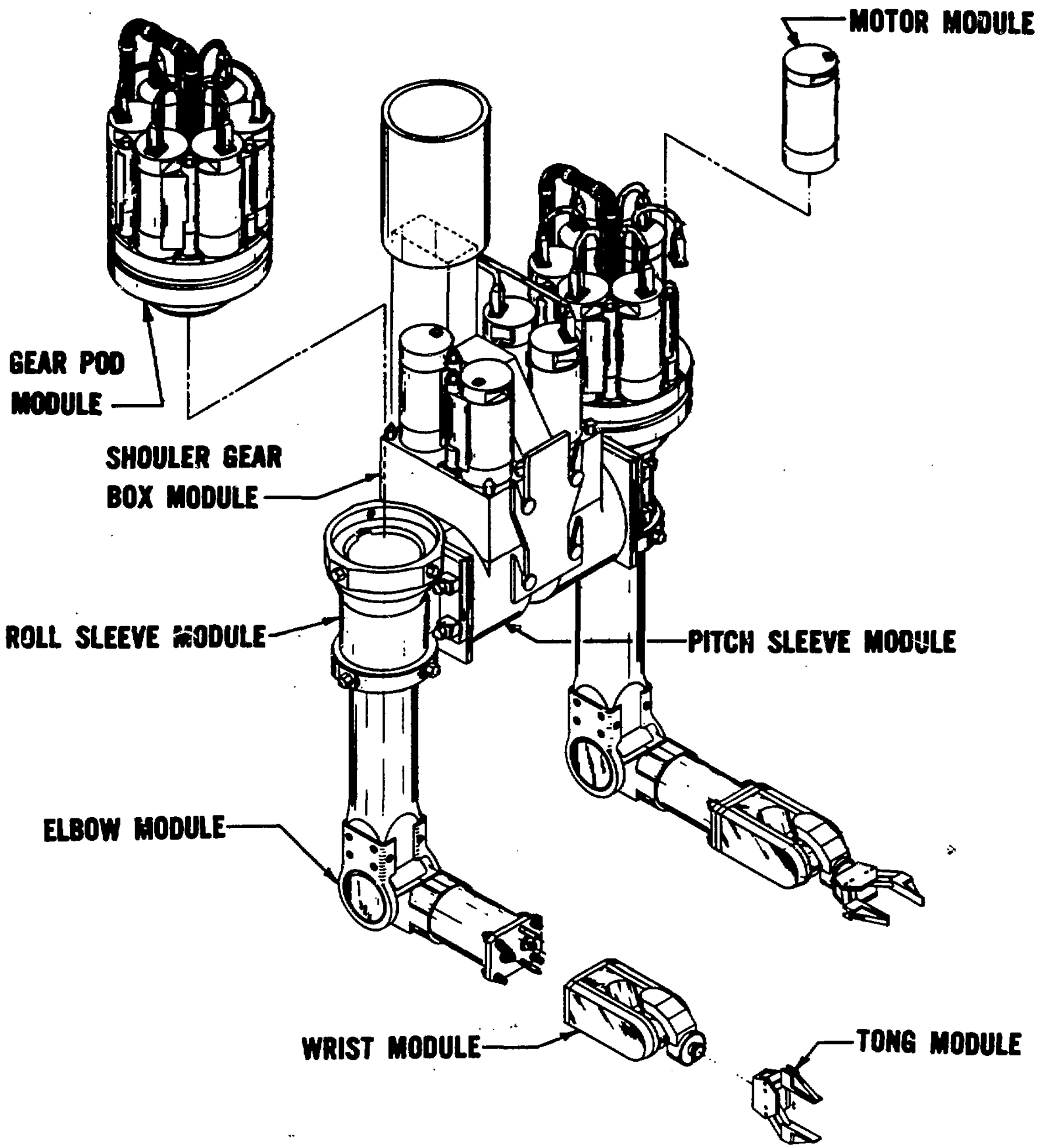

Fig. 9 Advanced Servomanipulator
Slave Arms

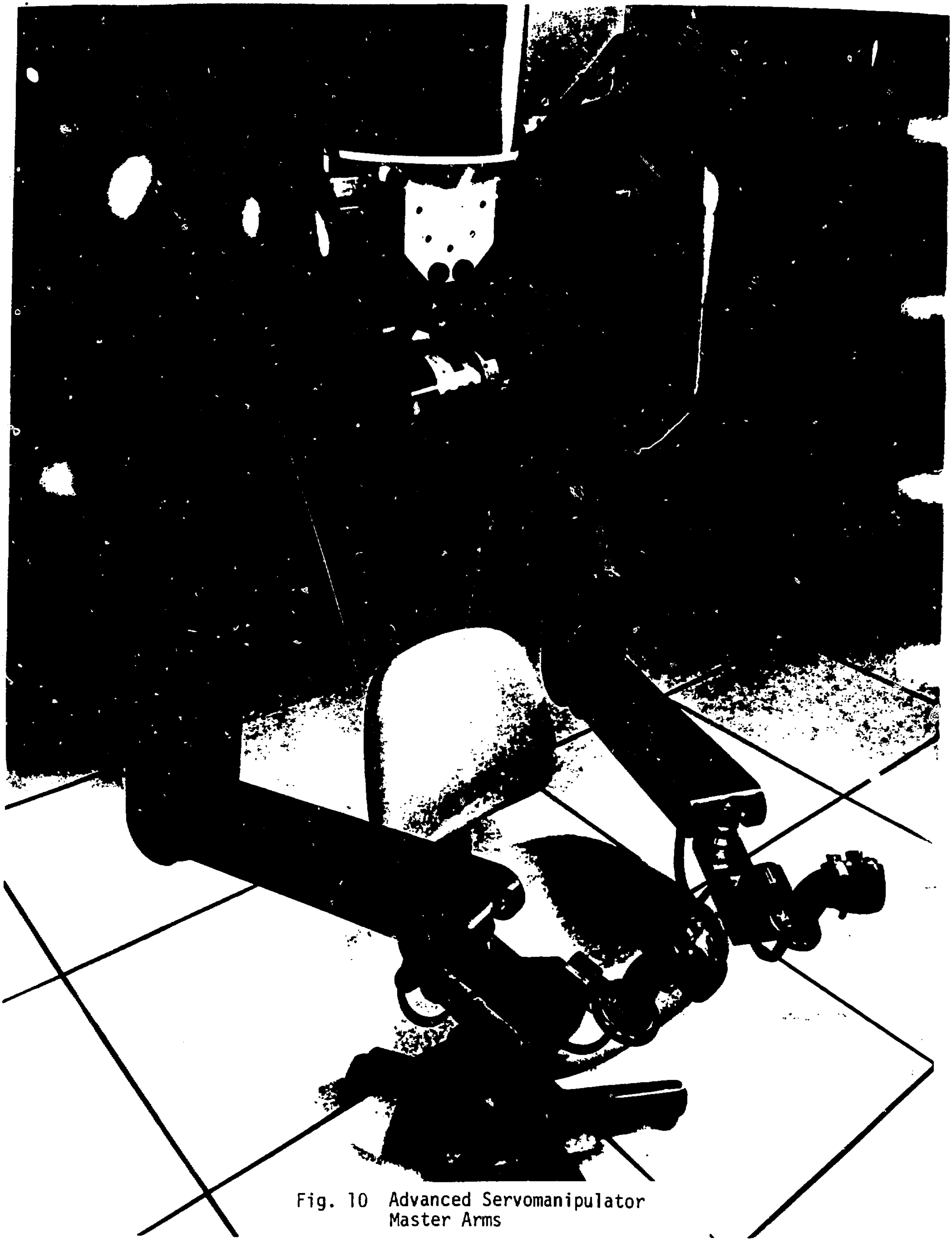

Fig. 10 Advanced Servomanipulator Master Arms

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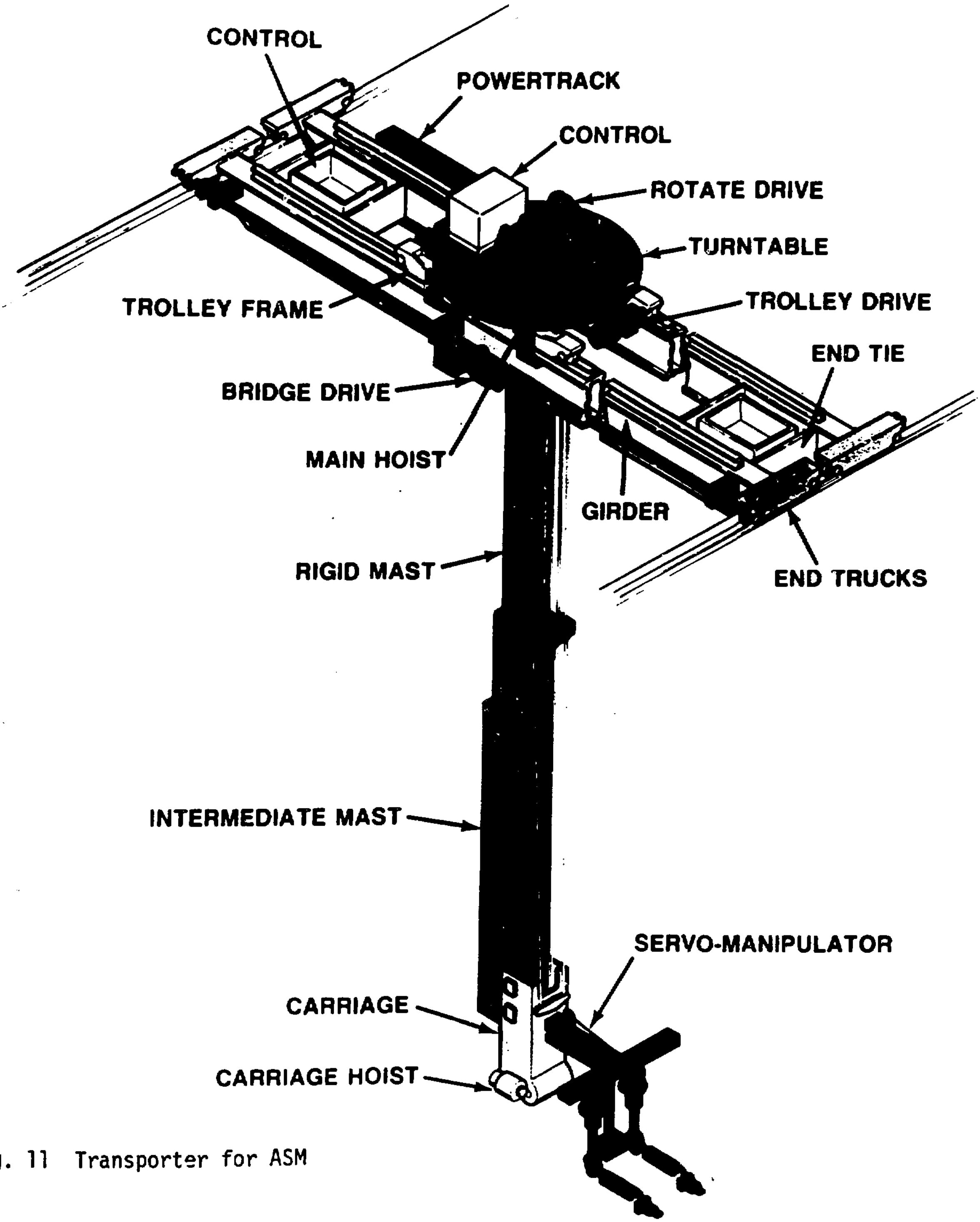

Fig. 11 Transporter for ASM

design are that the unit is larger and that there is a fixed mast whose length must be slightly over half the distance between the bridge and the floor. This means that the transporter must have an aisle in which to travel. The transporter has been operating in concert with the ASM for over one year.

VIEWING SYSTEMS

The use of servomanipulators dictated the need for radiation-resistant television systems. Because the cameras must be reasonably close to the slave arms, the entire camera must be radiation hardened when applied to large, mobile systems. Tests showed that operators could perform maintenance on stainless steel equipment as well with black and white systems as they could with color systems and that 3D systems resulted in operator fatigue.[11] An extensive review of commercially available black and white cameras was conducted. Although a number of camera systems are available with advertised radiation resistance to a dose of 10^8 rad, many of the vendors cannot document this radiation resistance with test data. In addition, almost all the available radiation-hardened cameras depend on the concept of remoting the majority of the electronics outside the radiation area. This approach requires complex cabling, usually with a separation limitation between the camera head and control electronics of 15 to 30 m (50 to 100 ft).

After the surveys of available hardware were completed, a Dage/MTI microscope camera system was selected. The control box of this camera was radiation hardened by ORNL engineers, who used a selective component replacement approach. The lens is a radiation-hardened, motorized zoom lens from Fujinon.

The entire camera system, including control electronics, has been radiation tested at ORNL and verified to be radiation hardened to doses exceeding 10^7 rad.

SIGNAL TRANSMISSION

To provide wireless signal transmission to a large mobile-maintenance system, a number of concepts have been studied. These include a confined-path radio frequency system, a free-space radio frequency (rf) system, an optical system, and an inductive system. Confined path rf and optic systems have been operated in conjunction with the TOS servomanipulator. However, the selected approach for a large cell is a free-space system using narrow-beam microwave techniques for an extremely high-bandwidth system while avoiding the multipath problem associated with normal free-space radio transmission. This type of system presents very few remote handling problems, and the associated high frequency electronic components are relatively radiation hardened. A ten-channel demonstration system has been fabricated and installed with the transporter/ASM at ORNL to demonstrate the concept. The system allows for five television, three digital data, and two audio channels over a single, bidirectional microwave link.

OPERATOR CONTROL STATION

Considerable attention was devoted to optimizing the man/machine interface for the ASM operator control station.[12] Early tests with the SM-229 servomanipulator provided the first input. Knowledge gained in operating the M-2 control room was added, and general requirements concerning human interface with control room equipment were gathered from standard human-engineering reference documents. After preparing a conceptual design for the operator control station, a foam-core mockup was built, and a wide range of our work force was tested covering the 5th percentile female to the 95th percentile male-operator population requirement. The resulting design was based on a two-person team with the primary operator handling the master manipulator controller and the secondary operator the television system and transporter and crane controls (Fig. 12). The operators are close enough for normal conversation and have a clear view of each other without obstructing their respective views of the monitors.

APPLICATION TO OTHER PROGRAMS

This paper has summarized a ten-year effort associated with designing a remotely operated fuel reprocessing facility and the equipment to maintain it. The question is: Where can this knowledge be applied in todays market? It is our opinion that what has been described can be utilized in any major production hot-cell facility such as repackaging reactor fuel for a permanent repository and for a high-level-waste vitrification plant. Some features may even be usable for the underground activities associated with a repository.

Fig. 12 Operator Control Station
for ASM

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