NAA-SR-3269
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TERMINAL STATUS REPORT FOR THE PROCESSING REFABRICATION EXPERIMENT

AEC Research and Development Report

ATOMICS INTERNATIONAL
A DIVISION OF NORTH AMERICAN AVIATION, INC.

Price $3.50. Available from the Office of Technical Services, Department of Commerce, Washington 25, D. C.

NAA-SR-3269
METALLURGY AND CERAMICS
210 PAGES

TERMINAL STATUS REPORT FOR THE PROCESSING REFABRICATION EXPERIMENT

BY

D. I. Sinizer
K. L. Mattern
E. G. Kendall

CONTRIBUTORS

J. L. Ballif	G. Gustovich	J. W. Savage
S. Berger	D. Janeves	G. L. Schalin
J. R. Foltz	F. J. Kamensky	G. L. Schmidt
T. A. Golding	T. E. Kapus	D. J. Stoker
N. P. Grisanti	D. W. Reed	G. P. Streechon

DESIGNERS

H. Bernard	C. F. Gifford	I. D. Shea
J. H. Burton	B. Granich	H. M. Spacone
R. O. Crosgrove	R. J. Grijalva	I. Villalva
B. H. Dixson	E. P. Kedzierski	F. Vonderahe
M. A. Fallandy	H. C. Lung	G. L. Young

ATOMICS INTERNATIONAL

A DIVISION OF NORTH AMERICAN AVIATION, INC.
P.O. BOX 309 CANOGA PARK, CALIFORNIA

CONTRACT: AT(11-1)-GEN-8
ISSUED: NOV 1 5 1959

DISTRIBUTION

This report has been distributed according to the category "Metallurgy and Ceramics" as given in "Standard Distribution Lists for Unclassified Scientific and Technical Reports" TID-4500 (14th Ed.) October 1, 1958. A total of 600 copies was printed.

CONTENTS

CONTENTS (Continued)

11

CONTENTS (Continued)

CONTENTS (Continued)

CONTENTS (Continued)

TABLES

FIGURES

FIGURES (Continued)

FIGURES (Continued)

I. INTRODUCTION

In the Atomic Energy Commission's program of reactor demonstrations, it has been assumed that, for a time, power reactor fuel can be processed at existing aqueous processing sites such as Oak Ridge, Hanford, Arco, and Savannah River. In the conventional chemical separation processes, decontamination factors of the order of 10^6 to 10^8 are achieved, permitting conventional unshielded refabrication of fuel elements after processing. However, in a mature power reactor economy, high burnup power reactor fuel can introduce high atomic weight isotopes, such as U^{236}, Pu^{241}, and Pu^{242}, which will complicate processing significantly.

Analytical studies of the buildup rate of fission products and fissionable isotopes in nuclear fuels, during successive cycles of power reactor operation (Appendix A), lead to the conclusion that low-decontamination processing of irradiated fuel materials would be sufficient for a power reactor fuel cycle. In certain reactor types, the increase in reactivity due to conversion of fertile material to fissionable isotopes during irradiation counteracts the loss in reactivity resulting from neutron absorption in accumulated fission products for at least six cycles of fuel irradiation. It is assumed, in the study, that no fission products except xenon are removed by low-decontamination processing of the irradiated fuel between successive irradiation cycles. Therefore, the major functions of fuel reprocessing may be the restoration of fissionable material depleted by fission during irradiation and the reconstitution of partially decontaminated fuel into elements suitable for reirradiation in the reactor.

The major factor affecting fuel reactivity is the depletion of fissionable material during the in-pile irradiation. This effect is shown in Appendix A for uranium fuels up to at least 6% enrichment. The study indicates that conventional high-decontamination aqueous processing may be unnecessary for power reactor fuels, and may even be less advantageous than proposed low-decontamination processing, from the standpoint of neutron economy.

A low-capacity, low-decontamination plant can be built, as part of a power reactor complex, to avoid long distance transfer of fuel to a high-capacity aqueous processing plant. Activation of such a complex, with the processing plant adjacent to the reactor it serves, could decrease the cost of the integrated fuel cycle. The study of this concept is a major objective of the Processing Refabrication Experiment (PRE).

Power reactor fuel processed by low-decontamination methods remains highly radioactive after processing. It is, therefore, essential that the fuel be refabricated in shielded hot cells to protect personnel. Contact maintenance of megacurie-level cells used for processing and refabricating power reactor fuel in a closed fuel cycle will be impractical when the development of a power reactor economy reaches maturity. Therefore, hot cells for fuel processing must be specially designed as a necessary adjunct to a power reactor. The special design of these cells introduces problems which can only be resolved in a large-scale engineering experiment such as the PRE.

In a large-scale engineering experiment, the feasibility of low-decontamination processing can be studied and evaluated. Problems of remote operation, handling, and maintenance of materials and equipment in the processing hot cells can be resolved. Criteria can be developed for the design and construction of equipment and facilities for low-decontamination processing of high burnup power reactor fuel. The final test of the feasibility of low-decontamination processing will be hot operation with irradiated fuel in a specially designed facility. The processed and refabricated fuel will be irradiated in successive cycles through the reactor to establish the technical feasibility of the method. Pertinent fuel cycle cost data can be generated only in such a large-scale engineering experiment.

II. PROCESSING REFABRICATION EXPERIMENT HISTORY

Intensive study of low-decontamination processing of power reactor fuels has been carried forward at Atomics International, or its predecessor at North American Aviation, Inc., for many years.[1] One low-decontamination process, the oxide-drossing of molten uranium, forms the basis for the treatment of fuel from the EBR-II reactor now under construction by Argonne National Laboratory at NRTS, in Idaho.[2] The process has been studied intensively at Argonne.[3,4,5] In this process, irradiated uranium fuel is induction melted in a zirconia or magnesia crucible. A reaction occurs between some fission products, notably the rare earths, and the oxide crucible to form a residue or dross containing stable fission product oxides. The dross remains with the crucible after the molten metal is poured. Metals such as plutonium, molybdenum, zirconium, and niobium, whose oxides are less stable than uranium oxide, remain as alloying constituents in the cast ingot after oxide-drossing. Volatile fission products such as cesium, tellurium, iodine, and noble gases are released from the melt and collected elsewhere in the system.

On the basis of promising results obtained in small-scale experiments, a large-scale engineering program, The Pyroprocessing Refabrication Experiment,[6] was proposed by Atomics International to the Atomic Energy Commission in June 1956. This development program was based on remote oxide-drossing and refabrication of uranium fuel irradiated in the experimental sodium-cooled and graphite-moderated reactor (SRE) which was designed, built, and operated by Atomics International at Santa Susana, California. A cold mockup of process and handling equipment was proposed, to develop design criteria for equipment and facilities for remote oxide-drossing and refabrication of metallic uranium fuel. The cold mockup was to be followed by the design, construction, and operation of a facility for processing highly radioactive irradiated SRE fuel.

The PRE program was activated under AEC sponsorship in July 1956, as part of Contract AT(11-1)-GEN-8. Experimental work carried on under this program has been reported in several PRE Quarterly Progress Reports.[7-10] Further reports are contained in AI Bi-Monthly Technical Progress Reports.[11-18] A summary of technical progress in the PRE, during calendar year 1957, is contained in the Annual Technical Report of Atomics International.[19] All reports, publications, and technical papers referring to the PRE are listed in NAA-SR-3703, entitled "Processing Refabrication Experiment Bibliography."

As originally conceived, the PRE program was based on the reconstitution of irradiated metallic uranium fuel. However, recent experimental evidence of the poor physical stability of unalloyed uranium fuel at high temperatures and high burnup led to decreased emphasis on metallic fuel and greater emphasis on refractory fuel. In particular, UO_2 fuels showed excellent dimensional stability after long burnup and relatively high temperature exposure. Therefore, the direction of the PRE effort was changed and the program was reoriented, during Fiscal Year 1958, toward the development of equipment, methods, and techniques for remote processing and reconstitution of highly irradiated and short-cooled UO_2 fuel. A proposal, delineating the reoriented Processing Refabrication Experiment program, appears in NAA-SR-2778.[20] In the reoriented program, shapes suitable for remote fabrication into SRE fuel rods were to be made, and SRE fuel rods were to be fabricated remotely. The remotely fabricated rods would be clustered into fuel elements for reirradiation in SRE.

Under the reoriented PRE program, engineering development, hot cave experiments, and supporting small-scale laboratory efforts were initiated at Atomics International, early in Fiscal Year 1958. The program was phased out, in the middle of Fiscal Year 1959, by AEC directive because of budget limitations. The partially completed work showed technical promise for early completion of a successful experiment in low-decontamination processing of UO_2 fuel. There is no similar work covering the scope of the reoriented PRE program now in progress by any other AEC contractor or laboratory.

III. PYROPROCESSING REFABRICATION EXPERIMENT FOR METALLIC URANIUM FUEL

The PRE program, as originally conceived, is described in NAA-SR-1670.[6] The proposal describes an engineering development program based on remote pyroprocessing and refabrication of unalloyed uranium fuel irradiated in SRE. SRE fuel, irradiated to a burnup of 3000 Mwd/t at a power level of about 20 Mwt, was to be processed in the PRE facility and refabricated into fuel elements suitable for reirradiation in the SRE.

In the first phase of the program, a series of mockup experiments on cold unirradiated uranium was proposed to develop design criteria, both for equipment to be installed in a suitable hot facility and for the hot facility itself. Process, handling, and maintenance equipment was to be designed and fabricated, and operated remotely under simulated in-cell conditions. A mockup cell was to be constructed for the development program. Successful completion of this first phase of the program would permit entering the second phase with a minimum of technical risk. In the second phase of the program, the PRE facility would be built and equipped. A cutaway view of the proposed facility is shown in Figure 1. In the program's third phase, the facility would be operated to process and fabricate highly radioactive metallic uranium fuel discharged from the SRE.

The flowsheet for processing metallic uranium in the PRE program is shown schematically in Figure 2. In the original proposal of NAA-SR-1670,[6] fuel element disassembly and assembly were to be done in the SRE hot cells. As the PRE program evolved, the concept was changed to include fuel element assembly and disassembly in the PRE hot cells.

The processing and fabrication of irradiated SRE fuel and the maintenance of process, fabrication, and handling equipment are carried out in a complex of three cells. In the first cell shown in Figure 2, elements are disassembled and fuel rods opened for removal of irradiated fuel. Irradiated fuel slugs are charged to an oxide-drossing furnace for melting and casting into an ingot. During melting, volatile fission products and noble gases are released and carried through in-cell filters to a gas-handling system located in a shielded subcell vault. Some fission products, such as the rare earths, are removed

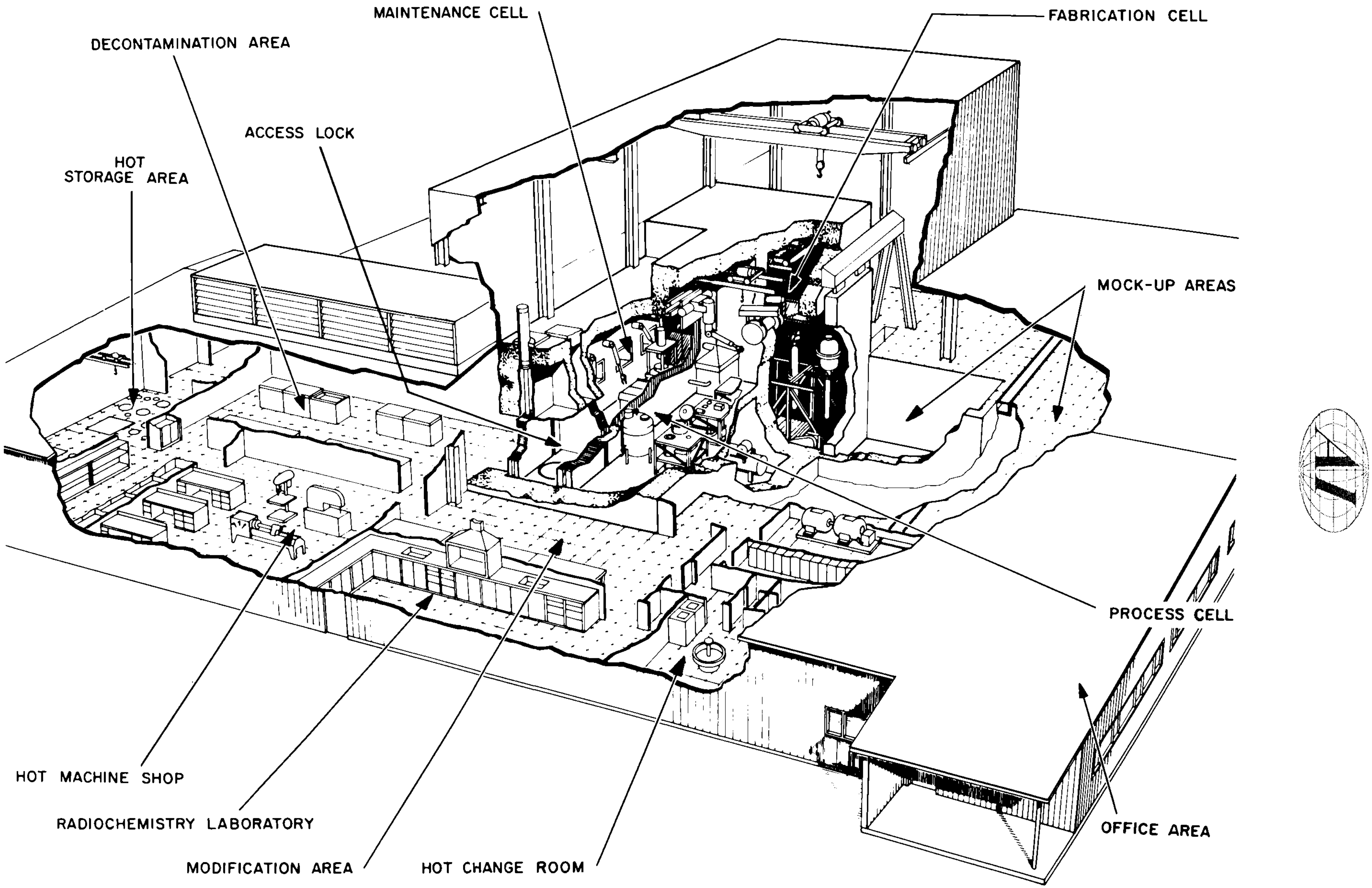

Figure 1. Proposed PRE Facility for Processing Metallic Uranium Fuel

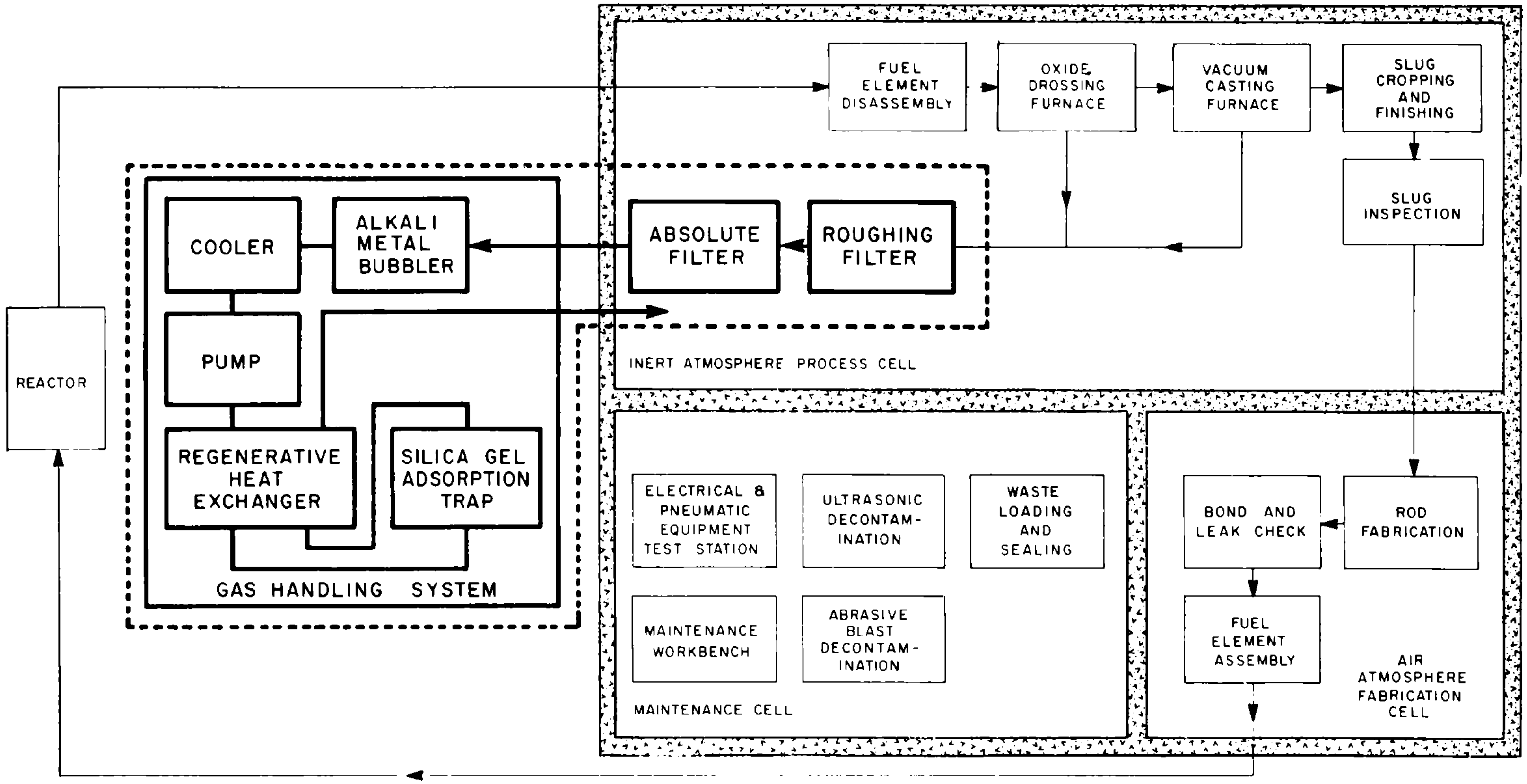

Figure 2. Metallic Uranium Flowsheet

from the melt as a solid dross which lines the crucible after pouring. Other fission products, such as niobium, zirconium, molybdenum, and plutonium, remain as alloying elements in the cast ingot.

The ingot cast from the oxide-drossing furnace is transferred to a vacuum casting furnace where the partially decontaminated metal is melted, re-enriched to restore fissionable material burned during reactor irradiation, and centrifugally cast into slugs of the proper diameter for making SRE fuel elements. The cast slugs are removed from the molds, cut to length, and inspected before transfer to a fabrication cell where fuel rods are loaded, sealed, and inspected, and fuel elements are reassembled. Reassembled fuel elements are returned to SRE in a shielded cask for reirradiation.

The proposed PRE program encompassed the demonstration of a single cycle of reirradiation of processed uranium fuel. However, the process is applicable to multicycle operation, subject to limitations to be determined in hot operation in the PRE program. One of the primary objectives of the PRE program is to determine what process limitations exist and their magnitude, if they do exist. The partial decontamination, reconstitution, and inspection of irradiated metallic uranium fuel, as shown in Figure 2, is carried out in a sealed hot cell containing an inert helium atmosphere. In-cell containment of the inert atmosphere with inflatable seals (of the type used for sealing aircraft canopies) is proposed for study in the PRE program. Inflatable seals are used for all ports through the cell liner in the PRE concept.

Noble gases and volatile fission products, released during the melting of fuel in the oxide-drossing furnace, are treated in a separate gas-handling system, shown schematically in Figure 2. In this system, volatile but condensable fission products, such as cesium, are collected on in-cell roughing and absolute filters. Trace amounts of gaseous oxygen, oxides, hydrogen, nitrogen, and other oxidants are removed from the gas stream in a molten alkali metal bubbler. Noble gases are adsorbed on silica gel at liquid nitrogen temperatures. The gas-handling system is located in a shielded vault below the process cell.

The fabrication cell, containing an air atmosphere, houses equipment for loading slugs into cans, filling the loaded cans with NaK and helium, sealing caps in the cans, inspecting the completed rods for NaK bond integrity and helium leakage, and assembling fuel elements.

The third cell in the PRE cell complex for processing metallic uranium fuels serves the multiple functions of repair, maintenance, decontamination, and preparation of waste for disposal. In accordance with the PRE philosophy of in-cell operations without any personnel contact, only rudimentary maintenance, such as changing entire pieces of equipment or large subassemblies, would be performed in the process and fabrication cells. If maintenance requires a higher order of manipulative dexterity, the equipment is moved through an access lock to the maintenance cell, where manipulators, a turntable hoist, and specialized tools would be available. If a still higher order of manipulative dexterity is required, the equipment is either partially decontaminated in-cell and removed for further decontamination and contact maintenance or discarded and replaced by a new unit, depending on the relative costs. In-cell decontamination is considered essential to preparing material and equipment for removal from the cell complex. Abrasive blasting and ultrasonic cleaning techniques are proposed for study in the PRE program as alternate methods for in-cell decontamination of process and handling equipment.

The problems associated with material handling and maintenance of in-cell material handling equipment which is inaccessible to human contact are recognized, and solutions to these problems are sought in the proposed PRE program. Equipment suitable for conventional hot cell operations, where intermittent contact maintenance can be performed, is not applicable directly to the proposed remote processing program. It is therefore considered essential that special cranes, manipulators, and other supporting mechanisms be devised which could be serviced from outside the shielding walls, should they become inoperable during their service life. The maintenance of viewing aids, such as lights, periscopes, and closed-circuit television systems requires development of special techniques and unique installations for use in the completely inaccessible hot cells proposed for PRE.

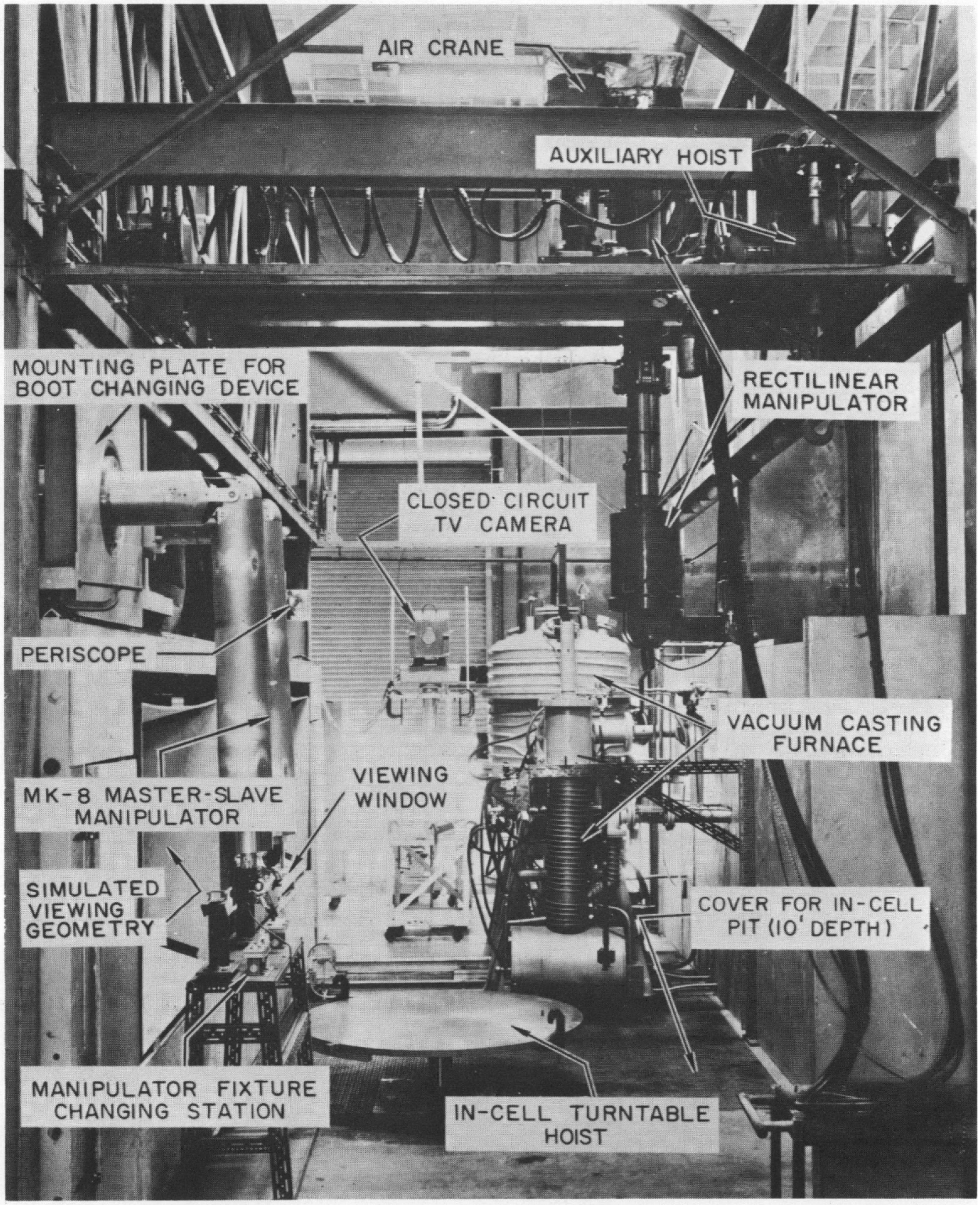

Figure 3. PRE Mockup Cell

IV. MOCKUP OPERATIONS IN THE PROCESSING OF METALLIC URANIUM FUEL

A. PROGRESS REPORTS

Progress in equipment development in the PRE program has been discussed in various PRE Quarterly Reports[7-10] and AI Bi-Monthly Progress Reports.[11-18] Technical progress during calendar year 1957 is summarized in the Annual Technical Report.[19]

B. MOCKUP

A hot cell equipment mockup, with its supporting utilities, was constructed at the Van Nuys Facility of Atomics International. This simulated cell is approximately 30 ft long, 10 ft wide, and 22 ft high. An interior view is shown in Figure 3.

The equipment mockup is not designed to reproduce the layout of any one PRE cell. In accordance with the concept put forth in the PRE proposal, the mockup is designed for checking out individual and adjacent pieces of process equipment for remote operability and maintainability. Handling, transferring, and viewing equipment is installed to simulate in-cell operations. In Figure 3, the plywood wall at the left simulates the 42-in. thick, dense-concrete, shielding wall. Mark VIII master-slave manipulators and a viewing periscope are mounted to the wall on dollies to permit setting them at any required position in the mock-up. A lead-glass viewing window, designed by and built for PRE, for observation of mockup operation, is installed on tracks in the simulated shielding wall so that it is movable to any required position along the mockup wall. Manipulators, periscopes, and windows are fixed in the operating hot cells of the proposed PRE facility.

The mockup was equipped with a commercially available air-actuated in-cell crane and a closed-circuit TV for viewing of in-cell operations. The crane and TV systems were modified to develop design criteria for PRE prototype units. Air, water, and electrical power outlets were installed to supply operating utilities to the mockup equipment. The mockup configuration was changed from time to time during the course of the program to accommodate various tests.

C. PROCESS CELL EQUIPMENT

1. Oxide-Drossing Furnace

The first step in the processing of metallic fuels in PRE requires removal of rare earth and volatile fission products from the irradiated fuel by melting in an induction furnace. The engineering development for the oxide-drossing furnace in the PRE program has been reported by Ballif.[21] In his work, an engineering mockup was carried out to demonstrate the remote operation and maintainability of the oxide-drossing furnace used in the PRE process. This effort included the installation and full-scale operation of a high-frequency induction furnace; and the design, fabrication, and modification of remotely operated supporting devices, such as molds, metal chargers, ventilation hoods, and transfer equipment. It was demonstrated repeatedly in the mockup that remote operation of this equipment can be carried on in a hot cell with only a crane for service. A cycle of charging, melting, pouring, and mold stripping took 2-1/2 hr to complete in mockup demonstrations. Conceptual drawings and specifications for an oxide-drossing furnace suitable for operation in a radioactive facility were prepared based on the mockup development program.

2. Vacuum Casting Furnace

The ingot cast from the oxide-drossing furnace is remelted for re-enrichment and centrifugally cast to slugs of the proper diameter in the vacuum casting furnace. Development effort in the PRE mockup of the vacuum casting furnace has been reported by Schmidt.[22] A full-scale prototype vacuum casting furnace was operated successfully in the PRE mockup under simulated in-cell conditions. In-cell handling and viewing equipment were used. All operations were performed from outside the simulated shielding wall. Operations included removal and replacement of components that would be affected by high temperature processing of metallic uranium fuel. Gaskets, crucibles, and coils were all removed and replaced remotely in the mockup demonstration. Complete cycles from loading through melting and centrifugal casting were performed remotely. The information and experience gained from the mockup operations have been translated into conceptual designs of an in-cell furnace suitable for use in a radioactive facility.

3. Finishing and Inspection

Cropping, finishing, and inspection of uranium slugs after vacuum casting was studied in the PRE mockup. The finishing and inspection of uranium fuel slugs in PRE was discussed by Cockrell, Foltz, and Guon.[23] Cold-short fracturing of uranium for rough cutting of uranium slugs to length was possible at temperatures below -130°C. End facing of fractured uranium slugs was necessary to meet SRE specifications. Alternatively, electrical discharge cutting was recommended for trimming cast slugs to length in a single operation rather than the two steps required if cold-short fracturing were used. A remotely operated device for checking length, diameter, and bow of metallic fuel slugs was designed and fabricated and operated remotely in hot caves.

Detection of subsurface defects in radioactive slugs made in PRE by radiographic techniques was impractical. Therefore, a study was made by Gershun[23] of the effect of subsurface voids on surface temperature distribution. Analysis revealed that even large voids caused only small temperature differentials at the slug surface, resulting from perturbation of the heat flow pattern. The calculated surface temperature differentials caused by subsurface voids were too small to be revealed by infrared scanning of the slug surface. The major effect of subsurface voids is to change the distribution of fissionable material in the slug without materially affecting the heat flow pattern.

The use of emission spectrography for the determination of U^{235} assay in PRE slugs, after re-enrichment in the vacuum casting furnace, has been described by Duffy.[24] Preliminary study of emission spectrography indicates that isotopic assay of uranium can be performed accurately. Assay differences between U^{235} and U^{236} in fuel samples can be measured with sufficient accuracy for process control in the PRE. In the PRE, it is planned either to take representative samples out of the cell for analysis or to spark the sample in the cell and record the emitted spectrum outside the cell. A shielded optical path transmits the emitted spectrum through the shielding wall if the second alternative method is used in the PRE.

4. Radioactive Source Intensities

The intensity of radioactive sources in the PRE cells was studied by Berger.[25] Determination of the radiation intensities from PRE equipment assemblies makes it possible to estimate incident radiation at any location in the process cell, and thus estimate the extent of radiation damage to such items as motors, TV equipment, insulation, seals, and gaskets.

Radiation intensities were calculated for the major process equipment assemblies found in the PRE process cell. The used oxide-drossing crucible, containing the residue from fuel decontamination, represents the most intense radiation source in the process cell, since there is little or no self-adsorption in the crucible or dross residue.

Radiation intensities were calculated for a 50-kg charge of irradiated and unprocessed fuel in the oxide-drossing crucible, a 50-kg processed ingot, an in-cell roughing filter, and a silica gel adsorption trap used in the gas-handling system for collecting xenon and krypton.

The thermal power of beta-gamma activity in irradiated, 10-day cooled, unprocessed fuel was calculated to be 11.7 w/kg. Over 75% of this thermal power remains in the oxide-drossing crucible residue after processing. This residue has a thermal power of 8.2 w/kg of fuel processed. After successive melts, this continues to build up, and the thermal power may exceed 2000 w, after ten melts. Some means of cooling the crucible for extended periods of time must be provided before the ultimate disposal of this crucible.

A gamma decontamination factor of two is calculated to result from high-temperature processing of metallic uranium fuel which has undergone a burnup of 3000 Mwd/t and a cooling period of 10 days. This is due to the fact that a large percentage of the gamma activity is contributed by Zr, Nb, Mo, and Ru which remain with the uranium after processing.

5. Inert Atmosphere Containment

Containment of an inert atmosphere within the PRE processing cell, using inflatable seals of the type used for sealing aircraft canopies, was studied by Ballif.[26] In the PRE mockup, development work was undertaken to determine whether inflatable seals would retain a vacuum, and if so, to determine their suitability for application to the PRE access lock doors.

A small test stand was designed and built. Tests were run with standard aircraft seals. The results showed that a vacuum of 0.08 microns of mercury could be maintained, using two seals with a pumpout between them. A half-scale engineering mockup of the access lock door was designed, constructed, and tested. In the tests, three seal-bead configurations, two seal-throw distances, and various seal-inflation pressures were utilized. Leakage of both air and helium was measured. Tests were run, evaluating single and double seals.

The tests in the PRE mockup showed that vacuums of less than 1 micron of mercury could be effectively maintained. Leak rates less than 1 ft^3/day were maintained, with either single or double seals, indicating that the application of inflatable seals to the access lock door is feasible. The double seals were found to be about ten times more effective in sealing than the single seals. Recommendations have been made for the proper use of seals, and information was presented on specifications which will insure better products for this application.

6. Gas-Handling System

Noble gases and volatile fission products released from the melting furnaces during processing are treated in a separate gas-handling system. Development effort in the PRE program has been described by Bernard.[27] Various gases, fumes, and particulates are evolved during fuel melting and are carried off in a helium gas stream. Condensable fumes and particulate contaminants are removed from the carrier gas by either electrostatic or impingment filters. Small quantities of gaseous contaminants such as oxygen, nitrogen, and hydrogen are removed in liquid metal absorbers; noble gases are adsorbed on silica gel at liquid nitrogen temperatures. A pilot gas-handling system was designed, constructed, and operated in the PRE mockup to establish design parameters for gas-handling equipment to be installed in the PRE hot facility.

D. FABRICATION CELL EQUIPMENT

1. Rod Fabrication Device

Mockup equipment for remote fabrication of dummy SRE fuel rods was operated in the PRE program. This work has been described by Golding.[28] Equipment was designed, fabricated, and operated for remote fabrication of dummy SRE fuel rods. The equipment was operated under simulated in-cell conditions from a console outside the mockup wall. The equipment was designed to permit remote maintenance. Major subassemblies and components can be removed and replaced, using only the in-cell crane. Wire-wrapped fuel rod tubes were loaded and filled with liquid metal, back-filled with helium, capped, and closed by welding in a sequence of remotely controlled operations. Leak-tight welds which exceed the physical property requirements for SRE fuel rods were consistently obtained in the remotely fabricated fuel rods.

2. Other Fabrication Cell Equipment

Development work on other fabrication equipment has been reported in PRE Quarterly Reports.[7-10] A remotely operated and maintained device for checking the NaK-bond integrity in PRE fuel rods was developed. A remotely operated and maintained device for checking leakage of helium from fuel rods made in PRE was designed, built, and tested.

E. MAINTENANCE CELL EQUIPMENT

1. Remote Maintenance Techniques

Remote maintenance techniques and procedures for PRE in-cell processing, handling, and fabrication equipment have been described by Stoker.[29] In maintaining PRE in-cell processing and handling equipment, it is essential that each piece of equipment or its major components be remotely replaceable. Operational techniques and special equipment auxiliaries have been developed and tested in the mockup. These techniques and equipment auxiliaries are applicable to the design of all PRE equipment, as well as general hot cell equipment which requires remote maintenance. Special utility couplings, methods of supplying utilities, motor mounts, drive-shaft couplings, gaskets, and fasteners have been designed, fabricated, and tested.

2. Elevating Turntable for Remote Maintenance

A turntable hoist, suitable for remote maintenance of equipment in the maintenance cell, has been described by Stoker.[30] This bench is capable of lifting a 2-ton weight to a height of 5 ft when the load is mounted on the table eccentrically 2 ft from the rotation axis. The turntable can be rotated completely about its axis, to bring equipment being maintained directly in view of the operator, who stands behind the shielding window. All actuating devices are located in a subcell vault, where they are accessible for contact maintenance. An in-cell packing gland around the hydraulic lift cylinder is completely maintainable, using the in-cell crane. Remote operation and maintenance of in-cell components of the elevating turntable have been demonstrated in the PRE mockup.

3. In-Cell Decontamination Methods

Methods for partial decontamination of in-cell equipment before removal from the cell complex have been studied in the PRE mockup program. Savage[31] has described process studies of abrasive blasting as a method for removal of surface contamination. In this work, abrasive blasting with cut wire was effective in removing artificially deposited radioactivity from the surface of stainless steel, carbon steel, copper, and aluminum alloys. Contamination was deposited on samples either by airborne contaminated dust within a sealed cabinet or by dipping samples into contaminated liquids and evaporating the liquid carried out by the sample. Contaminated dust produced by blasting with cut wire shot was considerably less than the dust produced by blasting with chilled iron shot or standard mineral abrasives. Surface decontamination could be reduced to or very near background after blasting with cut wire shot.

Stoker[31] has described the conceptual design of prototype equipment for abrasive blasting, suitable for installation in the PRE facility. A sealed cabinet was installed inside the PRE cell mockup. The blasting nozzle is held in a special manipulator mounted inside the cabinet. The equipment to be blasted can be rotated on a turntable inside the cabinet through any angle about a vertical axis to permit blasting from any desired angle.

Savage has described some preliminary study of equipment decontamination by ultrasonic methods in Appendix C of this report. Under the conditions used in these tests, contamination deposited either by airborne particulate matter or from radioactive solutions was only partially removed. It was not possible to reduce surface contamination to background, using ultrasonic techniques, in these tests. In some cases, decontamination factors of 100 or more were achieved. In isolated tests, decontamination factors of about 10^3 were observed. Ultrasonic decontamination appeared to work well on samples where contamination was firmly fixed by deposition from radioactive solutions.

F. HOT CELL SUPPORTING EQUIPMENT

1. In-Cell Crane

In the proposed PRE hot cells, the crane is the primary tool for remote operation and maintenance. Operating conditions impose special requirements on a PRE hot cell crane. Therefore, the development of a suitable crane represents a critical problem in the PRE program. Crane development effort was continued after reorientation of the program from metallic to refractory fuels. Discussion of the crane development and plans for future study appear in Section VI-E-1 of this report.

2. Rectilinear Manipulator

In the PRE program, a rectilinear manipulator was modified to permit remote maintenance of the manipulator in a cell inaccessible for contact maintenance. The development was reported by Streechon.[32] In this work, a commercially available rectilinear manipulator was modified to permit the remote removal and replacement of the manipulator and its major components. The feasibility of the PRE modifications and techniques for operation and maintenance were satisfactorily demonstrated in the cell mockup. An in-cell crane, or the unique PRE through-roof hoist,[33] can remove either the carriage or the manipulator bridge and lower it to the cell floor for remote maintenance.

The modifications made during the PRE program are applicable to manipulators for use in any hot cell. Therefore, the development effort in modifying the rectilinear manipulator was continued in the PRE program after the program was reoriented toward study of refractory fuels. Further discussion and future development plans are given in Section VI-E-2 of this report.

3. Lighting and Viewing

Special equipment and techniques for handling in-cell lamps and luminaires were developed in the PRE mockup and described by Gustovich.[33] A unique through-roof hoist is used to lower an inoperative lamp or helium-cooled luminaire from its position on the cell ceiling to the cell floor, where the lamp or luminaire can be replaced or serviced remotely. During the service operations, there is no violation of the cell-liner integrity or loss of cell shielding. A complete demonstration of the equipment and techniques was performed in the mockup, simulating operating conditions in the PRE cells.

A specially designed window was installed in the PRE mockup. Special features of this window are described by Gustovich.[34] This window was designed to permit replacement from the cold side of the cell shielding wall without losing the in-cell atmosphere. A protective cover glass and the gasket which seals it to the cell liner have been replaced remotely in a mockup demonstration, using only the in-cell crane.

Closed-circuit television and periscope modifications for use in the PRE hot cell are discussed in Section VI-I of this report.

4. Mark VIII Master-Slave Manipulators

In the PRE air atmosphere cells, it is planned to use Mark VIII master-slave manipulators. One-piece booting from shoulder to wrist is proposed to aid in retaining cell atmosphere and minimizing the migration of suspended particulate matter. Both a method and equipment were devised for remotely changing the shoulder-to-wrist boot of the Mark VIII master-slave manipulator arms. This device has been partially demonstrated in the PRE mockup under simulated cell operating conditions. Development of the boot-changing device and future development plans are discussed in Section VI-E-4 of this report.

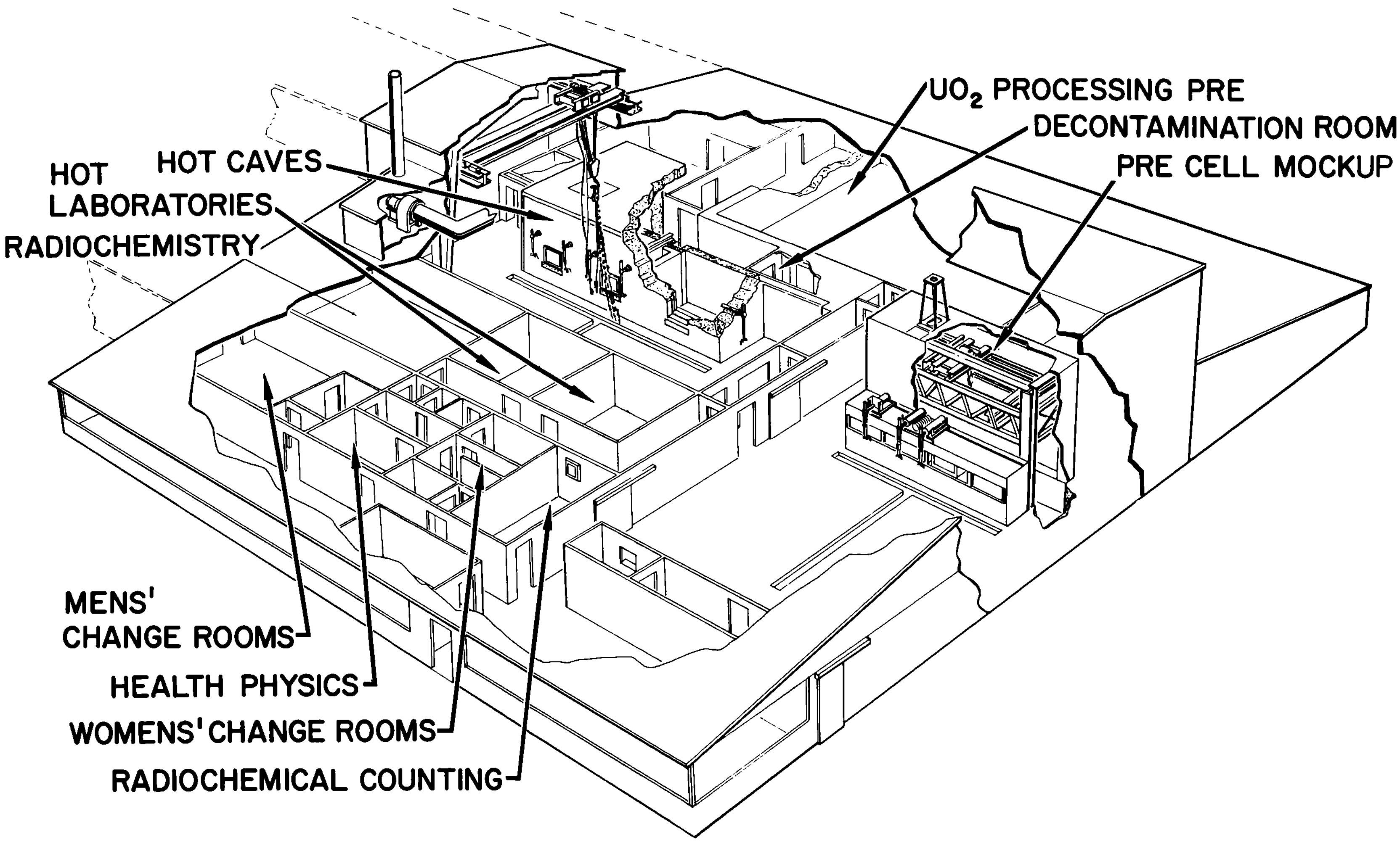

Figure 4. First Phase Facility for Processing UO_2

V. THE PROCESSING REFABRICATION EXPERIMENT FOR UO_2

Recent experimental evidence of the poor physical stability of uranium metal fuel at higher temperatures and burnup led to decreased emphasis on unalloyed uranium fuel in the PRE program and greater emphasis on refractory fuel. In particular, UO_2 has shown excellent dimensional stability after long burnup at relatively high temperature. Therefore, the PRE program was reoriented toward development of equipment, methods, and techniques for remote processing and reconstitution of highly irradiated and short-cooled UO_2 fuel. The revised PRE program is described in NAA-SR-2778.[20]

In the first phase of the reoriented program, it was proposed that equipment and techniques for processing, shape reconstitution, and fuel rod fabrication be mocked up and operated by direct personnel contact with natural uranium, to determine processing parameters of the integrated PRE process line. Equipment used with natural uranium would be moved to the PRE mockup for development of remote operating and maintenance procedures and techniques. After completion of both development stages in the PRE mockup, criteria would be established for equipment to be installed in the PRE hot cells. Supporting hot cave and laboratory work to establish optimum conditions for PRE processing were proposed.

In the program's second phase, two hot cells for processing UO_2 fuel and reconstituting fuel shapes were to be constructed at Santa Susana. A hot cell was proposed for the fabrication of fuel rods and clustering of fuel rods into elements. Other cells were proposed for remote maintenance, decontamination, and preparation of waste for disposal. The proposed facility would be capable of processing short-cooled UO_2 fuel after 10,000 Mwd/t burnup. Fuel processed and fabricated in PRE was to be reclustered into SRE fuel elements and returned to the SRE for a second cycle of irradiation.

In the first phase of construction, shown conceptually in Figure 4, the PRE facility was to consist of a hot-cave complex and supporting laboratories, a refractory-processing development area, and a cold area for mockup of hot-cell equipment and required supporting services. The two shielded hot caves are separated by a transfer lock that joins the caves to the operating galleries. The hot-cave complex is located in a high-bay area that is serviced by an overhead crane.

The work in the hot laboratories is devoted to gram-scale experiments, designed to study the reactions taking place during reprocessing of UO_2 fuels. Kilogram-scale experiments, using irradiated fuel, are conducted in the hot-cave complex. These studies include:

a) Fission product release and handling

b) Scaleup of particle comminution methods

c) Effect of radiation history

d) Dust control

e) Equipment decontamination

Chemical analyses, supporting the PRE efforts, are performed in the radiochemical laboratory. Other space in this area includes:

a) Cave-experiment reassembly area

b) Operating gallery and work area

c) Operating-gallery storage

d) Cave-ventilation equipment area

e) Hot laboratories

The cold mockup area, where PRE equipment is to be operated remotely behind simulated hot-cell walls, is located in the high-bay area separated from the hot-cave operating galleries. The area for development and modification of refractory-processing equipment and other supporting services is located in adjacent low-bay space.

The first-phase PRE facility is used for the development of remote operation and maintenance techniques for PRE process and supporting equipment. This equipment will be operated and maintained remotely in the mockup under conditions simulating PRE hot-cell activities. Equipment will be developed, operated, and modified in this area to establish design criteria for the PRE hot cells and PRE hot-cell equipment.

The first-phase facility contains approximately 25,500 ft^2, of which about 7500 ft^2 is high bay. Adjacent outside pad space of approximately 1400 ft^2 is required. The first-phase facility is designed so that the PRE hot-cell complex can be added in the second phase. The second-phase addition can be added as a separate wing and share services with the first-phase facility.

In the second phase of the facility construction program, a hot-cell complex will be constructed for the processing of multikilogram quantities of irradiated UO_2 fuel. Conceptual design of the hot cells and their equipment will be based on criteria developed in the cold mockup. The facility hot cells will be designed for treatment of 10-day cooled fuel. The walls of the cells consist of dense concrete 3-1/2 ft thick, which provides shielding against megacurie quantities of radioactive material.

Figure 5 presents a conceptual view of the proposed PRE cell-block configurations. It contains two process cells, a fabrication cell, a repair and maintenance cell, and a decontamination cell. Access is provided to all cells through a subcell tunnel. In this cell configuration, each cell can be extended and more cells added, affording maximum flexibility in the facility.

The processing line proposed for irradiated UO_2 in PRE is shown schematically in Figure 6. In the first process cell, which contains an air atmosphere, irradiated UO_2 fuel elements are disassembled, decontaminated, and charged to a furnace in which the UO_2 is oxidized to U_3O_8. During this process, the UO_2 fragments from the fuel elements are comminuted to a fine particle size. Xenon, krypton, cesium, iodine, and ruthenium are released during the oxidation cycle.

The oxidized U_3O_8 powder is transferred through a lock into a second process cell containing a nitrogen atmosphere. In this cell, the U_3O_8 powder is reduced with hydrogen to UO_2, suitable for processing and sintering to shapes with no further preparation. Preliminary information, determined in small-scale laboratory experiments, indicates the feasibility of the proposed process. The UO_2 is weighed, re-enriched to restore the U^{235} burned out during reactor operation, granulated with a binder such as polyvinyl alcohol or a mixture of waxes, pressed, and sintered in a hydrogen atmosphere to shapes suitable for loading into SRE fuel rods. The shapes are surface finished, if necessary, and inspected. The inspected shapes are transferred to an air-atmosphere fabrication cell in which tubes are loaded, sealed, and leak checked for reassembling into fuel elements.

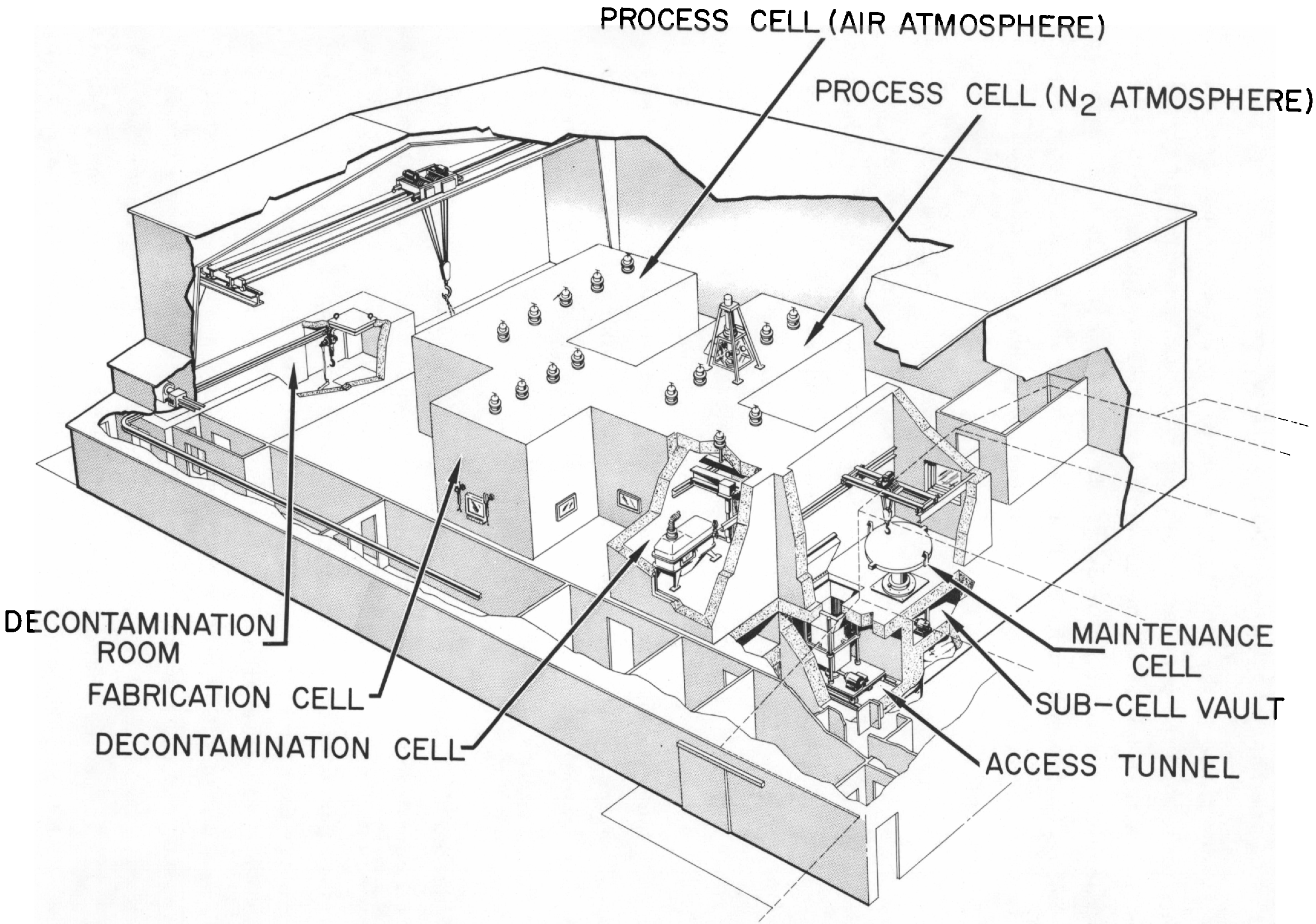

Figure 5. Second Phase Facility, PRE Hot Cells for Processing UO_2

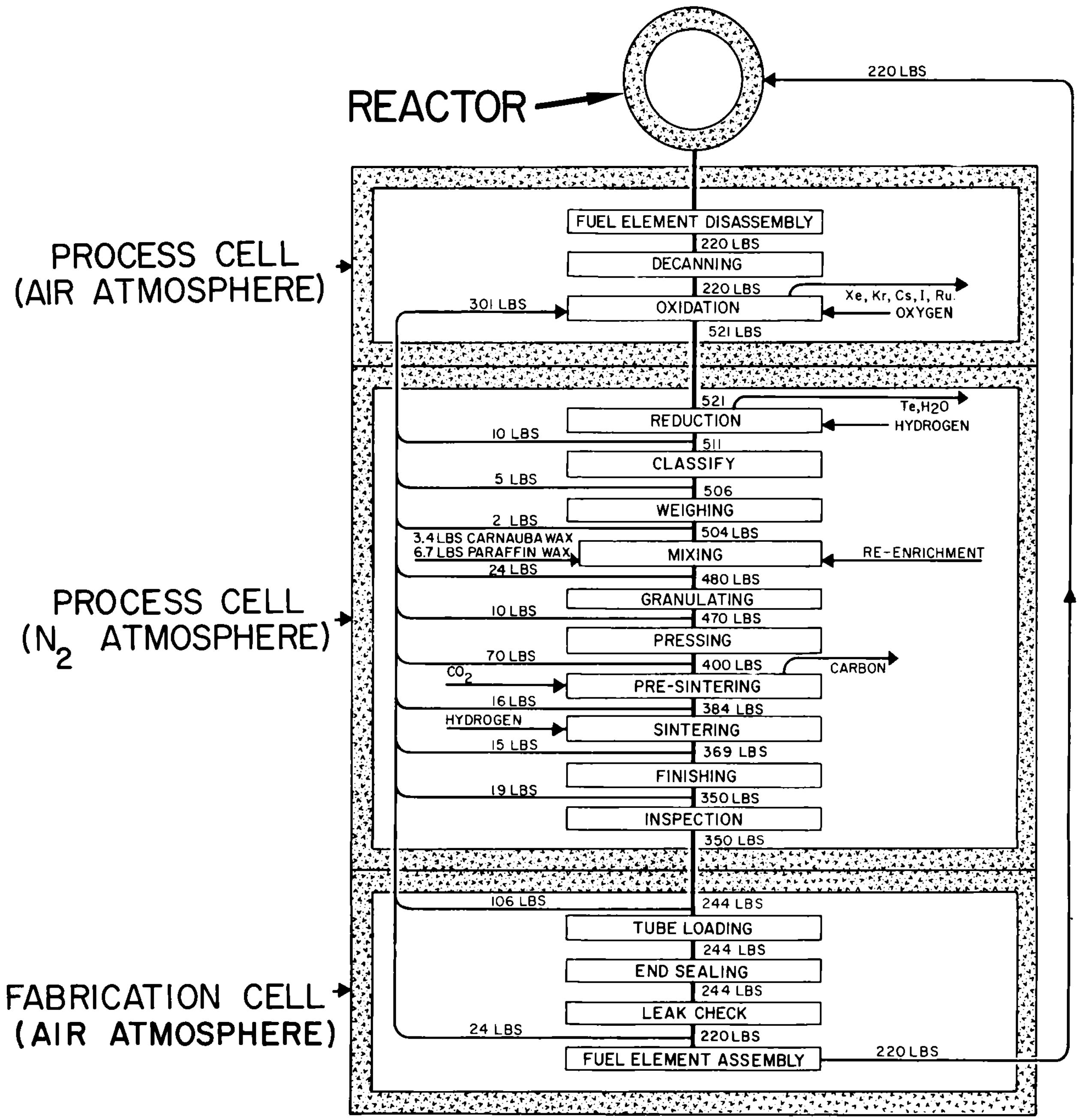

Figure 6. UO_2 Flowsheet

Noble gases and volatile fission products released during the processing of irradiated UO_2 are compressed and stored before ultimate disposal. In the PRE philosophy, radioactive atmospheres will be contained within the cells or compressed and stored.

The problems of material handling and equipment maintenance are not significantly different in the processing of UO_2 than those met in the processing of metallic uranium fuel. Much of the equipment and many of the techniques devised for material handling and maintenance in a PRE processing metallic uranium fuel are directly applicable to a PRE for processing irradiated UO_2.

Efforts in the revised PRE program have been directed toward design, specifications, and procurement of equipment for processing UO_2. It was planned to operate this equipment in an integrated cold processing line, using contact methods to develop processing parameters and operating techniques. In this part of the mockup program, all work was to be performed on natural UO_2 in a special exclusion area designed for that purpose. The second aspect of the mockup program was the development of remote operating and maintenance techniques, using nonradioactive materials in place of UO_2 in the cell mockup of Figure 3.

Much of the work in the mockup development program for UO_2 had been initiated when the program was cancelled by AEC directive. All of the tasks undertaken under this program are incomplete, however. The terminal status of such tasks is outlined in Section VI of this report. Each portion of Section VI describes operations performed up to the program's terminal date, and outlines a direction for future effort when the program is reactivated.

VI. MOCKUP OPERATIONS IN THE PROCESSING OF UO_2 FUELS

A. UO_2 PROCESSING - AIR ATMOSPHERE

1. Processing Operations

Three separate UO_2 processing operations are to be performed in the air atmosphere process cell. The first operation is the disassembly of an SRE fuel element into separate rods. This operation is referred to as declustering. A proposed UO_2 fuel element for SRE is composed of 19 fuel rods supported in a frame which allows coolant flow around each of the rods and permits the element to be loaded into the reactor. Stainless steel wire is wrapped helically around some rods in the element. The wire wrap must be removed prior to decanning.

The second operation to be performed in this cell is the decanning of the fuel rod. The fuel rod consists of an 8-ft long, 0.010-in. wall, Type 304 stainless steel tube with welded end caps, containing stacked UO_2 right solid cylinders, 0.356 in. in diameter by 0.356 in. high. The nominal clearance between the UO_2 pellet and the tube wall is 2 mils. The function of the decanning operation is to separate all of the UO_2 from the stainless steel tubes.

The oxidation of UO_2 to U_3O_8 is the third operation to be performed in this cell. The oxidation, when performed at about 375°C, comminutes the sintered UO_2 to powder of -325 mesh. At the same time, the oxidation causes the removal of fission product elements, such as xenon, krypton, iodine, ruthenium, and cesium.

2. Terminal Status of Equipment Development

a. Declustering

The initial evaluation of this problem indicated that a master-slave or rectilinear manipulator would be required to perform declustering. The wire wrap is removed by snipping the wire at the two end caps where it was tack welded to the rod. Materials were procured and the majority of the components for a dummy cluster were fabricated before the PRE program was halted. It was planned to use the dummy cluster for the development of remote declustering techniques and equipment in PRE.

b. Decanning

One proposed decanning technique would be entirely mechanical and would involve slicing the fuel rod longitudinally along its entire length. The other proposed technique would be both mechanical and chemical in nature. It would involve slicing the tube across the diameter into short lengths and then oxidizing the UO_2 to U_3O_8, causing it to separate from the stainless steel jacket. Development of the mechanical decanning technique was initiated because of the unresolved process problems associated with the chemical separation method. It was planned to reconsider the chemical method for decanning after it had been proven by small scale process initiation studies in bench-scale tests.

Conceptual design was initiated on a decanning device and a process specification was written. The device was to consist of a fuel rod hopper or magazine, feed and transfer mechanism from hopper to tube opener, tube opener and stripper mechanism, a hopper for collected fuel, and a hopper for metallic scrap. The various hoppers were to have a capacity for material from 19 fuel rods. The UO_2 powder was not to be contaminated by the addition of foreign matter such as metallic filings or saw chips. The machine was to be remotely operable and was to be designed so that it could be remotely assembled or disassembled in the cell. To pass through the proposed cell equipment access locks, no assembled section could be greater than 5 ft in width, 7 ft in length, or 6 ft in height.

Figure 7 depicts a conceptual design of a decanning machine which meets the requirements of the process specification outlined above. Air connectors, guide pins, fasteners, gaskets, and motor mountings are fabricated in accordance with PRE standards.[29] The machine consists of two major sections; one containing the rod magazine and feed mechanism, and the other containing the end cap shear, rod-flattening rolls, tube opener assembly, and powder and scrap-storage hoppers.

Rods from the declustering operations are loaded in a rod magazine. Individual rods drop from the magazine onto the rod feed chain and are fed into the rod guide to the end-cap shear. The shear, operated by an air piston, parts the end cap from the rod. The rod is fed by the drive rolls to the rod-flattening rolls. The movable flattening roll is actuated by the air piston and the rod is

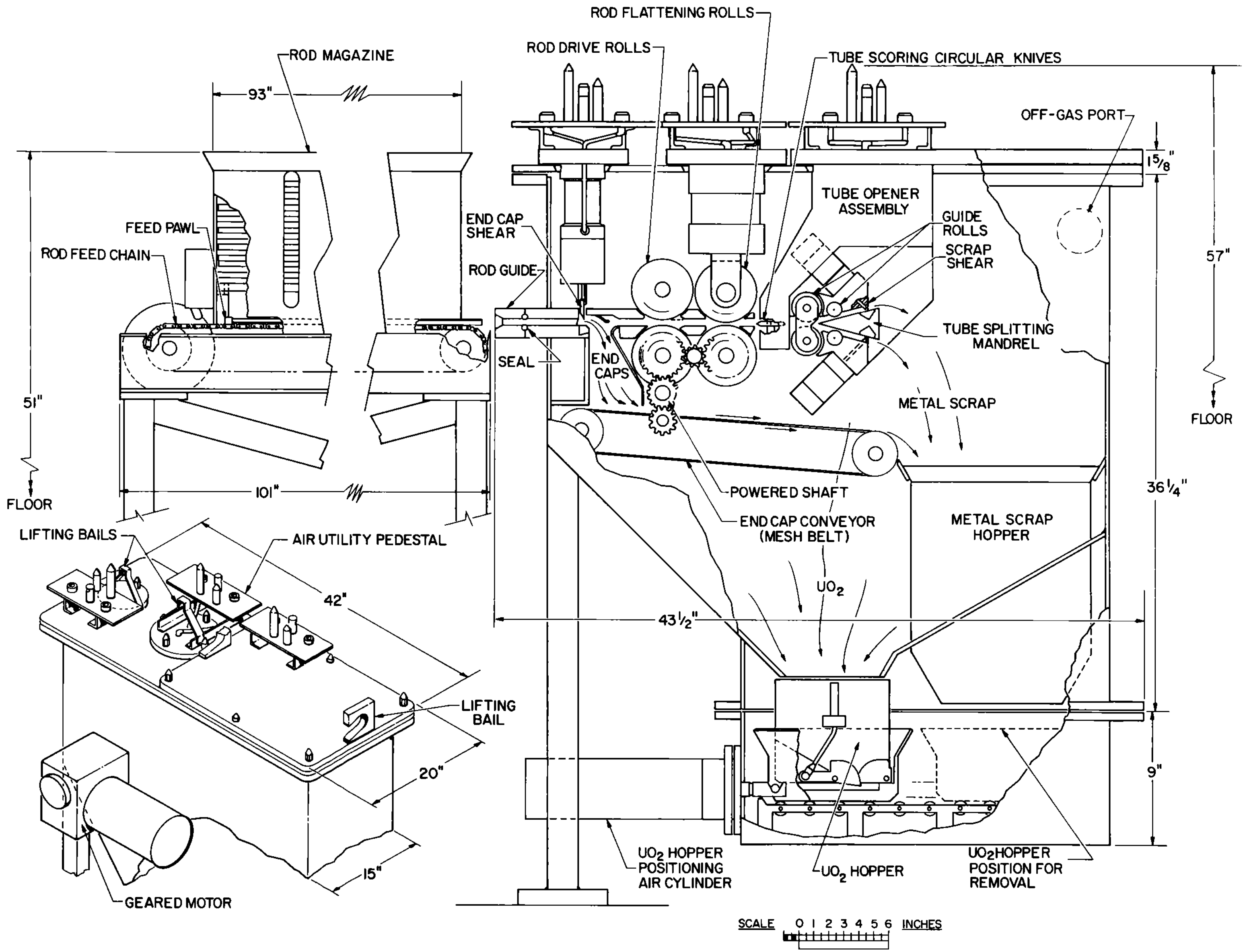

Figure 7. Fuel Rod Decanning Machine

flattened to an elliptical shape. From the flattening rolls, the rod passes through a set of opposed knives which score or split the rod longitudinally. The split rod passes over a mandrel which scrapes loose any powder clinging to the tubes. The two halves of the tube are sheared into pieces which drop into a scrap hopper.

The end caps from the cap shear drop onto a woven wire conveyor belt which carries the end caps into the metallic scrap hopper. The UO_2 powder obtained from splitting and scraping the tube passes through the belt conveyor and drops into a hopper. All tube-opening operations are performed in a contained atmosphere which can be pumped to the gas-handling system if xenon or krypton are released during the tube-opening operations.

After a complete rod magazine load is decanned, the tube opener assembly is removed, giving crane-hook access for removal of the scrap hopper. When the scrap hopper is removed, an air cylinder positions the UO_2 hopper so that it can be removed by the crane. The UO_2 hopper is taken from the decanner to the oxidation furnace where the powder is discharged into the furnace.

The decanner is designed so that many individual subassemblies can be remotely replaced with a crane. The rod-magazine drive motor can be replaced as a unit. The end-cap shear, retractable rod-flattening roll, and the tube-opening assemblies are replaceable as separate units. The drive motor for the scrap conveyor and rod-drive rolls is replaceable, as is the UO_2 hopper-positioning mechanism.

In order to simulate irradiated fuel rods in the cold mockup development of a decanning device, it was planned to use swaged UO_2 rods. Consequently, equipment was assembled to vibratory-pack UO_2 into tubes, prior to swaging. The equipment included a glove box, vibratory feeder, a jolter or a vibratory table, and a hand tamper. Figure 8 shows the assembled apparatus with a tube in place.

Studies of powder loading in fuel rods were conducted with an air-operated jolter and with an electric vibratory table to determine operating conditions which would result in the highest packed densities. PbO powder, passing 200 mesh, (theoretical density 9.53 g/cc) was used in these tests in place of

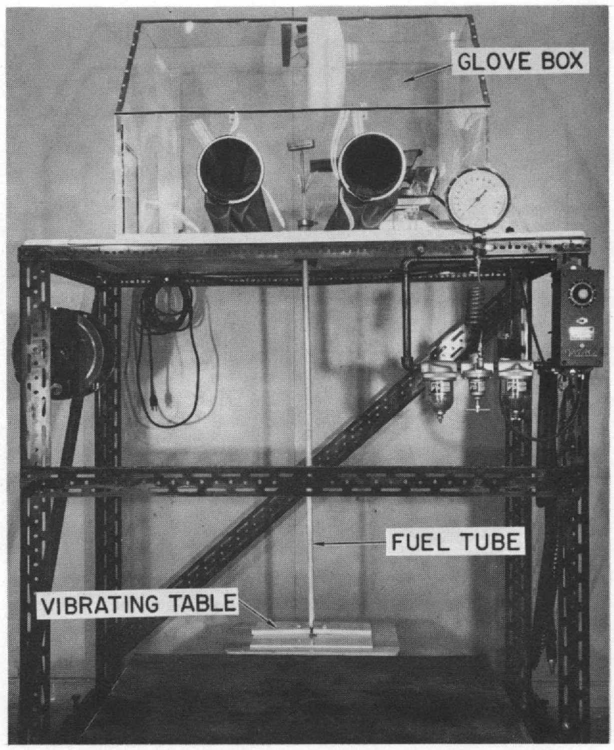

Figure 8. Vibratory Packer Assembly

UO_2 because of the lack of a controlled area for cold UO_2 work. The vibratory feeder, capable of delivering PbO at rates up to approximately 100 g/min, loaded powder into fuel rod tubes. Low feed rates, of the order of 10 g/min, yielded the highest packed densities with both the jolter and the vibratory table. Maximum packed densities obtained with the vibratory table were 2% higher than densities obtained with the jolter. With both the jolter and the vibrator, hand tamping was used to obtain the maximum packed densities.

c. Oxidation

Both batch and continuous furnaces were considered for this unit operation. It was concluded that a batch furnace would occupy less space and be more desirable, since the proposed through-put in PRE does not require continuous operation.

A study of the gas-flow requirements in the oxidation furnace resulted in an operational procedure as follows:

1) Begin operation of the loaded furnace at a pressure of about 600 mm Hg. The atmosphere in the furnace is air.

2) After heatup, maintain the slight negative pressure in the furnace by adding pure oxygen, as oxygen is consumed in oxidizing the UO_2 to U_3O_8. With nitrogen as a diluent, there will be less chance of losing control of the reaction. To insure intimate contact of the oxygen and the oxide powder, agitation of the powder is essential.

3) At completion of the reaction, evacuate the furnace to 1 mm Hg.

4) Purge the furnace with air by raising the pressure to 100 mm Hg and evacuating again to 1 mm Hg. Calculations have shown that eight such purges will lower the noble gas concentration in the furnace to less than toxic limits.

Preliminary design was completed of a furnace having a capacity of 100 lb of UO_2. The furnace shown in Figure 9 consists of a rotating drum inside a fixed heating cuff. The major components of the furnace include the rotating drum assembly, the upper and lower heating cuffs, drum-drive motor and support, furnace supports, vacuum plug, and discharge gate. All fasteners, guide pins, electrical plugs, and utility pedestals are standard PRE designs.[29]

The rotating drum has internal baffles to assure thorough mixing of the powder with the oxygen atmosphere as the drum revolves. The rotating drum assembly, which will be remotely removed as a unit, includes the support shafts, pillow blocks, rotary joint, and the utility-jumper pedestal. The rotary joint will be designed so that it can be replaced in the maintenance cell. Gas connection to the utility pedestal will be effected by the use of a standard PRE jumper.[29]

The fixed heating cuff is split into four sections, so that it can be remotely removed. Power for the heating cuff is brought to the furnace by two standard PRE jumpers which connect at utility pedestals located on each furnace support. The lower heating cuffs which plug into electrical plugs on the heater support arm contain the power plugs for the top heating cuffs. The lower cuffs are aligned by pins in the heater support arms and the upper cuffs are aligned by the lower cuffs.

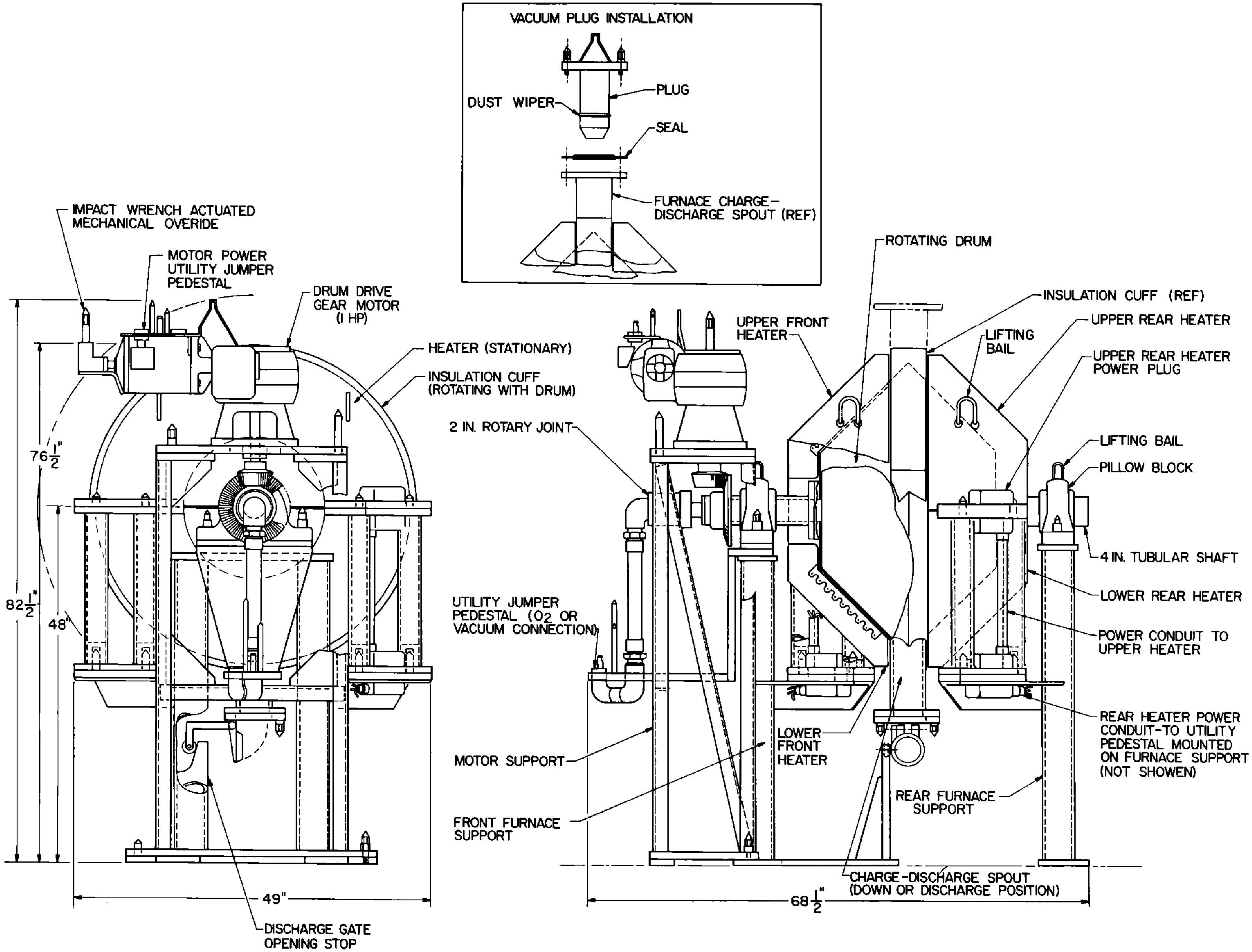

Figure 9. Oxidation Furnace

A gear head motor rotates the drum; a mechanical override is provided, so that the drum can be rotated by an impact wrench in case of motor failure. The motor is mounted for remote removal and replacement with only a crane, according to standard PRE methods.[29] The motor support is a separate frame which bolts to the furnace support.

Two separate furnace supports are bolted to mounting pads on the floor and can be remotely removed. The front furnace support has an arm which triggers the discharge gate when it is installed.

To charge the furnace, the drum is rotated into a position where the spout is in an upward position. The discharge gate is removed and powder is poured into the furnace from a bottom opening hopper which may or may not be vibrated. The furnace is closed by inserting the vacuum plug into the spout. This plug prevents powder from residing in the spout during rotation and also permits a vacuum to be maintained in the drum, when necessary, during operations.

At the completion of oxidation, the spout is again rotated to an upward position. The vacuum plug is removed and replaced by the discharge gate. One-half revolution of the drum causes the arm of the discharge gate to lock in the stop position on the furnace support and the discharge gate is opened. Powder from the furnace is dropped into a hopper which moves on a rail cart. Once the furnace is discharged, the hopper can move out from beneath the furnace and be carried by the crane to a transfer lock. A similar lock is described elsewhere in this report.

Only a crane and its attachments, such as an impact wrench, are required to assemble or disassemble the furnace. To disassemble the furnace, the upper heating cuffs and the drive motor must be removed first. A yoke is used in the removal of the heating cuffs. A yoke, which attaches to the lifting bails on the pillow blocks, is used to remove the drum assembly. Once the drum assembly has been removed, the lower heating cuffs, motor support frame, and furnace supports can be removed, if necessary.

3. Future Development Plans

a. Declustering

A dummy cluster would be fabricated and assembled. With this dummy cluster, techniques for declustering would be developed. No specific changes to the cluster have been determined, but it is possible that the upper guide and fuel hanger assemblies can be modified so that the upper guide restrains each fuel rod. This would permit the removal of rods simply by removing the upper guide, rather than removing clip wires from each rod, as is required in the present design.

b. Decanning

Design would be completed on a mechanical decanning device. The conceptual design described herein presents preliminary thoughts on fuel rod decanning equipment, but many of these preliminary ideas would be used in the final design. Test work on the rod-flattening and tube-opening assemblies would be done before preparing final designs. Tubes loaded with PbO and swaged UO_2 tubes would be used in these tests.

Upon completion of the final design, a machine would be fabricated and tested, using swaged UO_2 tubes. After any necessary modifications are made, the equipment would be operated in the PRE mockup cell, to ascertain that the design was ready for in-cell application.

The vibratory packing equipment would be used to load UO_2 into tubes, prior to swaging. The UO_2-loaded tubes would be swaged to fuel-rod size and used in the testing of the mechanical decanning device. It was expected that the swaged UO_2 rods would have a density of 85 to 90% of the theoretical density of UO_2.

c. Oxidation

An oxidation furnace would be purchased and tested, using nonradioactive sintered UO_2 pellets and pieces. The main areas of testing would be the charge and discharge operations and the powder agitation for maximum oxidation cycle efficiencies. The remote assembly and disassembly of the equipment would be checked. The furnace would be designed according to the preliminary sketch shown in Figure 9, except that the first model would have a two-piece flanged rim and a variable-speed drum-drive motor. This design would permit varying the interior baffles of the drum and also the rotational speed, in order to determine the best final design conditions for oxidation of the UO_2.

During operation of the furnace in the cold mockup, the charging and discharging operations would be studied, to determine the possible need for vibrational aids. These operations would also determine proper hopper design and hopper-handling techniques. An attempt would be made to modify the spout, in order to eliminate the need for changing the spout cap after discharge of the powder.

After optimizing the drum interior, rotational speed, and charge-discharge equipment, a one-piece drum with the proper interior geometry would be installed and other necessary modifications would be made. The furnace would then be installed and tested in the PRE mockup cell, to prove that it was ready for in-cell application.

B. UO_2 PROCESSING - INERT ATMOSPHERE

1. Processing Operations

Upon completion of the oxidation process, the fuel is in the form of U_3O_8 powder. Hydrogen is utilized to reduce U_3O_8 to UO_2. The dry U_3O_8 powder is tumbled in the internally finned rotating reduction furnace and subjected to a continuous flow of dry hydrogen at a temperature of 650°C (1200°F) for a period of one hour. The byproduct of the reaction is water vapor. The furnace is located in the inert atmosphere process cell.

Preliminary investigation has been made of both batch and semicontinuous furnace operation. Batch operation appears to be better suited to remote operation in PRE.

2. Terminal Status of Equipment Development

a. Reduction

The hydrogen reduction furnace is shown conceptually in Figure 10. The basic components of the hydrogen reduction furnace are the retort, resistance heating unit, cooling jackets, seals, and motor drives.

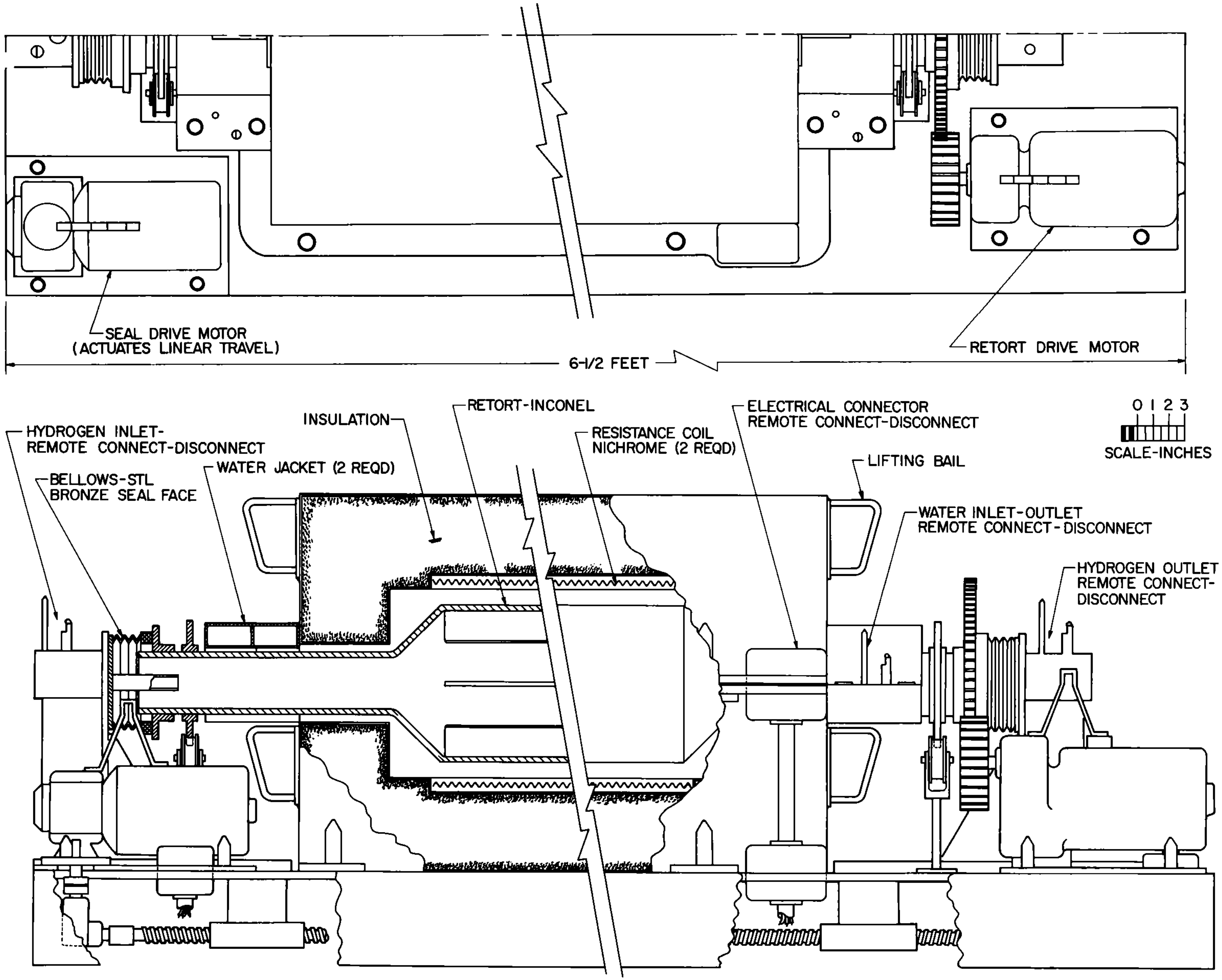

Figure 10. Hydrogen Reduction Furnace

The Inconel retort has a charge capacity of 50 lb when approximately 30% of the retort volume is filled with UO_2 powder. When the retort is rotated, longitudinal baffles cascade the material to allow maximum surface exposure to the reducing gas. The retort is freely supported on a pair of rollers and rotated by a gear head motor.

The heating units consist of a lower section and an upper section which are electrically heated by Nichrome resistance windings to 650°C. A remotely operated coupling[29] connects the furnace winding to the power supply and also connects the semicylindrical cooling jacket to the coolant supply line.

The cooling jackets are attached to the upper heating unit and slip down over the retort ends. A copper wire mesh, attached to the inside diameter of the cooling jacket, bears on the retort and conducts heat back through the cooling jacket. This method allows a shorter cooling jacket than does conventional jacketing. The heat transfer medium in the cooling jacket may be introduced through the remotely operated fluid and power coupling.[29]

The rotating seals at both ends of the retort are of the pressure type. Actuated by a reversible gear head motor, both seals move simultaneously to engage or disengage the seal face. Seals are moved in opposite directions by screw threads of opposite hand. The seal is mounted to a steel bellows to compensate for misalignment or eccentricities of the retort. The remotely operated couplings, for the introduction and exit of the dry hydrogen, are part of the seal assembly.

The motors for rotating the retort and for moving the seals are 220/440-v ac, 3-phase, reversible, gear head units with explosion-proof housings. In the event of operational failure, they may be installed or removed remotely by standard methods developed in PRE.[29] All components of the furnace (heating units, retort, seals, and motors) are easily accessible to the in-cell crane for purposes of maintenance or replacement. The overall dimensions of this furnace will not exceed 7 ft by 4 ft by 4 ft high.

The operations cycle of the hydrogen reduction furnace will be as follows:

1) Remove the top heating unit (in-cell crane).

2) Actuate motor to disengage seals.

3) Remove retort and transfer it to loading station.

4) Load retort and return it to furnace.

5) Replace top heating unit.

6) Actuate motor to engage seals.

7) Start rotation of retort.

8) Start cooling flow.

9) Purge retort.

10) Start hydrogen flow.

11) Bring up to heat (650°C) and hold for 1 hr.

12) Cut off heat and allow retort to cool, continuing rotation until retort temperature decreases to ambient. Top heating unit may be removed to hasten cooling.

b. Powder Classification

Preliminary evidence indicates that the product of the reduction furnace can be used for reconstituting high density UO_2 pellets. However, study of powder classification in PRE was instituted, in case further study reveals that classification is essential. UO_2 from the hydrogen reduction furnace would be sized by a commercially available gas classifier, operating with nitrogen gas. Oversized products would be recycled, either to the oxidation furnace or to the reduction furnace, depending on the results of further process study.

A commercial classifying unit, shown in Figure 11, was purchased. No further study was instituted.

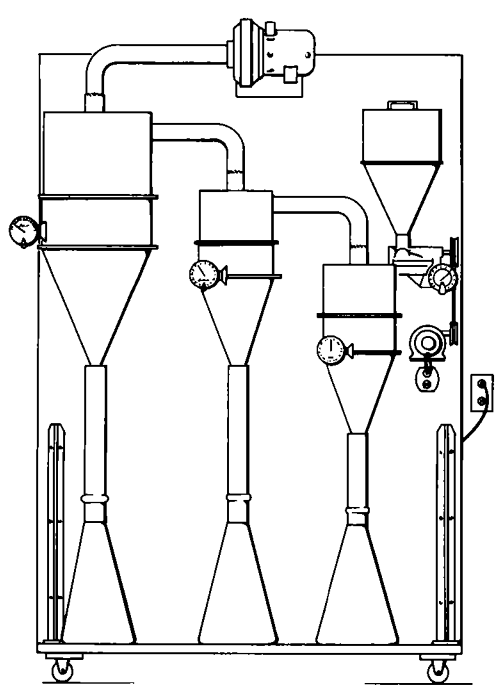

Figure 11. Classifying Unit

Graduated mesh valves on the three-unit panel-mounted collector and classifier control the maximum and minimum size of particles delivered to the classifier discharge spouts. The classifying unit will separate three grades of finished product, at a rate of 100 to 200 lb/hr. In the PRE, -325 and +325 mesh materials produced by the unit are discharged into separate hoppers. The hopper containing the -325 mesh material is transferred to the weighing station. The other hopper of +325 mesh powder is recycled.

3. Future Development Plans

A conceptual design has been made to provide for the loading and unloading of the retort without removing it from the furnace. This concept will bear further investigation.

By demonstration in the scale mockup, it has been shown that the retort should rotate at a speed between about 2 and 10 rpm. Entrainment of powder in the hydrogen flowing through the furnace will necessitate filtering the exit gas. Process study should be instituted to determine whether a continuous flow of reducing gas is necessary or if a single charge of hydrogen would suffice. This would eliminate one rotating seal which, of all the components, will probably present the most problems.

Emphasis should be placed on various configurations of the rotating seals, loading and unloading of the retort, diameter-to-length ratio of the retort, and the inner baffles of the retort.

C. RECONSTITUTION OF UO_2 FUEL SHAPES

1. Processing Operations

In the proposed Processing Refabrication Experiment[20] for irradiated UO_2, alternate methods for the reconstitution of fuel shapes and the fabrication of fuel rods were suggested. These methods included: (1) cold pressing and sintering of UO_2 pellets, (2) swaging of fuel rods loaded with UO_2 powder, and (3) loading of sintered shot into fuel rod tubes. On further study, the cold pressing and sintering method for reconstituting fuel shapes was chosen for intensive development in the PRE mockup program. The technology of this method is farthest advanced at Atomics International and at other AEC contractor sites, such as WAPD and HAPO. Standard commercially available equipment is available. Commercially available equipment can be modified for remote operation and maintenance, based on early experience in the PRE development program.

Preliminary tests at Atomics International indicate that UO_2 pellets can be consistently reconstituted by cold pressing and sintering, after one cycle of oxidation and reduction, to pellets of 93% theoretical density. Excellent results have been obtained in reconstituting a simulated one-cycle "fissia" containing many of the fission products calculated to be present at the end of one cycle of SRE irradiation.

In the flow sheet of Figure 6, the reconstitution of UO_2 fuel shapes consists of all steps from classifying the reduced powder through weighing, mixing, granulating, pressing, presintering, sintering, finishing, and inspection. These operations are carried out in the PRE process cell containing a nitrogen atmosphere.

Early laboratory experiments have indicated that elimination of the classification step is feasible in PRE, since high density pellets have been made directly from the UO_2 powder produced by oxidation of UO_2 to U_3O_8 and hydrogen reduction of U_3O_8. It is expected that later operational experience with UO_2 as a reactor fuel will reveal that the surface finishing of UO_2 pellets by grinding can be eliminated. Early and incomplete evidence indicates that pellets can be used in the SRE as-sintered. Size tolerances after sintering will satisfy the nuclear requirements for SRE. Elimination of the finishing operation will simplify the process considerably and result in a lower cost fuel cycle. It is felt that a significant economy and simplification will be achieved by eliminating UO_2 pellet surface finishing.

2. Terminal Status

a. Mixing

The double ribbon mixer, shown in Figure 12, is a remotely operated and maintained unit, used in the PRE to mix and blend UO_2 powder at -325 mesh and a wax binder at -100 mesh. UO_2, comminuted by alternate oxidation and reduction after irradiation, is blended in the mixer with a binder and enriched makeup UO_2, to restore the fuel depleted by burnup during irradiation. The unit is sized to handle a 1-ft^3 batch of UO_2 powder and binder material.

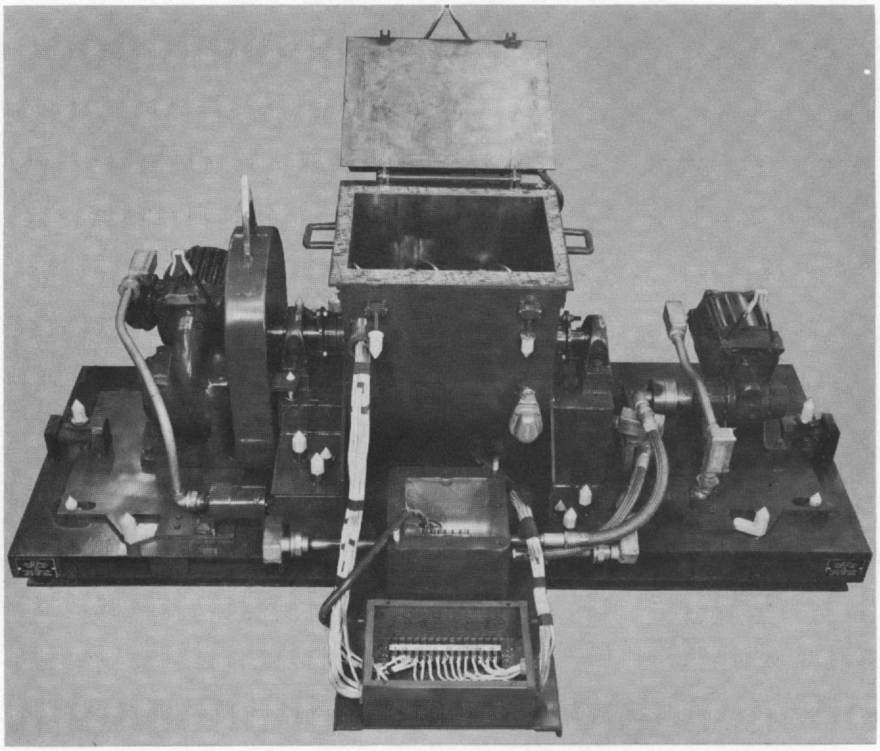

Figure 12. Ribbon Mixer

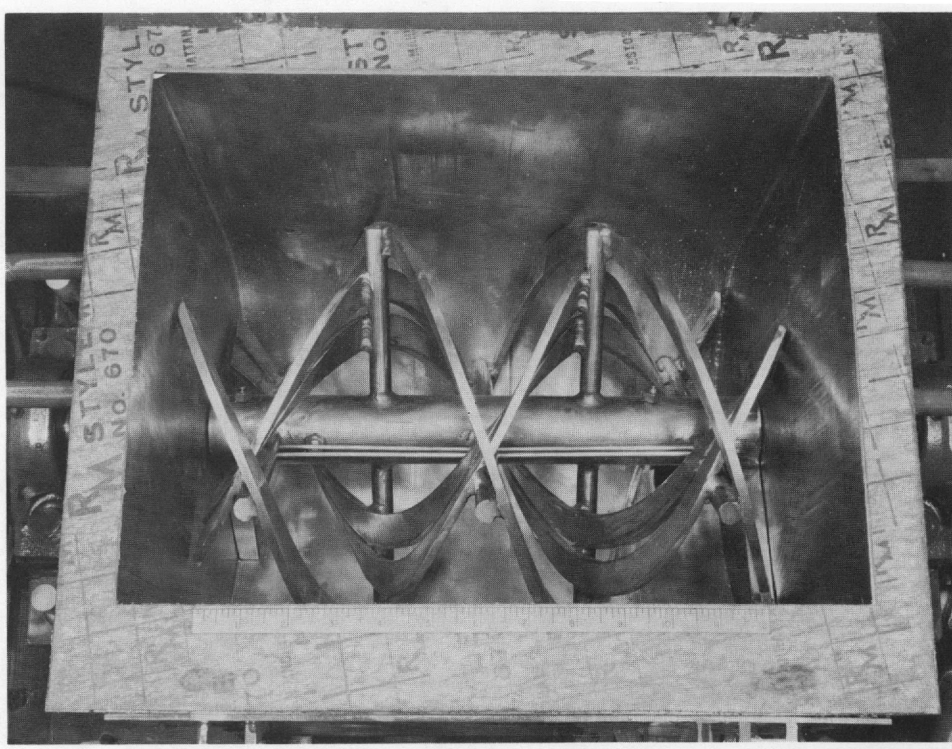

Figure 13. Rotor and Trough Assembly

The rotor consists of two helically wound metal ribbons, welded to spokes of a hub which is pinned to a motor-driven shaft. The rotor, and the trough in which it is mounted, are made of type 304 stainless steel. The rotor, as shown in Figure 13, is dynamically supported by self-aligning bearing blocks which are mounted to the base structure of the ribbon mixer. The rotor is aligned to the semicylindrical inner surface of the trough, so that a close gap of 0.015 in. is maintained between the helical blades and the trough. The UO_2 and binder are continually tumbled and intimately mixed as the rotor turns in the trough. In the PRE mockup, electrical heating of the trough will simulate the beta-gamma heating of irradiated UO_2 during the mixing cycle.

The 1-1/2 hp electric motor driving the rotor is coupled to the rotor shaft through a gear which engages a pinion on the rotor shaft. This configuration permits the remote removal of the unit from the base of the mixer when motor maintenance is required. A 1/6 hp electric motor, which opens and closes the bottom discharge gate valve, can be uncoupled by remote means and disconnected from its power supply by standard PRE techniques.[29]

Electric drive motors, rotor, and trough are maintained and replaced by in-cell handling devices. Each electric motor is bolted to a separate mounting plate that has elongated slots to receive fixed guide pins. The pins align the motor with the fixed centers of the couplings when the motor is replaced. The rotor, which is pinned to the drive shaft with four tapered dowels, is removed from the trough by extracting the dowels and slipping the drive shaft out of the rotor hub. The trough assembly, consisting of the rotor and shaft, bearing and blocks, and their mounting platforms, is removed from the mixer base by disengaging the chamfered hexagonal bolts with a remotely operated in-cell impact wrench. All electrical components of the rotary mixer are provided with electrical couplings that operate automatically to make or break the electrical connections when units are removed and replaced during in-cell maintenance operations. These electrical components and electric motor mount platforms are similar in design to the standard units used in PRE.[29] The ribbon mixer has been designed to be operated by remote control in an inert atmosphere cell.

The UO_2 powder and the organic binder charged to the mixer are transported in batch lots from the weighing station by the in-cell crane. The weighed batch is charged to the charging hopper and mixed until satisfactory uniformity of blending is achieved. After blending is complete, the mix of UO_2 and binder is emptied from the mixer trough by opening the slide gate under the trough. The material is collected in a stainless steel hopper which is provided with two standard PRE lifting bails[29] and transported by an in-cell crane to the next process station in the inert atmosphere process cell.

No experimental or cold mockup effort on the remote operation of the PRE ribbon mixer have been undertaken. The design and fabrication of the unit has been completed. Component assemblies of the mixer have been functionally tested for continuity of electrical hookup. The mechanical components have been checked for bearing alignment, and contact operations duplicating the in-cell remote operations of removal and replacement of motor and gears were conducted.

b. Granulation

Granulation of processed UO_2 with a binder is necessary to produce free-flowing granules for compacting into UO_2 right solid cylinders. A commercial granulator was purchased for modification to match the requirements of remote operation and maintenance in processing UO_2 of -325 mesh, in batch lots of 200 lb, in the PRE. The first modification of a commercially available batch granulator for the PRE mockup is shown assembled in Figure 14. The screen and rotor assembly are shown in Figure 15.

The granulator is horizontally mounted. All assemblies exposed to UO_2 are fabricated of type 304 stainless steel. The major components include the: (1) upper hopper and cover, (2) lower hopper, (3) rotor assembly, consisting of a drive shaft, rotor bars, bearing pads, and plates, (4) rigid-frame screen, (5) gear box and electric motor, (6) clutch and oscillating drive mechanism, (7) granulator pedestal, and (8) discharge spout. All fasteners, guide pins, electrical plugs, and utility pedestals are standard PRE units designed for remote maintenance.[29]

The cover plate supports a built-in hopper whose throat opening fits against the screen. The hopper straddles the rotor bar assembly and its end plates. UO_2 drops through the hopper into the granulating area.

The rotor assembly and its associated components are connected to the electric drive through a remotely operated coupling[29] which allows the

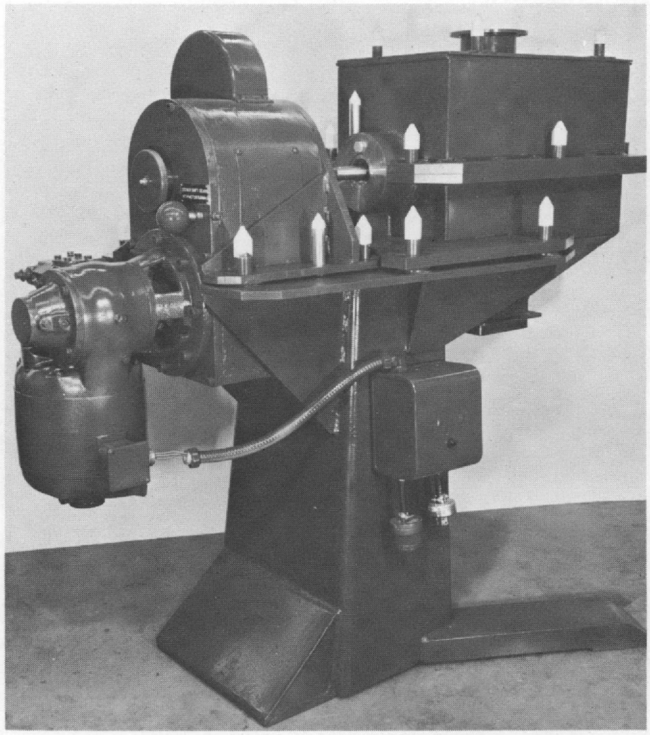

Figure 14. Granulator

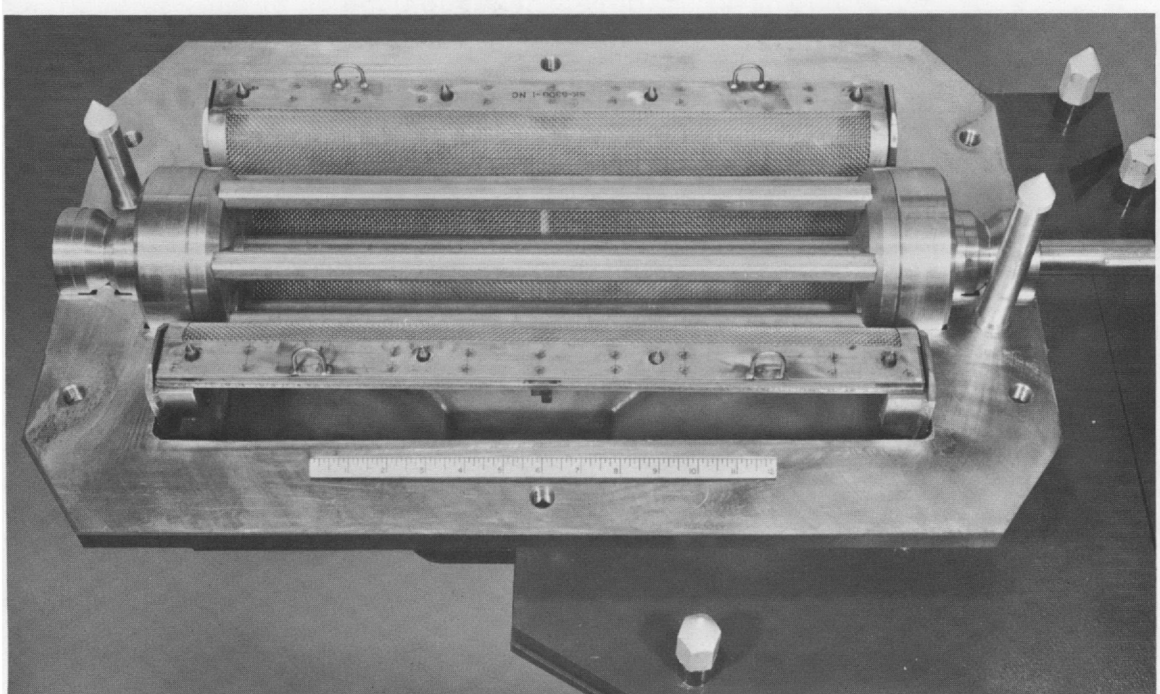

Figure 15. Screen and Rotor Assembly

removal of the rotor assembly from the hopper for maintenance operations with in-cell handling devices. As the rotor assembly rotates, the rotor bars travel over the screen through which the material is extruded to produce free-flowing granules. Rotation or oscillation of the rotor produces uniformly sized clusters.

Only a crane and its attachments, such as an impact wrench, are required to assemble or disassemble the granulator. The granulator can be disassembled remotely into six main components. They are: (1) the rigid frame screen, (2) the rotor bar assembly, (3) the gear box and electric drive assembly, (4) the cover plate, (5) the upper hopper section, and (6) the lower hopper section. Only the rigid-frame screen and rotor-bar assembly will require contact maintenance in PRE. These components are expendable in PRE hot operation.

The remote removal and replacement procedures for the rigid-frame screen and rotor-bar assembly are as follows:

Rigid-Frame Screen

1) Disconnect the rotor-bar assembly drive-shaft coupling from the gear box and electric motor drive.
2) Unfasten the six tapered hexagonal bolts of the upper hopper flange.
3) Remove the upper hopper assembly, which consists of the cover plate and rotor-bar assembly, exposing the rigid-frame screen.
4) Remove the screen and replace with a new assembly.
5) Replace the upper hopper assembly.
6) Secure the upper hopper assembly and engage the shaft coupling.

Rotor-Bar Assembly

1) Repeat steps No. 1, 2, and 3 of the rigid-frame screen procedures.
2) Invert the upper hopper assembly and unfasten the hexagonal bolts holding the bearing block spacers to the hopper end walls.
3) Remove the rotor-bar assembly and replace with a new unit.
4) Repeat steps No. 5 and 6 of the rigid-frame screen procedures.

c. Pressing

The agglomeration operation in PRE produces free-flowing granules of UO_2 and binder. In the next process operation in the inert atmosphere process cell the granules are compacted to the required shape.

Preliminary studies of the physical requirements for compacting the UO_2 granules into right solid cylinders, approximately 0.400 in. in diameter, indicated that a commercial 12-ton double-acting single-punch pellet press could be modified for remote operation and maintenance of the punches, die, and their related components.

A commercial compacting press was purchased and a conceptual design of modifications to the punch, die, and die table assembly, as shown in Figure 16, was partially completed. No fabrication effort was expended on the proposed modifications of the press for demonstration of remote operations.

The pellet press is capable of exerting a load of 12 tons. The opposed punches move simultaneously to produce UO_2 fuel pellets of uniform density in the die cavity. The press is equipped with a hydraulic pressure release and equalizer mechanism which can be adjusted to ensure the application of uniform punch force with each compression stroke, regardless of variations in the particle size of the feed. The unit is driven by a variable-speed electric motor. Speed is established as a function of the depth and diameter of the die cavity and the quality of the feed. Punches and dies are made of highly polished tungsten carbide, having a surface finish of 4 RMS or better, to withstand abrasion and to resist high compressive stresses.

Preliminary design effort in PRE was directed toward the development of methods for remotely installing, replacing, and adjusting the die and punch complex.

No modifications are required for remote maintenance of the main shaft drives and cam control units of the press, based on the expected life of these basic components in PRE service and the probable cost of discarding the components, in the event of failure. However, the design of the modified pellet press is based on protecting the mechanisms from gas-borne particles in the process cell.

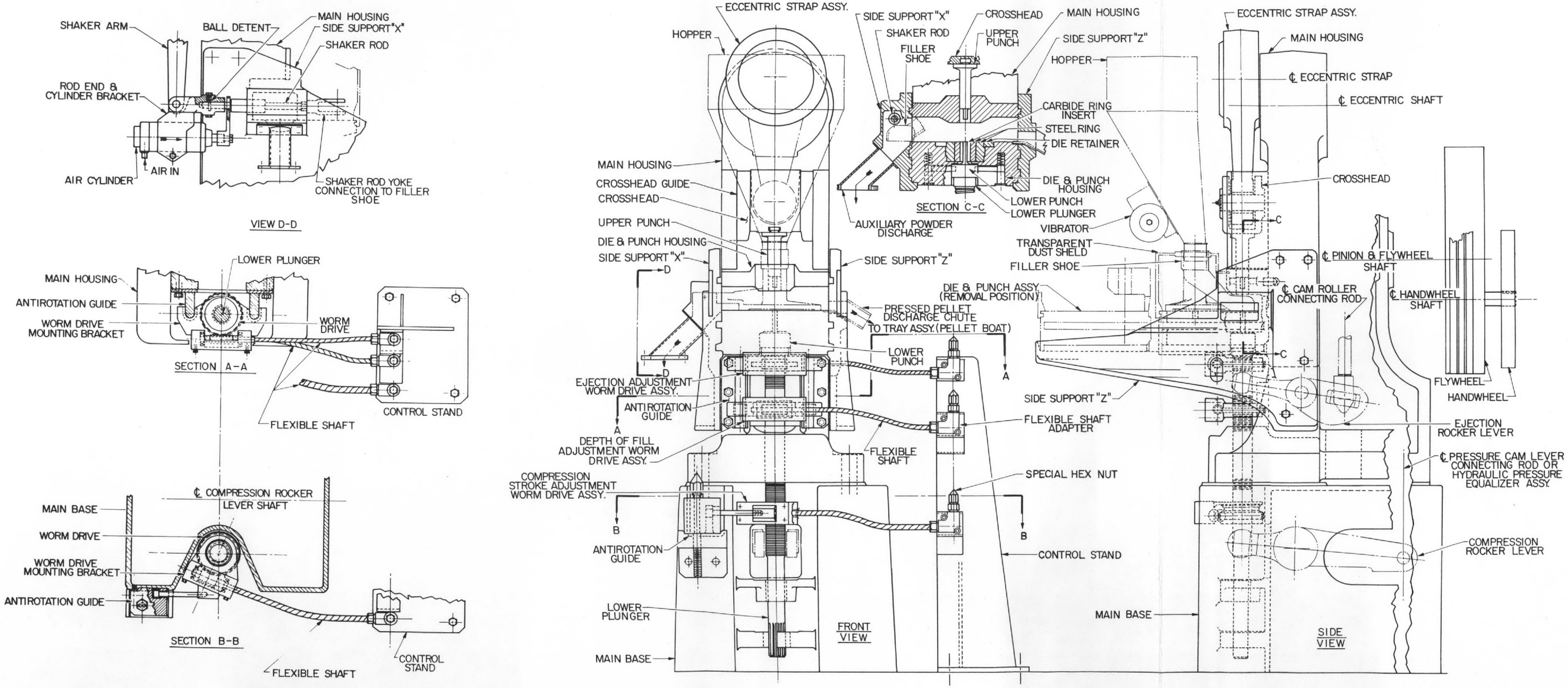

Figure 16. Pellet Press

The purchased pellet press is designed to be operated and maintained by contact methods. The upper and lower punch units and the single die block are each separately affixed to the actuating mechanisms and are removed or adjusted as single units of the press. The proposed design integrates the die and two punches into a single assembly which can be installed and removed by remote operations as a prealigned component. This modified punch and die assembly, with its punches prealigned, slides out of the press on T-slotted ways for removal and replacement. A balsa wood scale model of the modified pellet press in Figure 17 shows the punch and die assembly moved out of its operating position so that it can be remotely removed and replaced. The punch and die assembly is slid back toward the press frame on its T-slotted ways to restore it to its operating position.

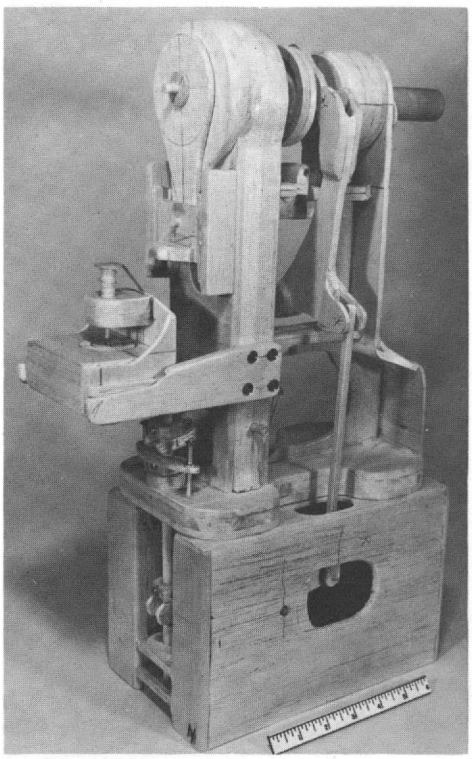

Figure 17. Pellet Press - Scale Model

In the standard compacting press, punch travel into the die requires adjustment for the correct compression ratio to produce sound pellets. However, with the proposed PRE modifications, adjustment of the lower plunger establishes a predetermined stroke for the upper punch. Remote adjustment of the upper punch is not required.

The ejection stroke, the depth of fill, and the compression stroke must be adjusted remotely in the modified press to control pellet size and density. These adjustments are made remotely by worm gear units, driven by an impact wrench, through flexible shafts, as shown in Figure 16.

In order to maintain or remove the die and punch assembly, the hopper must be unloaded. In normal operation of the press, the filler shoe, which carries powder from the hopper to the die cavity and also serves as a mechanism to eject the green pellet, is oscillated by a shaker rod mechanism actuated by a drive cam on the press. In the modified press, the shaker rod can be disconnected from the filler shoe assembly, thus permitting the filler shoe to be rotated to clear the die and punch assembly. With the filler shoe in this position, shown in Section CC of Figure 16, excess powder in the loading hopper can be discharged through the filler shoe into a transport hopper for storage until completion of the maintenance operations.

d. Presintering

In the presintering operation, the organic binder and lubricant, added to the mixed UO_2 powder before pressing, is removed by decarbonization in a suitable, controlled environment at an elevated temperature. The fuel compacts are heated to 800°C and held for 2 hr in a continuously flowing, dry, deoxidized CO_2 atmosphere for presintering.

A conceptual design has been made of a sealed presintering furnace for processing fuel compacts. The conceptual design is shown in Figure 18. A CO_2 atmosphere can be introduced and the reaction products exhausted.

The furnace is designed for batch operation. It is vacuum tight, for vacuum purging before introduction of the CO_2 atmosphere. All structural material is of type 304 stainless steel. A Nichrome wound furnace heats the vacuum retort to presintering temperatures. The retort and surrounding high temperature refractory is encased in a flanged cylindrical vacuum shell mounted to the furnace base plate. An annular plate inside the shell connects the shell and retort.

The furnace is sealed with a hinged cover-manifold. This consists of a flanged cover, a conical collector with an annular plate at its base, a counter-balanced standard PRE bail, and a flanged exhaust manifold connected to the cover by a stiffening plate. In the open position, the trays on which pellets are loaded are exposed to permit loading of the furnace remotely. In the closed position, a leak-proof system is insured by gaskets between the furnace shell flange and the cover-manifold flange. Closing the cover also seals the exhaust manifold into its operating position.

The inside of the retort is provided with a grooved ring stand and a diffuser cone to direct the flow of CO_2 to four gas-distributing tubes

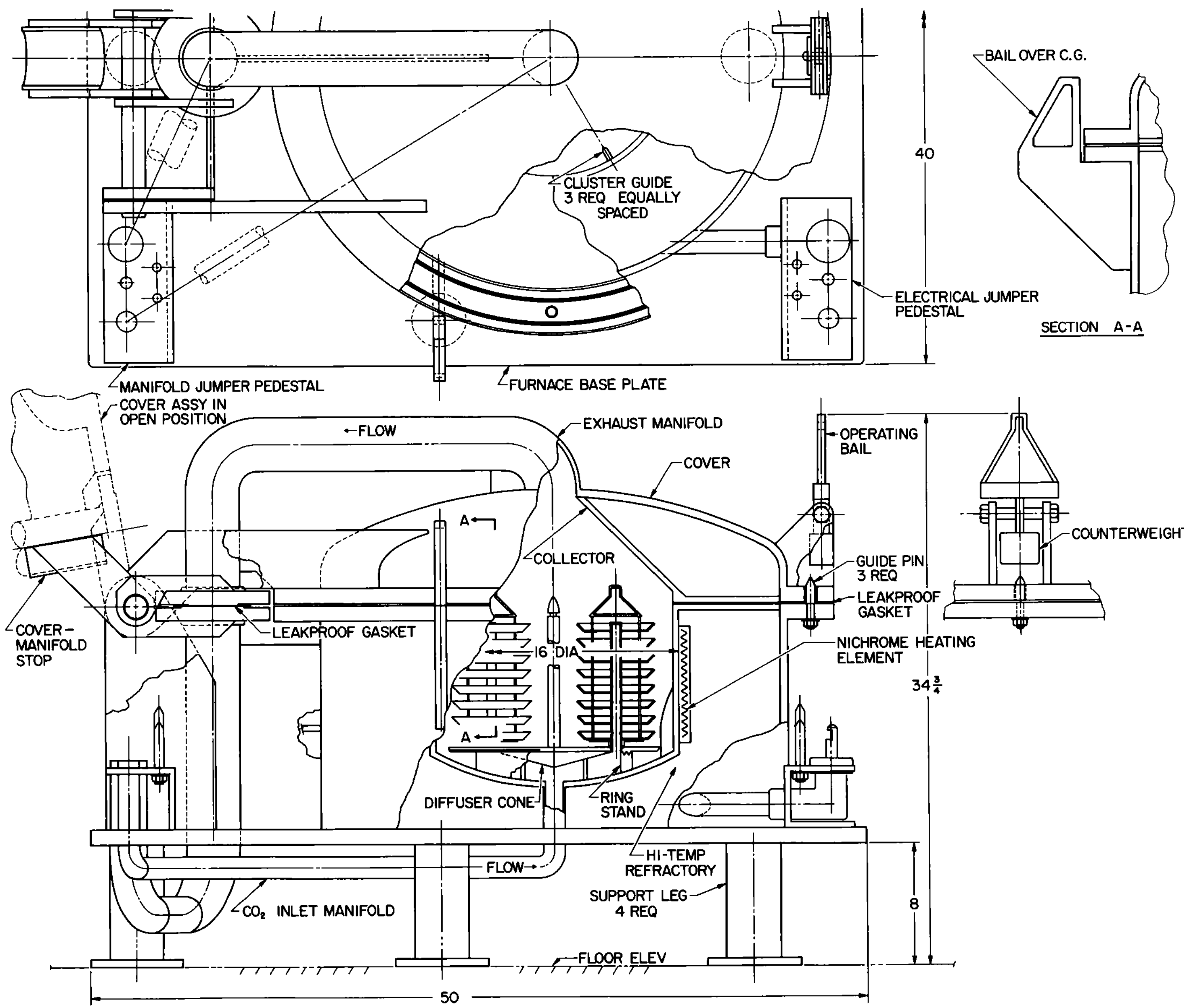

Figure 18. Presintering Furnace

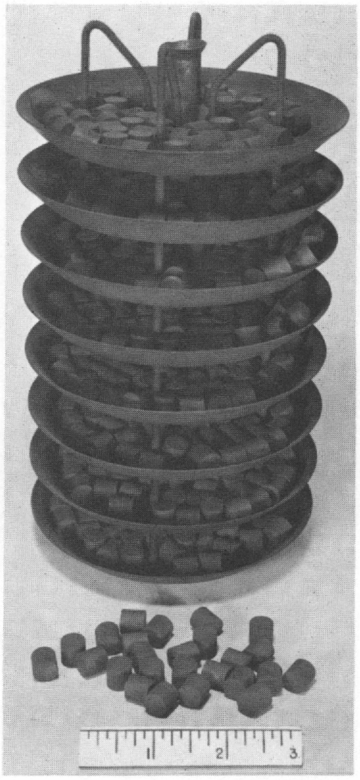

Figure 19. Pellet Tray Assembly

mounted on a base plate. Pellets are loaded in stacked trays, as shown in Figure 19. A loaded assembly is mounted on each of the four gas-distributing tubes. Three equally spaced guides are located on the inside wall of the retort to align the assembled stacks of pellet trays during loading operations. In its lowered position, the base plate seals the annular opening of the intake manifold to direct gas flow. CO_2 flows through four holes in the base plate to the fuel compacts through radial holes in each gas-distributing tube.

Two standard PRE utility jumper pedestals[29] are mounted on the furnace base plate, thus permitting remote connection and disconnection of utilities. The furnace unit can be transported by the two bails connected to the shell at the center of gravity. A flanged vertical pipe connected to the furnace shell by a stiffener plate serves as a pedestal for the cover-manifold unit hinge. The control console, vacuum pump, CO_2 supply, and other supporting equipment are located outside of the process cell.

To load the furnace, the in-cell crane lifts the cover-manifold by the counterbalanced operating bail until the cover-manifold rests on its stop. A single cluster of four trays is loaded into the furnace by means of a crane-transported grapple which holds the top of the central rod of the tray assembly. The grapple is released and returned to its in-cell storage rack. The furnace is sealed by closing the cover-manifold unit with the in-cell crane.

After loading, the system is evacuated through the exhaust manifold by the out-of-cell vacuum pump. Nitrogen removed from the furnace during evacuation is returned to the process cell. Dry, deoxidized CO_2 is admitted to the retort through the inlet manifold at a constant flow rate for the complete cycle. The charge is heated at a rate not to exceed 400°C/hr until the presintering temperature of 800°C is reached. The furnace is held at 800°C for 2 hr.

The furnace is allowed to cool to 100°C, at a rate less than 400°C/hr, with the CO_2 atmosphere maintained within the furnace. After opening the cover-manifold, the pellet tray assembly is removed by the crane-transported grapple and carried to the next processing station.

e. Sintering

In the conventional method of UO_2 pellet production, pellets are sintered in hydrogen at 1700°C, after presintering in CO_2 to achieve a powder compact of high density. In PRE, pellets removed from the presintering furnace are transported to a second furnace for sintering. The design of the sintering furnace is based on batch loading and unloading of a single pellet tray assembly, operation at temperatures up to 1750°C, remote control of the circulation of dry hydrogen through the furnace, and remote operation and maintenance of furnace components.

No conceptual design of the PRE sintering furnace has evolved. However, it appears that a molybdenum-wound, refractory insulated, hydrogen atmosphere muffle furnace can be adapted to PRE requirements. There is preliminary evidence presented by others[35] that an atmosphere containing steam can reduce the hydrogen sintering temperature from 1700 to about 1400°C. This would simplify furnace design and heating element material selection.

Preliminary evaluation indicated that a PRE sintering furnace, operated batchwise, was smaller than a continuous furnace and more easily maintained. Therefore, a batch furnace is better adapted to PRE hot cell operation.

f. Powder and Pellet Handling and Transporting

U_3O_8 powder and UO_2 pellets or powder must be transferred between each of the unit operations within the PRE inert atmosphere process cell. All transporting of process material must be accomplished remotely and the transfer equipment must be capable of being remotely replaced, in event of malfunction. Schematic diagrams of powder and pellet handling methods are shown in Figures 20 and 21.

To maintain the integrity of the air atmosphere process cell and the inert atmosphere process cell, during the transporting of process material between these cells, a material transfer lock has been specified. U_3O_8 powder from the oxidation furnace in the air atmosphere cell is transported through the material transfer lock into the nitrogen atmosphere process cell in a process-material transport hopper, as shown in Station 1 of Figure 20.

The bottom contour of the hopper will be U-shaped, with parallel side walls and a pouring spout at one end for quick and complete discharge of the process material. Two standard PRE lifting bails[29] are attached to the hopper. One is mounted above the center of gravity, the other at the end opposite the pouring spout. A pair of trunnions at the spout end provide the pivot axis for the hopper when the process material is discharged at any of the process stations. The lifting bail above the center of gravity provides a hookup for the in-cell crane when the hopper is moved from station to station. V-blocks, attached to the charge spouts of all process equipment stations, as shown in Figure 20, provide a pivot axis for the hopper trunnions when the end bail is used with the in-cell crane to tilt and discharge the hopper.

To charge the hydrogen furnace (see Figure 20, Station 1) with U_3O_8 carried in the hopper from the material transfer lock, the furnace tube is transported to an auxiliary stand by the in-cell crane. The tube is placed in a near horizontal attitude, with either one of the open ends affixed to the bottom throat of the charge spout. The hopper of U_3O_8 is transferred into the charge spout by lifting the end bail and tilting the hopper.

The discharge of process material from the hydrogen reduction furnace is also remotely controlled. The furnace tube is removed from the furnace assembly and positioned, with the in-cell handling equipment, at an angle such that the process material discharges from one of the open ends into the standard hopper. The material discharged into the hopper is transported by the in-cell crane to the next process station. Remote transfers, similar to those used in the hydrogen reduction station, would be repeated at the classifying, weighing, mixing, and granulating process stations, shown in Stations 2 to 5 of Figure 20.

A study of powder inspection methods has been instituted in the PRE program. Consistent relations have been shown between mean particle size and the oxidation-reduction conditions. These results are discussed in Appendix B. A method has been developed which may be applicable to process control of powder particle size in PRE. Low magnification micrographs of powders, made under polarized light with crossed Nicol prisms, are projected in a

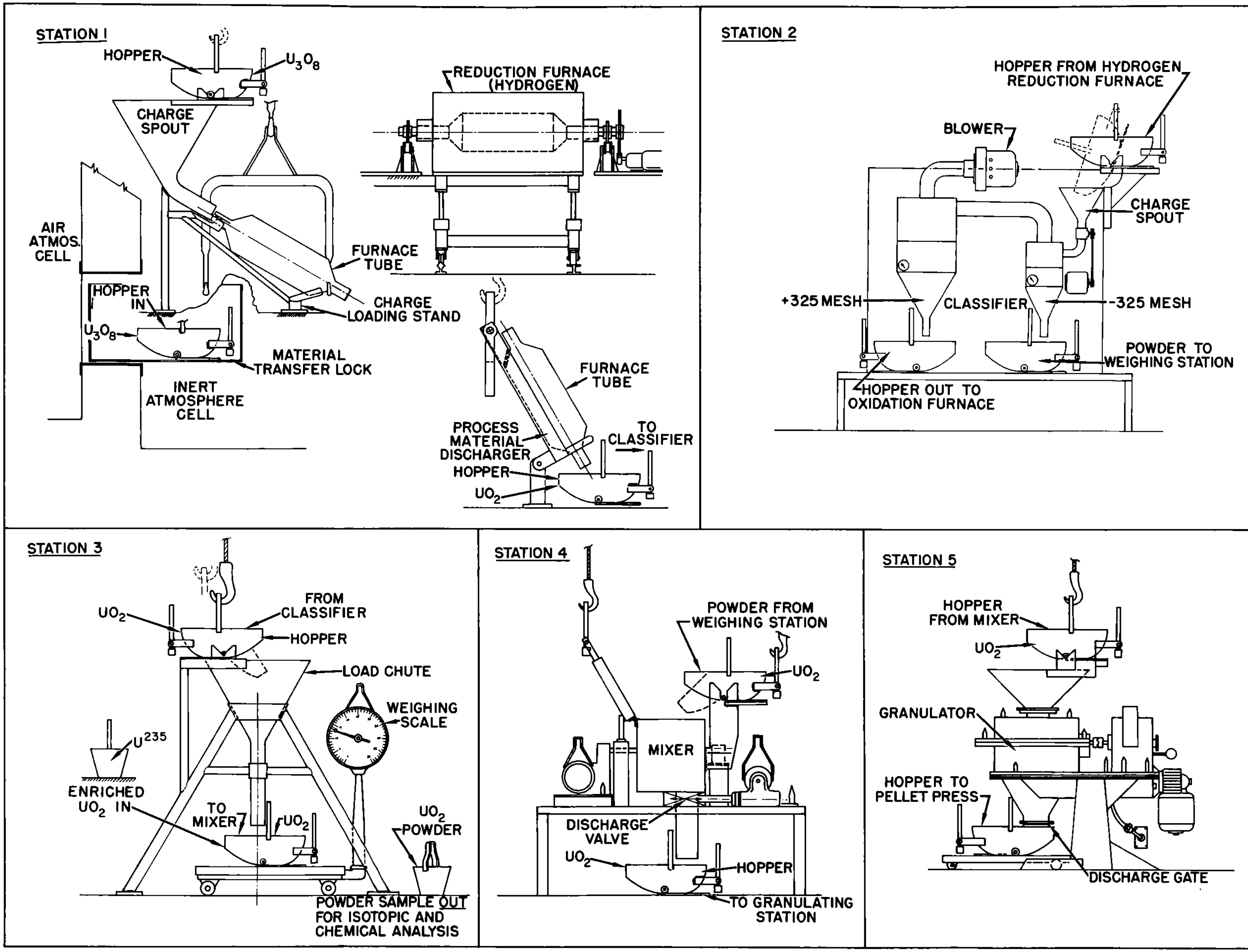

Figure 20. Powder and Pellet Handling Methods
(Stations 1 through 5)

photographic enlarger and counted with a calibrated transparent overlay grid. Early results show promise of producing a satisfactory method for the determination of powder size in the PRE cells.

The charge spout of the 12-ton pellet press will be provided with a cradle mount to receive the hopper trunnions, as shown in Station 6 of Figure 21. The compacting of the free-flowing UO_2 powder granules, transported by in-cell handling equipment from the granulator, into right solid cylinders is a remotely controlled pellet press operation. The green pellets produced by the 12-ton pellet press are automatically ejected, by the filler shoe of the press, into the tilted press chute which empties its load into the pellet-tray assembly shown in Figure 20.

The pellet tray synchronizes the relative rotary and vertical motions of the pellet-tray assembly. The assembly is positioned so that each tray level in turn is made to match the exit end of the pellet press chute while the assembly is being loaded by gravity. A spot check of the density of the green pellets is made as a method of process control by weighing an occasional pellet in the weighing station shown at Station 6 in Figure 21. A green pellet is handled at the weighing station by the in-cell rectilinear manipulator.

Pellet trays, for use in PRE process studies of presintering and sintering, were made of molybdenum to withstand the high temperature and corrosive atmosphere of the sintering furnace. The pellet-tray assembly is a direct means of remote control handling of a large quantity of UO_2 pellets evenly distributed in each tier of trays. It is an integral part of the CO_2 gas-manifolding system, which ensures a positive gas flow pattern over each tray of loaded pellets.

The presintering furnace charge is made up of a cluster of four pellet-tray assemblies, loaded with green UO_2 pellets which have been transported from the pellet press by the in-cell crane. The cluster-handling device (shown in Figure 22) consists of a circular top plate with a standard PRE lifting bail[29] attached, and a circular base plate which supports four pellet tray assemblies and directs the flow of CO_2 from the furnace-manifolding system to the manifold tubes of the pellet-tray assemblies during presintering. A 2-pawl grapple

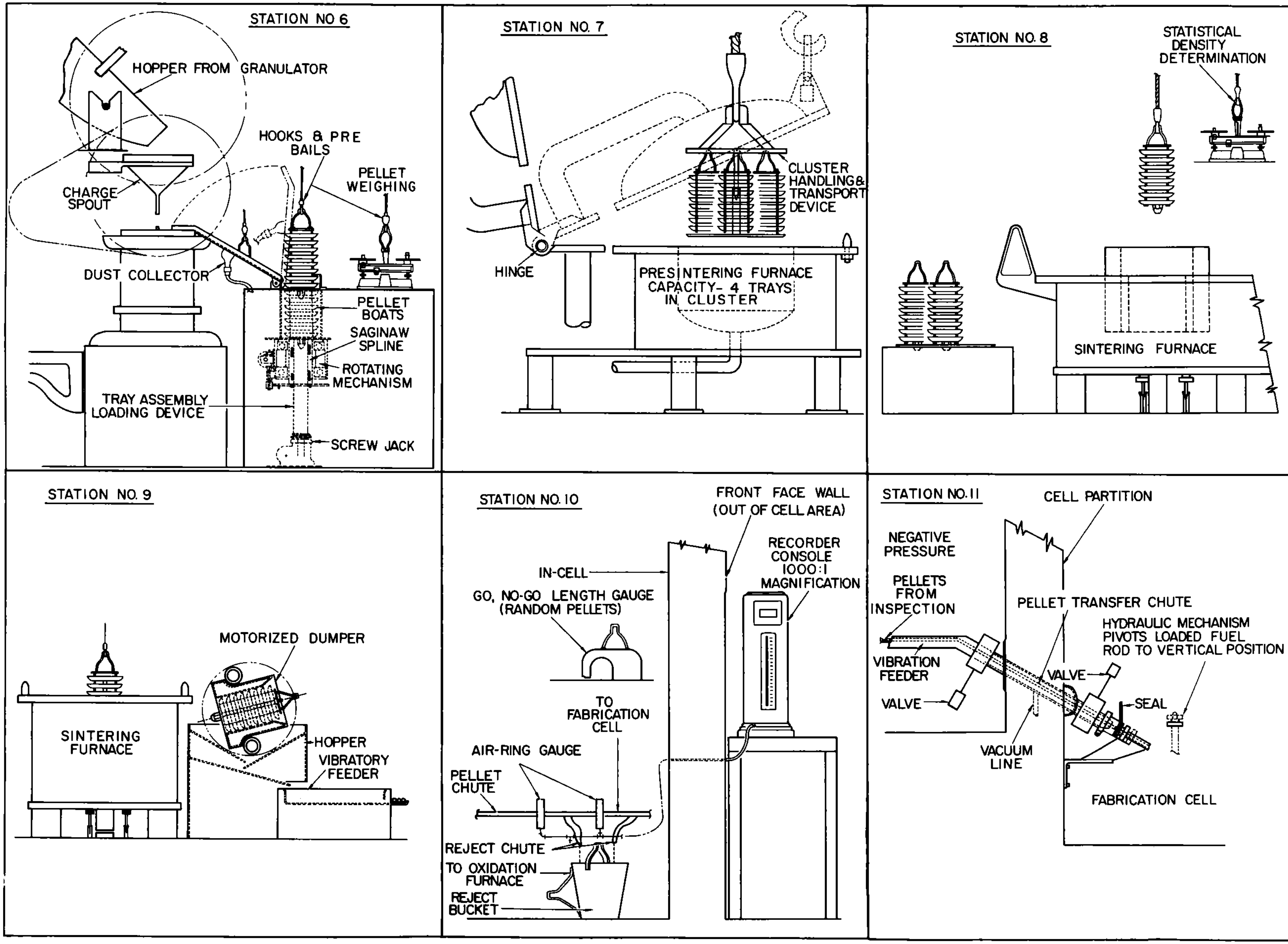

Figure 21. Powder and Pellet Handling Methods (Stations 6 through 11)

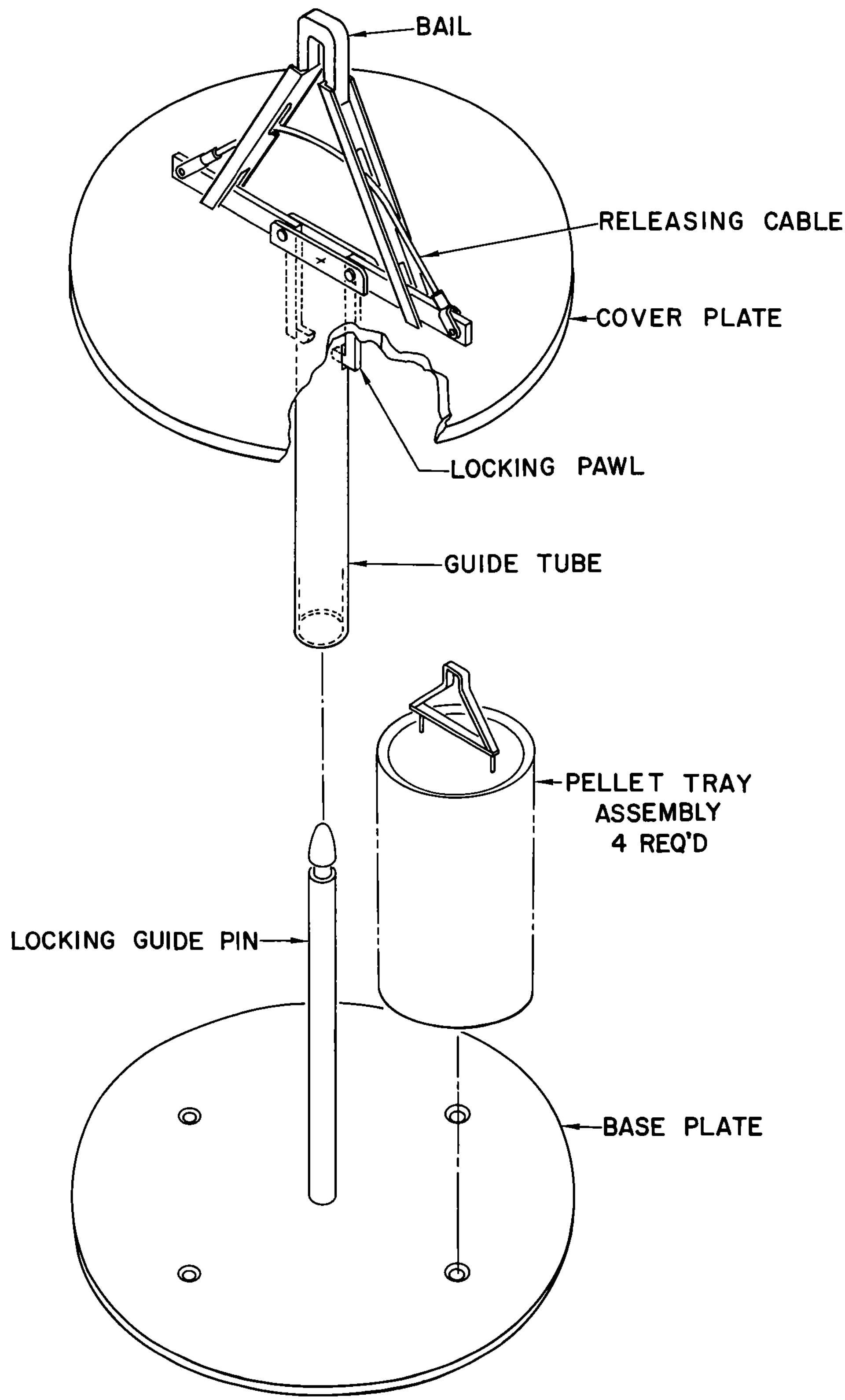

Figure 22. Cluster Handling Device

engages and lifts the loaded cluster when the grapple is lifted by the bail during the charging or discharging of the furnace with the in-cell crane. The grapple releases when it is lifted by the releasing cable after the cluster is loaded into the furnace.

The remotely operated sintering furnace is charged with UO_2 pellets, which have been previously processed at the presintering furnace station. UO_2 fuel pellets are transported to the sintering furnace by the cluster handling and transporting device. The internal configuration of the sintering furnace will probably be designed to accommodate one loaded UO_2 pellet-tray assembly at a time. In preparing the charge for the sintering furnace, the UO_2 pellet-tray assemblies are disassembled from the cluster by the in-cell crane. The detached pellet-tray assembly, with its lifting bail, is transported from the disassembly station by the in-cell crane and lowered into the sintering furnace, as shown in Station 8 of Figure 21. After the completion of the process cycle in the hydrogen sintering furnace, the UO_2 pellet-tray assembly is removed by the in-cell handling equipment and transported to a pellet-weighing station to determine the density of random lots of pellets. The in-cell pellet-weighing equipment located at this station is similar to the unit used at the pellet press station.

At the pellet inspection station of the inert-atmosphere process cell, as shown in Stations 9 and 10 of Figure 21, the batch of sintered pellets is unloaded from the pellet transfer tray assembly into the hopper of a vibratory feeder, which positions the pellets and moves them at the proper speed from the agitator along the pellet guide chute to the air-ring gauge. Pellets are automatically sorted into Go, and No-Go sizes. The counting and transporting of good pellets to the fuel rod fabrication device is the next operation to be performed at the pellet inspection station. The subtolerance pellets are to be processed again, into powder of -325 mesh, in the oxidation-reduction furnace. The transport of rejected UO_2 pellets from the air-ring gauge to the air atmosphere process cell for reoxidation is the last operation to be performed.

The pellet inspection air-ring gauge is a bench-mounted, remotely operated unit which measures the dimensions of sintered pellets by the variation of pressure or flow of air through the annulus between the pellet and the ring gauge. The gauge is a comparator instrument that indicates dimensional deviations from masters of a calibrated size and tolerance. The response of the gauge is not affected by the length of piping from the instrument to the recorder. The recorder console will be installed outside the cell wall.

Pellets from the inspection device are transferred from the inert atmosphere process cell to the air atmosphere fabrication cell through a transfer chute in the wall between the cells. Development of the chute in PRE has been described elsewhere.[7-10]

3. Future Development Plans

a. Mixing

The ribbon mixer would be installed in the proposed PRE exclusion area, operated by personnel contact. Two hundred pounds of simulated UO_2 powder with organic binder would be placed in the mixer and operated to ascertain the optimum operating conditions of mixing time and shaft speed. Heat cycling runs would be made in the range of 120° ambient temperature to 375°F for 2 hr, to demonstrate the operational stability of the mixer in simulated operation with radioactive UO_2. High temperature operation duplicates the thermal conditions produced by beta-gamma heating of irradiated fuel.

Air driven motors and linear actuators would be substituted for the electric units now installed and demonstrated under the same operating conditions. This modification would permit the interchange of motive power to the mixer if electric units were found to be damaged by radiation effects of the irradiated UO_2 fuel.

After the optimum operating conditions were established with UO_2, the mixer would be moved to the PRE mockup where it would be operated remotely under simulated in-cell conditions. The electrical control console would be designed, fabricated, and installed on the front face of the mockup cell. Modifications would be made, as necessary, before considering the development task complete and before designing a mixer for installation in the PRE process cell.

b. Granulation

Remote operation and maintenance techniques for the modified granulator have not been demonstrated. Test runs on mechanical and electrical components have been performed only by contact operations.

In order to conduct simulated in-cell remote maintenance operations on the individual units of the granulator, standard PRE lifting bails[29] would be installed. Air motors would be substituted for electric motors if the electric units were found to be damaged by radiation effects induced by the irradiated UO_2 fuel.

The manually operated selector mechanism of the rotor assembly, which is used for shifting either to rotary or oscillatory motion for granulation, would be modified to permit remote actuation by a double-acting air cylinder. A remotely controlled mechanical override system would be installed on the free end of the rotor driveshaft to rotate it, in case of failure while processing UO_2. Demonstration of remote operation and maintenance would permit installation of the granulator in the proposed PRE hot facility.

c. Pressing

No modifications have been made on the 12-ton pellet press to adapt it for remote operation and maintenance. Future development plans call for removal of the complete die and punch configuration from the press and substitution of a packaged assembly, as shown in Figure 16.

The manual control unit for the variable-speed drive would be altered so as to be operated by a remotely controlled device. A remote device would be installed to duplicate the contact operations of hand turning the inertia flywheel for the initial start and punch adjustment. A double-acting air cylinder would be incorporated for engaging and disengaging the main drive clutch. An integrated lubricating system would be installed, with provisions to control the escape of surplus lubricants around the die and punch area. Remote handling accessories would be installed on the electric drive motor, and electrical disconnects would be devised and tested.

Decontamination procedures for the unmodified portions of the press and for the holding fixtures, and transport dollies would be investigated.

After process study of pellet pressing in the PRE exclusion area, the press would be moved to the cell mockup for demonstration of remote operation and maintenance.

d. Presintering

A mockup prototype presintering furnace would be fabricated, in accordance with the conceptual design of Figure 18. The furnace would be operated in the PRE exclusion area to optimize operation techniques and moved to the mockup for demonstration of remote operation and maintenance procedures. The furnace would be modified, as required, based on the mockup operating experience.

e. Sintering

Process study of steam sintering at 1400°C would be initiated. Conceptual design of the sintering furnace would depend, in a large part, on the results of the process study. A conceptual design would be made of a furnace employing an air lock complex to prevent the influx of cell atmosphere to the furnace while loading and unloading. Test runs on the furnace assembly would be made to determine modifications required for remote operation and maintenance. The equipment would be mocked up, in the PRE mockup cell, to ascertain that the design was ready for in-cell application.

f. Pellet Inspection

The pellet inspection device and its associated component parts would be integrated into a remotely operable bench-mounted unit. The vibrating feeder would be tested, under simulated effects of beta-gamma heating of the irradiated UO_2 fuel pellets. The electrical components of the unit would be modified such that remote removal or replacement could be demonstrated. The air-ring gauge, with its leading and trailing pellet guide chutes, would be designed and fabricated. Mockup studies would be undertaken to devise either a mechanical or electronic rejection mechanism for the No-Go sintered UO_2 pellets. Transporting the accepted pellets from the air-ring gauge, either by the in-cell crane or by gravity, to the transfer chute; and automatic counting of pellets, by mechanical or electronic devices, will require study and development.

D. FUEL ELEMENT FABRICATION

1. Terminal Status

a. Rod Fabrication Device

A prototype device for fabricating fuel rods remotely, from UO_2 pellets made in PRE, has been operated in the PRE mockup.[28] Short dummy rods, similar to SRE fuel rods, have been consistently sealed with leak-tight structurally sound welds between the stainless steel cap and can. All components of the prototype rod fabrication device are remotely maintainable. Further development of the device is required before installing it in the PRE hot cells.

b. Leak Test Device

A leak test device is to be used to check the integrity of the cap-to-can weld of each PRE-made fuel rod, after fabrication in the rod fabrication device. The leak test device will be installed in the fabrication cell adjacent to the rod fabrication device. This cell will have an air atmosphere.

The leak test device will consist of a vertically mounted cylindrical test chamber, approximately 9 ft long, with a top cap which can be removed and replaced by the in-cell crane. The device is to be connected to a vacuum system in the fuel transfer tunnel and, through remote control valving, to a mass spectrometer leak detector located in the operating gallery. Figure 23 is a general arrangement drawing of the complete device.

A remotely operable coupling is installed in the vacuum manifold immediately adjacent to the test chamber to make it possible to remove the chamber from the cell. Figures 24a and 24b show a mockup of a remotely operable manifold coupling, including a simulated vacuum valve. Figure 24a shows the closed coupling. In Figure 24b, the coupling is unlocked and a simulated valve and seal have been removed. By use of only the in-cell crane, this mockup coupling has been unlocked, the seals replaced, the simulated valve replaced, and the coupling closed again. Leak tests, made with a mass spectrometer leak detector after this demonstration, showed zero leakage. This coupling has other applications in PRE in which the valve is required; however, for use in the leak test manifold, no valve is required and the manifold flanges will be brought together with only the removable seal between.

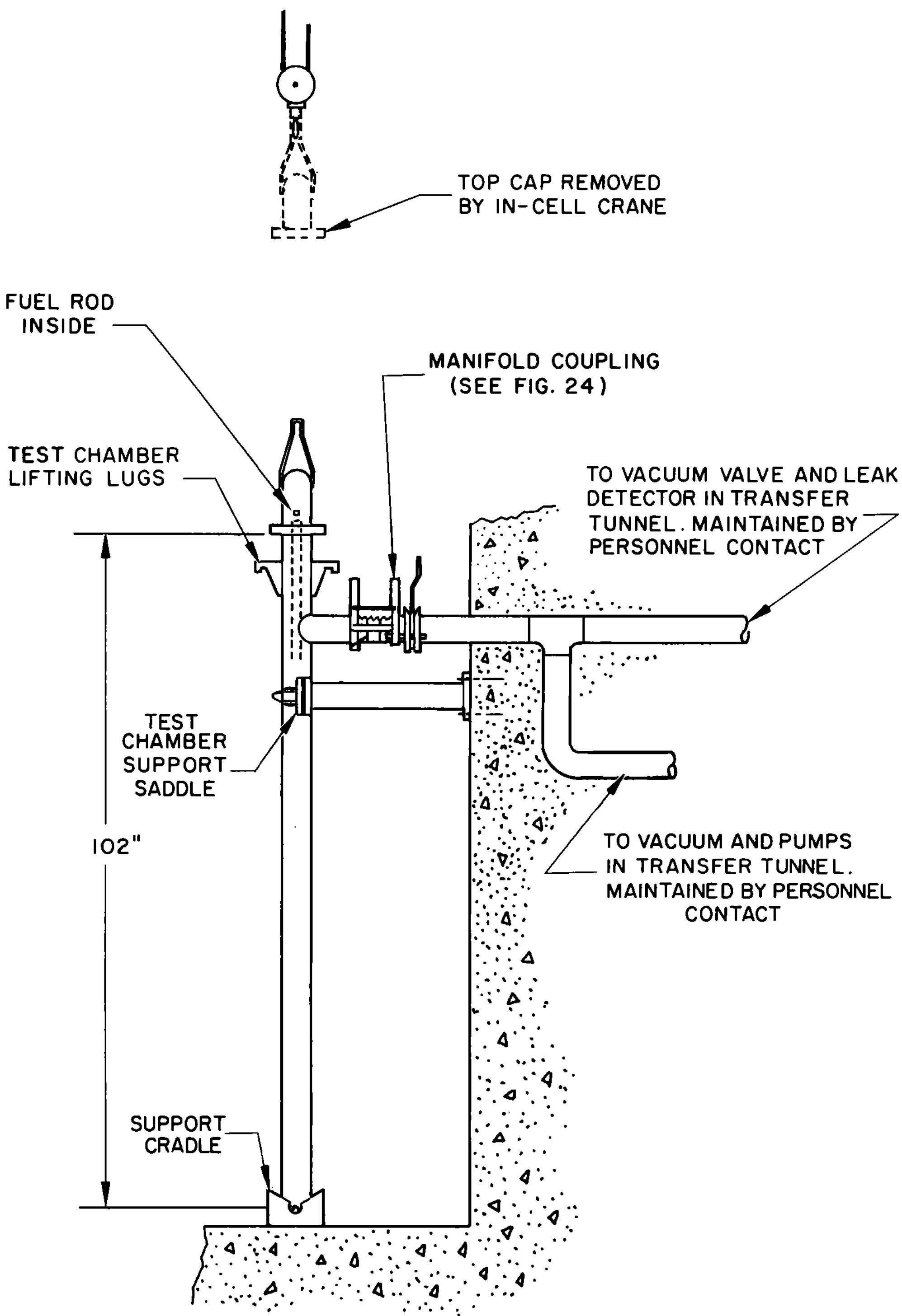

Figure 23. Leak Test Device

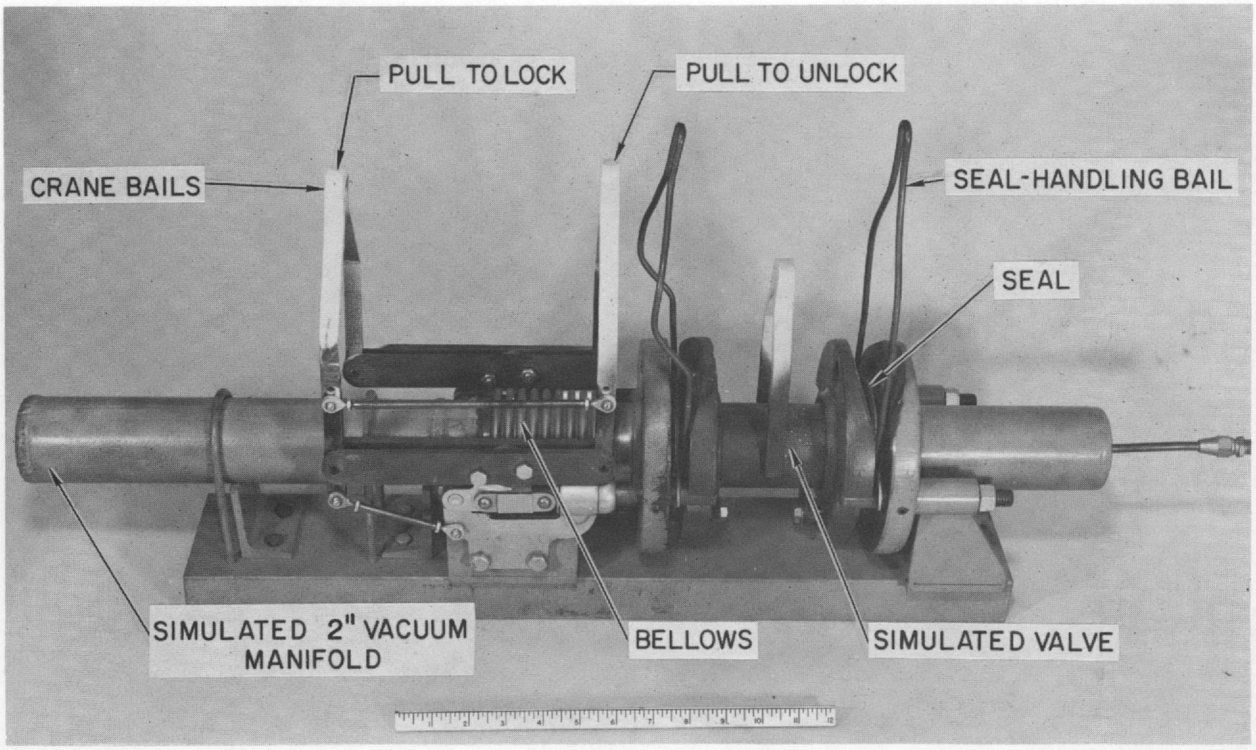

Figure 24a. Simulated Vacuum Manifold Coupling - Closed Position

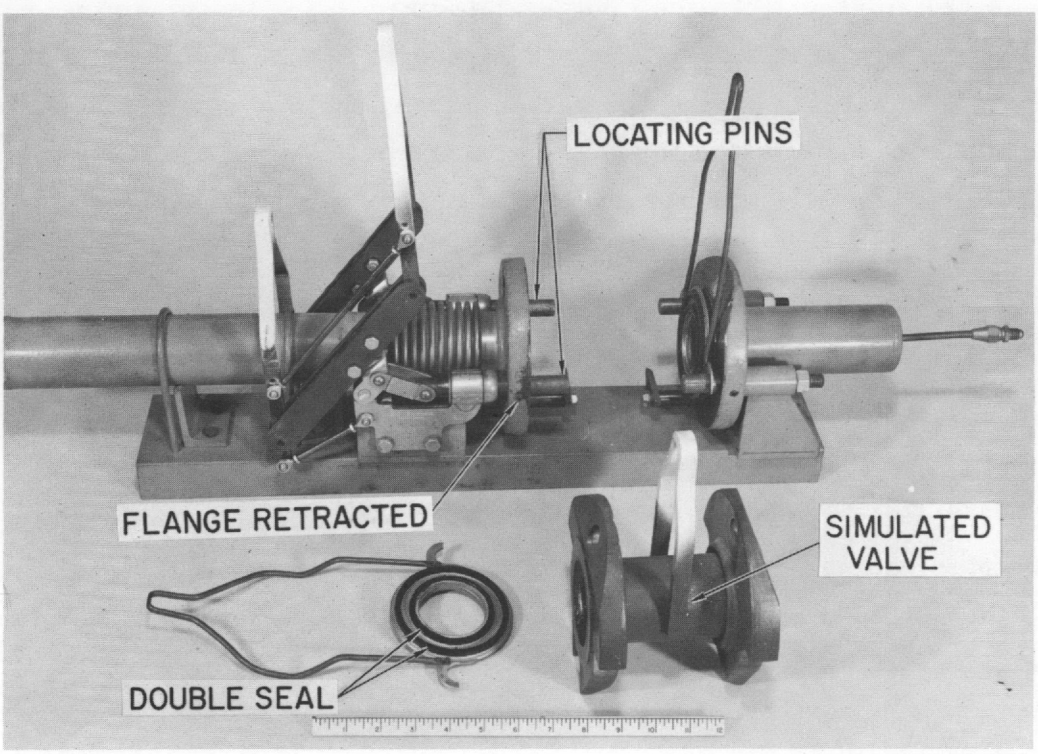

Figure 24b. Simulated Vacuum Manifold Coupling - Valve and Seal Removed

The test chamber can be lifted out of the support cradle, after unlocking the coupling and removing the bolts in the support saddle with an impact wrench.

The top cap of the test chamber is provided with a lifting bail to permit easy handling by the crane. A seal ring on both sides of a metal retainer, as shown in Figure 24, is placed between the top cap and the top flange of the test chamber to seal the cap to the chamber. The seal ring can be remotely replaced with the in-cell crane or manipulator.

Operation of the leak test device will consist of a rough pumpdown of the chamber, by pumps located in the transfer tunnel, and sampling of the chamber vacuum, by a mass spectrometer leak detector located in the operating gallery. The fuel rod, as it is received from the rod fabrication device, contains a helium-argon atmosphere at a pressure of about one-half standard atmosphere. If there is a leak in the cap-to-can weld of the fuel rod, the helium escaping from the defectively welded rod into the test chamber will be detected by the mass spectrometer.

The valves installed in the vacuum manifold will allow the mass spectrometer to be isolated from the contaminated air in the test chamber while it is being evacuated by the pumps. They will also permit the isolation of the vacuum pumps from the system, during the vacuum sampling phase, and will protect the vacuum of both the pumps and the mass spectrometer when the test chamber is open, during the insertion or removal of a fuel rod.

Handling of the fuel rod in its supporting tube and handling of the top cap of the leak test device will be simple crane operations with, possibly, light assistance from a manipulator to prevent swinging of the fuel rod as it is placed in the device. The entire operation can be monitored visually through the cell window.

The short, mockup leak test device, shown in Figure 25, was used to test the O-ring vacuum seal and to demonstrate handling of the top cap of the device by the in-cell crane. Tests made with the short, mockup leak test device,

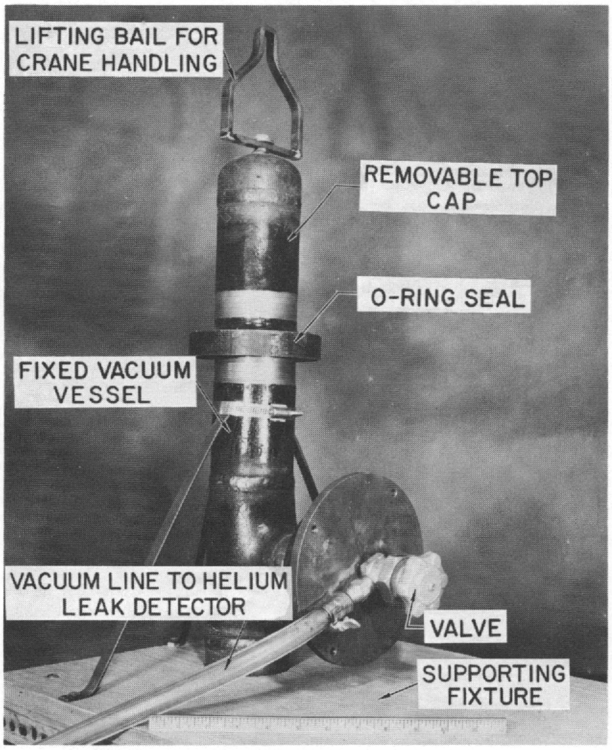

Figure 25. Leak Test Device Mockup

shown in Figure 25, have proved that the weight of the cap on the O-ring provides sufficient sealing to allow pumpdown of the chamber. The top flange of the chamber is beveled, as is the inner surface of the skirt on the cap, to permit easy positioning of the cap by the crane.

The remotely operable coupling, shown in Figure 24, was used to demonstrate the remote replacement of vacuum seals. This coupling will make it possible to disconnect the test chamber from the fixed manifold if it is necessary to decontaminate, repair, or replace the test chamber. Development work done to date has shown no serious shortcomings of the design. The preliminary tests indicate that the top cap seal concept is sound, the manifold coupling can be operated, and seals can be remotely replaced.

2. Future Development Plans

a. Rod Fabrication Device

The prototype bell jar assembly, with some modification, will be used to study the effects of heat on the operation of the turntable bearing, drive motor, and indexing mechanism. Resistance heaters can be used to simulate the induction furnace of the in-cell rod fabrication device. In addition, techniques for remotely maintaining all mechanical components can be worked out and demonstrated. By use of the prototype bell jar and the most recent version of the integrated welding-chill block mechanism, further studies can be made of the variables which influence the quality of welds.

Test runs to date have shown that effort should be turned toward the development of a bell jar which can be removed from and replaced on the base plate of the device without the use of the crane. Complete removal of the bell jar, to load and unload the device, entails the use of a bail and requires extreme care to avoid damage to mechanisms, on the top of the bell jar as well as the turntable, which could be stuck by the bell jar. Remote removal of the bell jar is slow and occupies the crane in a repetitive operation which could be done by a simple mechanism. The bell jar presently in use, if properly hinged and counterbalanced, could be opened and closed by a remotely controlled air cylinder. This design change also reduces both the number of automatic electrical disconnects and the frequency of make and break of the circuits feeding the bell jar.

The development of in-bell jar actuator units can be carried on, using the current bell jar vessel. Combined assemblies of the rod fabricating mechanisms and their actuator assemblies, installed entirely within the atmosphere envelope, can be investigated to eliminate the dynamic shaft seals now in use.

Continued operation of the device may disclose difficulties in the operation of the turntable drive motor in a vacuum or inert atmosphere. If so, either an externally mounted motor could drive the turntable, by means of a vacuum-sealed shaft passing through the base plate; or an inert-gas-operated actuator, internally mounted and exhausting outside the vessel, could rotate the assembly.

b. Leak Test Device

The next phase of the development of this device should be the construction of the complete, full-size, in-cell system, followed by operation, using dummy fuel rods containing the helium-argon atmosphere. Rods known to leak should be tested. Remote maintenance techniques must be further developed, using the complete system.

E. IN-CELL MATERIAL HANDLING

1. Pneumatic Crane

a. Introduction

A principle aim of the PRE is to develop prototype equipment for a production facility for processing irradiated fuel. This equipment must be capable of functioning under the worst possible environmental conditions in the PRE hot cells. Any low-decontamination fuel process, in all probability, will require at least one cell having an inert gas atmosphere, necessitating either the use of gas-tight seals or the adaptation of the equipment for operation with the same gas serving as the cell atmosphere.

Numerous hot cells in use today were equipped with the understanding that periodic maintenance by personnel contact would be possible during scheduled shutdown of hot operations. For PRE purposes, no access to hot cells by personnel is permissible after the initiation of hot operations. It is assumed that every in-cell mechanism will fail during its lifetime in the facility; hence, the design and development efforts must be built around a feasible, remote-maintenance procedure. The service needs of processing equipment require the installation of a crane, at a height sufficient to maintain all other mechanisms in the cell. Reliance on the crane for the maintenance of in-cell equipment, and also for the performance of some processing operations, requires that it have a high degree of dependability. The crane has this potential, since the components which are vulnerable to radiation damage will generally be far enough away from radiation sources to have acceptable life expectancies; and also its handling capacity is very large, as compared with the other devices in the cell.

The guiding concept for the development of an in-cell crane is that it will be the basic in-cell handling mechanism, and should perform the maximum number of handling operations with a minimum of assistance from other devices.

Operating requirements for a crane to be installed in the proposed PRE hot cell facility include: provide maximum cell coverage; provide maximum sensitivity of control commensurate with both simplicity of design and ease of maintenance; permit the use of mechanical overrides to position an inoperable crane carriage for removal from and replacement on its runways; be capable of functioning in an inert atmosphere without contaminating the atmosphere; and permit the remote removal and replacement of each and every in-cell mechanical component, individually or in an integrated assembly, of the crane installation.

Considering the various operations[29] which the PRE crane is relied upon to perform, the major crane hook requirements are as follows:

1) It must be stationary, in a position either parallel or perpendicular to the cell wall.

2) The hook should be capable of rotation in a full circle, but with fixed indexing stops at 0, 90, 180, and 270 degrees in the swing circle.

3) It must have sufficient throat clearance to allow for ease of approach in making contact with the bails.

4) The hook should approach all walls as closely as possible.

5) It should be fabricated from material capable of handling a 4000 lb load with a minimum acceptable safety factor.

6) The hook should not have a circular cross section at the point of contact with lifting bails; greater stability of load position is possible with a rectangular cross section.

7) The crane block should have some type of antiswing or swing-damping arrangement for the lifting cable.

Since the PRE crane must function in an inert atmosphere, its motors must operate with compressed inert gas in a closed system, and be effectively sealed to minimize leakage of the operating fluid which could alter the cell atmosphere. When using inert gas as motive power for the crane, some leakage from the crane could be tolerated. Any leakage from the crane motors into the cell would be adjusted for by the compressor in the gas-handling system, in order to maintain a negative pressure in the cell.

It is the intention of PRE to develop an in-cell crane, using components which are either prelubricated or capable of dry operation. This need is emphasized by the fact that most lubricants increase in viscosity, due to radiation damage, and thereby present both lubrication and contamination problems. Crane component temperatures may exceed 200°F, for prolonged operation with the trolley located directly under a cell light, thus accelerating lubricant breakdown.

Compressed gas is delivered to and exhausted from the in-cell crane through hoses connecting each drive motor with the gas supply and exhaust. The vulnerability of rubber hoses to radiation damage justifies the use of flexible metal hoses to give maximum duration of trouble-free operation. These hoses, with a burst pressure of about 800 psi, have a generous safety factor at an operating pressure of 100 psi. The disconnects of the gas supply system are to be handled by an auxiliary through-roof device.[33]

Control sensitivity, the ability of the bridge, trolley, and hoist to respond incrementally and smoothly to the operator's manipulation of the control devices, is of major concern to in-cell equipment operations. Therefore, special emphasis was placed on the selection of proper valving and control devices which determine lag in starting and stopping, the inching limitations, and speed variation.

The PRE philosophy of remote maintenance points out the need for providing a means of overriding the crane drive components after they fail, keeping in mind the possibility of completing the operation being performed at the time of failure. The override[32] positions the crane under a through-roof rigid-armed hoist[33] which can lift the crane carriage and then the crane bridge from their runways and lower each unit to the cell floor for replacement and/or maintenance.

Under conventional environmental conditions, a motorized crane should function properly with little, if any, repair for three to five years. Structural failures are usually caused by either the instability of the supporting structure or mechanical abuse. The resultant misalignment of the crane would present a major problem only if settling of the cell structure occurred after the cell went hot. This type of structural failure is rare and, for PRE purposes, can be considered negligible because major emphasis would be placed on engineered footings for the tremendous mass of the shielded cell complex. Mechanical failures will be more frequent, but can be minimized by cleaning and the replacement of bearings.

Electrical failures could occur in motors, connectors, conduits, and control boxes. The control boxes are vulnerable and therefore should be placed outside the cell. Premature breakdown of electrical components can be caused by overloading, or sudden reversals at high speeds and high loads.

Development efforts have been carried out primarily with an air crane installation in the PRE mockup; however, many of the solutions to the remote handling and installation problems are also applicable to the design of an electric crane.

With this philosophy in mind, a PRE design concept was developed of a crane for use under extreme conditions of radiation, inert atmosphere, and remote maintenance in a hot cell. As in-cell restrictions on crane performance are reduced, some of the components which are PRE necessities could be eliminated, with a consequent lowering of initial equipment costs.

b. Description of Equipment

The PRE cell mockup (Figure 3) consists of a partially enclosed steel structure, representing the in-cell walls, having approximate dimensions of 24 ft high, 30 ft long, and 11 ft wide. Support rails were installed on the side walls, at a height of 19 ft, for the crane bridge. The 7 ft 4 in. of vertical clearance between the rails provides the necessary clearance for the removal of the manipulator, by raising the arm carriage high enough for the arm to clear the bridge. The top of the framework, representing the ceiling of the cell, is approximately 4 ft above the crane bridge to provide the estimated clearance needed between the ceiling mounted in-cell lights and the crane trolley.

The PRE crane is a modified commercial crane, assembled from readily available parts, components, and subassemblies. Basically, it is a top-riding, 2-ton pneumatic, remotely operated bridge crane, consisting principally of:

1) Hook and block assembly

2) Rigging

3) Hoist unit with motor and drive

4) Trolley unit with motor and drive

5) Bridge unit with motor and drive

6) Air supply system

The PRE crane hook has an angular cross section, to provide a firm seat for a matching bail of the same cross section. To facilitate access to the matching bails, the throat clearance is increased over that of commercial crane hooks.

A block assembly, incorporating the hook-aligning device shown in Figure 26, provides a multiple-direction hook with fixed indexing stops at 0, 90, 180, and 270 degrees to the axis of the crane bridge. Indexing is actuated by lowering the crane hook until it strikes a horizontal surface and forces the hook to rotate through one quadrant and settle into that detent.

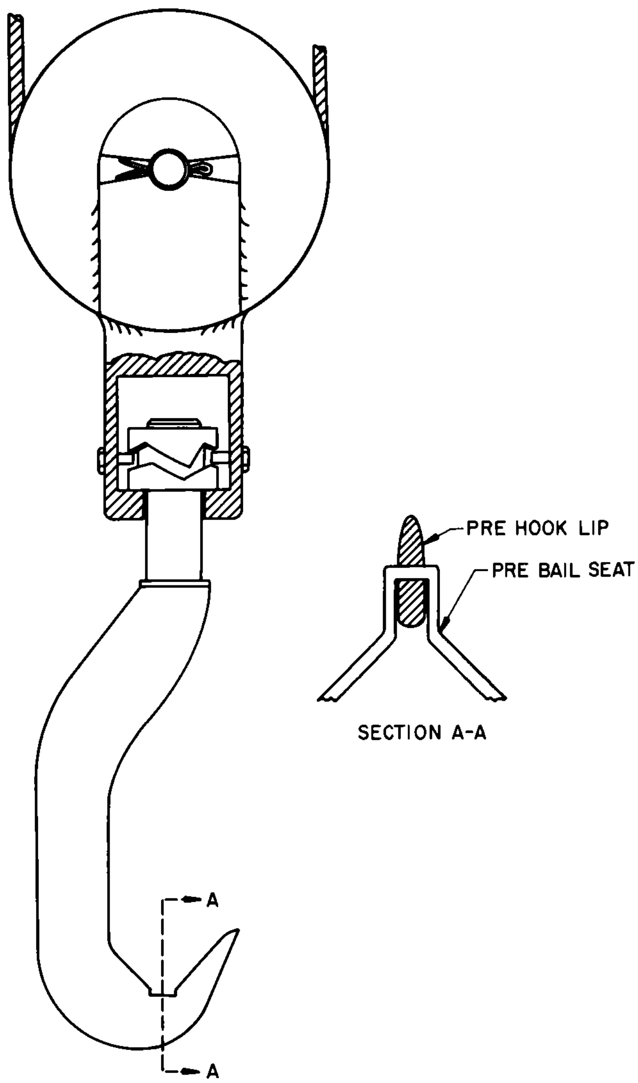

Figure 26a. Integrated Hook and Indexing Block

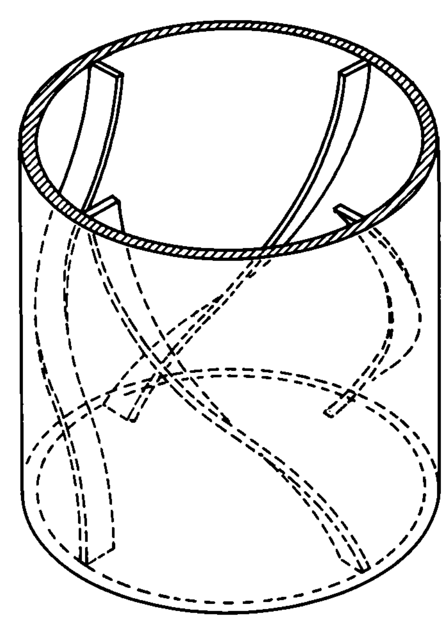

Figure 26b. Indexing Fixture for Conventional Free-Swivel Hook

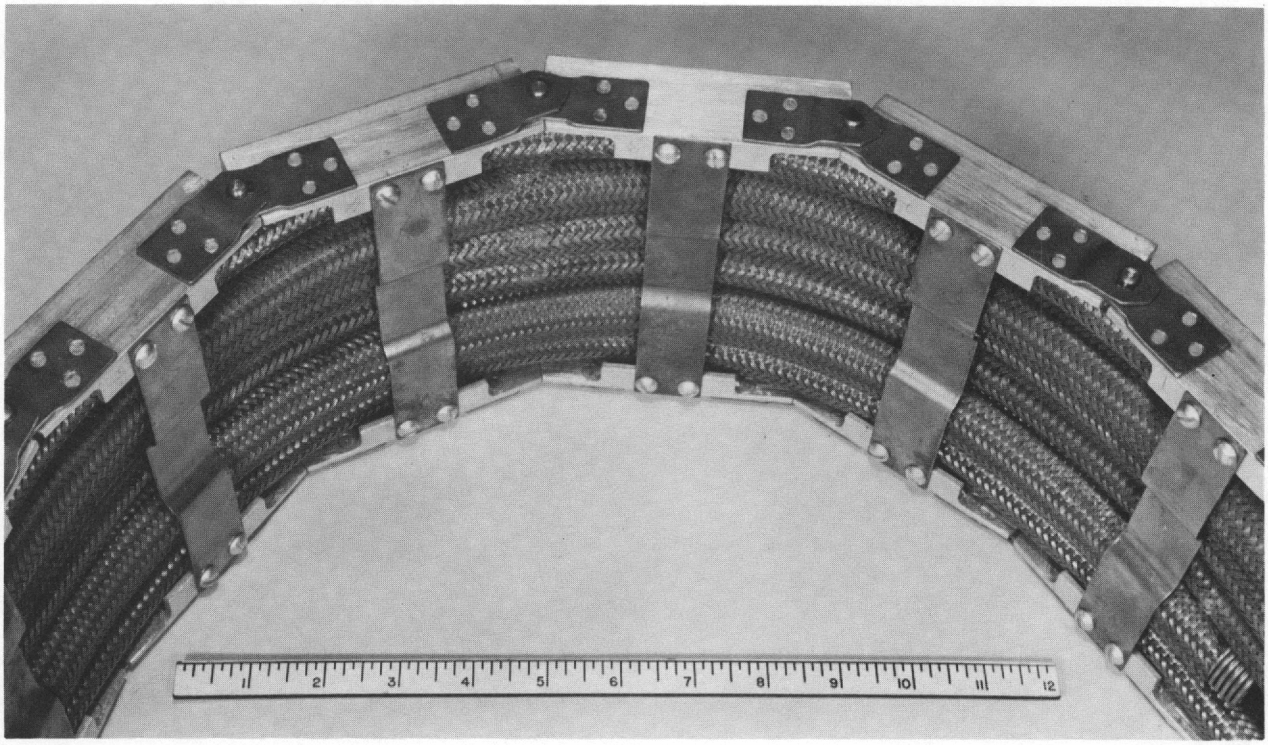

Figure 27a. Hose-Bundle Support Linkage

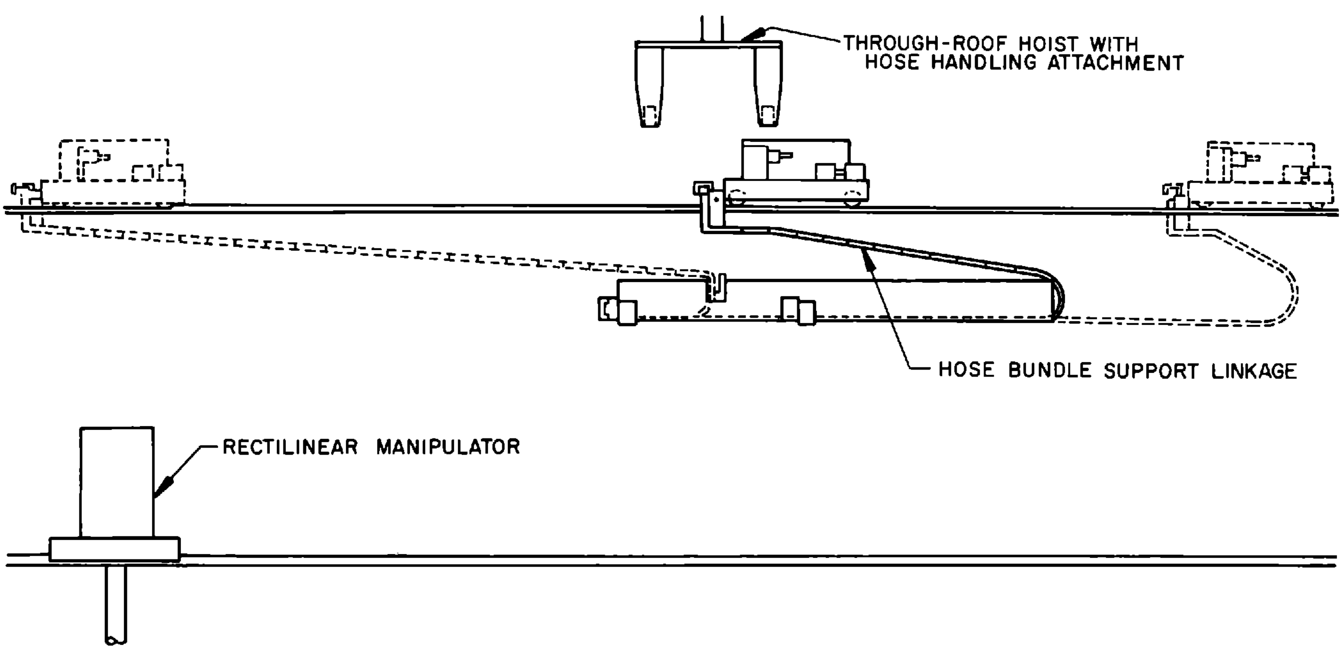

Figure 27b. Hose-Bundle Installation

The block and hook assembly is supported by a dual, two-part rigging system with one right-laid and one left-laid cable, to counteract the tendency of laid cable to stretch and twist under load.

The crane hoist is powered by a 3 hp air motor with an air consumption of from 0 to 90 ft^3/min, and a hoisting speed of from 0 to 30 ft/min.

The trolley is a top-riding unit, powered by a 1 hp air motor with an air consumption of 0 to 30 ft^3/min and a travel speed of from 0 to 10 ft/min. The crane bridge is a double-girder unit, powered by a 1 hp air motor with an air consumption of 0 to 30 ft^3/min and a travel speed of from 0 to 10 ft/min.

The hoist, trolley, and bridge drives are powered by high-torque piston-driven air motors with remote air valves and the motor exhausts exterior to the cell. These valves, with oilers and filters, are mounted on the face of the mockup structure, approximately in the center and at the 12 ft level.

All air supply and exhaust lines are flexible metal hoses held in a ribbon bundle by the hose-bundle support linkage, shown in Figure 27. The linkage restricts the travel of the hose loop to a plane parallel to the face of the cell and supports itself and the hoses. The hose bundle acts as a rigid spanning member, when extended in one direction, and folds as a loop to lie in a trough, as the crane moves toward the other end of the cell (see Figures 27a, b, c, and d). All subassemblies,[32] such as motors and gear boxes, are remotely removable units, thus providing for ease of maintenance and/or replacement.

c. Conclusions

The design and development efforts put forth on the PRE crane were based on a remote-operating philosophy that emphasizes the need for reliability and independence of operation of the crane in keeping all in-cell equipment able to perform its design functions.

Maximum sensitivity of control and hook stability must be preserved in any in-cell crane, if it is to perform as the primary tool for in-cell maintenance. It is doubtful that a simpler hoist rigging than the opposite-lay dual two-part system employed in the PRE mockup can give an in-cell crane the ability to perform its remote handling functions without appreciable support and guidance from the more vulnerable manipulators, which have much smaller load capacities.

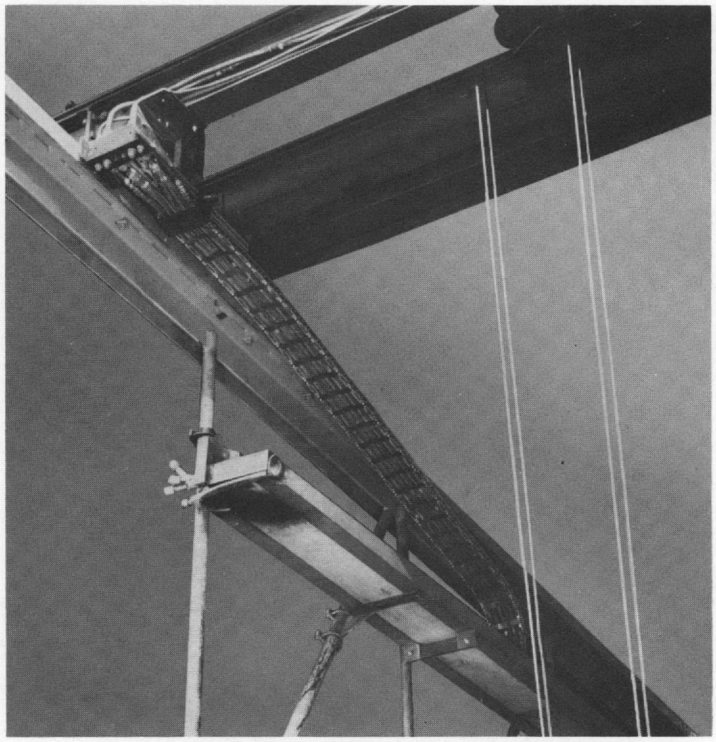

Figure 27c. Hose Bundle Installed in Mockup

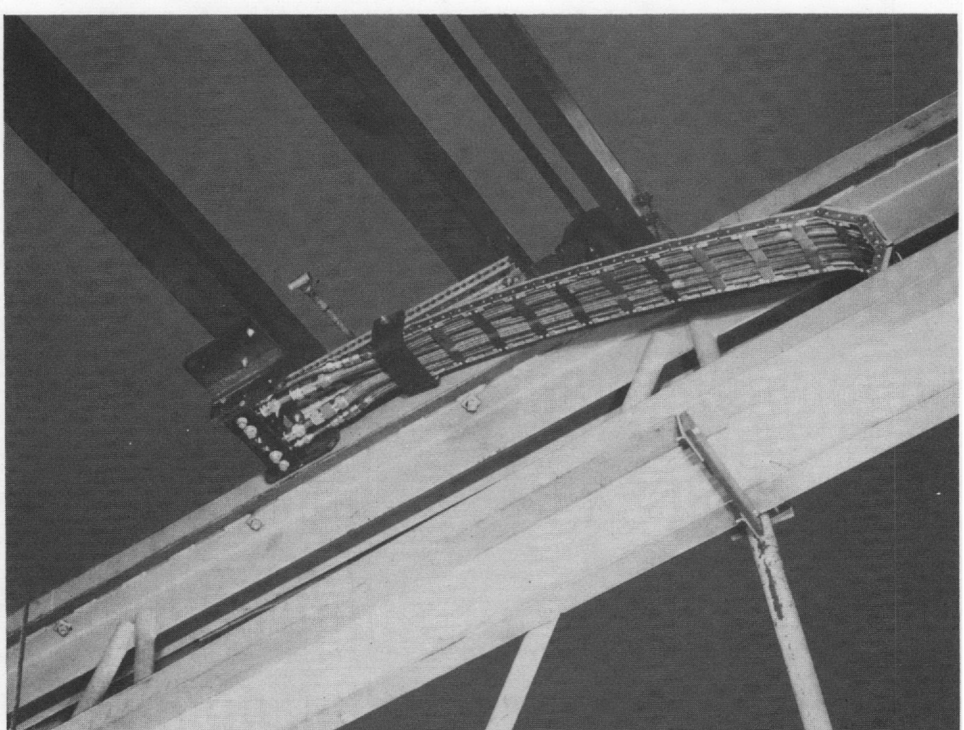

Figure 27d. Hose Bundle-to-Bridge Disconnect

The loop-in-trough configuration for handling air hoses is believed to offer fewer problems in remote replacement and to require less cell height than standard hose-and-reel installations.

Mechanical overrides must be incorporated in the original installation of any in-cell crane or rectilinear manipulator for which contact maintenance is impossible. The override system[32] must be designed to facilitate remote replacement of components. The override installation, if developed to the ultimate degree of reliability, would make possible the out-of-cell location of the primary motive power for the bridge and trolley. The PRE schedule of equipment development does not offer sufficient latitude to investigate the out-of-cell powered crane; therefore, the normal stationary type of override was selected. The mechanical components for such an override system would require maintenance only to overcome the effects of corrosion and, consequently, the required frequency of maintenance would be very low.

It is feasible to repair any malfunction of the crane by replacing the subassembly as a separate unit or by replacing the major component of which it is a part.

The gas used to power an in-cell pneumatic crane should be selected to have the same purity characteristics as the processing atmosphere, which is controlled by the economic limitations of the nuclear fuel under process. A helium-powered crane, operating in a cell containing a helium atmosphere, the development goal of the PRE program, offers the ultimate safety in inert environmental operations.

d. Terminal Status

(1) Hook Assembly

In order to facilitate crane operation of in-cell equipment over the maximum horizontal coverage, the hook must be rotatable. The initial development for hook positioning incorporated a free-turning hook which, when lowered into a fixture (Figure 26b) would be rotated from its existing position 90 degrees to a new position by the guiding action of the helical vanes.

The disadvantage of this system is that, with a free-turning hook, any collision with in-cell hardware would cause misalignment of the hook and would necessitate returning the hook to the fixture for realignment. This disadvantage was eliminated by including a hook-positioning device in the crane block (Figure 26a) and thereby enabling the hook to index through 90-degree increments by lowering the hook against any horizontal surface.

No matter how accurately the hook is directed, the point contact between a commercial crane hook and a bail of circular cross section is not conducive to maintaining a preset alignment between the hook and the load. Consequently, a crane hook with rectangular cross section was devised, to provide a firm seat for matching bails of the same cross section, as shown in Figure 26a. To facilitate access of the PRE crane hook to the lifting bails, the throat clearance was increased over that of commercial crane hooks. To provide uniformity of bails, the same dimensions were used on the rectilinear manipulator hook.

(2) Hoist Rigging

A crane hook is supported below the hoist mechanism by two or more cables. These cables are inclined to twist under load; this tendency makes a two-part cable rigging unacceptable for remote use in PRE hot cells, since the block-hook assembly would change direction with the elevation in the cell and with the load imposed. When commercial prestretched cable and nontwist cable were investigated in a two-part rigging, twisting of the rigging was excessive for the requirement of PRE. A dual two-part system, utilizing opposite-laid cables, proved to be satisfactory with respect to hook stability.

The requirement of maximum crane hook coverage of the cell area is sufficiently important to in-cell operations to warrant some recessing of the upper portion of the cell walls and the installation of the craneway therein. Location of hoist rigging and cable attachments will govern cell coverage in part.

(3) Air Supply

Power to pneumatic drive motors of the crane must be delivered and exhausted by simple and reliable plumbing. Most industrial air-crane installations use one air hose to supply pneumatic power to all crane-drive motors, with individual exhaust ports on each drive motor, and pilot-operated controls in the remote console. This plumbing configuration requires the use of remotely operated three-way valves on each drive motor to govern the direction of motion. The frequency of service required by these valves exceeds the maintenance requirements of all other mechanical components in most of these air-crane installations. Consequently, in the PRE air-crane installation, the valves were removed from the trolley and bridge and placed outside of the mockup to facilitate maintenance operations. Also, instead of exhausting air from the crane motors to the cell, the exhaust ports were plumbed to an out-of-cell exhaust. In PRE, the motors would exhaust outside each cell to avoid loading the cell-atmosphere purification systems. Closed-cycle plumbing and out-of-cell valving required the development of six flexible conduits to supply the mockup crane air-driven motors, as well as precision valving and control devices.

Several hose installations and the associated hose-handling systems were devised and evaluated. These systems include hose-and-reel combinations, a hose-bundle loop-in-trough arrangement, and a number of sheave-and-counterweight systems.

The mechanical feasibilities of hose-and-reel assemblies were determined by operation of a commercial air crane in the PRE mockup, with a hose reel placed in the upper center of each of three simulated cell walls. The action of the reels, both in swiveling and reeling, was spasmodic and uncertain. The reels were modified, by installing a metal divider to separate each of two hoses, and mounted without swivels at one end of the cell. Roller hose guides compensated for the loss of flexibility caused by omission of the swivels. Although bridge and carriage operations were improved, trolley and hoist hoses impeded movement of the trolley at the reel end of the cell; and, at the opposite end of the cell, spring tension in the three reels impeded movement of the bridge.

To decrease the number of reels, a flat multihose bundle was investigated. Since the hose life would be dependent upon the amount of flexure, minimum diameter reels were investigated. A reel to handle the hose bundle would be placed inside the cell at the ceiling and supported by a through-roof conduit which could be maintained in the same manner as the through-roof hoist.[33] Replacement and/or maintenance of the reel would be accomplished by lowering the unit to the floor of the cell for accessibility. The reel diameter required for this system would be in excess of 3 ft, thereby increasing the required cell height. To minimize cell height, the reel could be placed outside the cell in a gas-tight shielded glove box. Out-of-cell maintenance operations would involve normal glove box techniques. With the reel on the cell roof, the connect and disconnect of the hoses would require a through-roof actuating mechanism. Remotely maintainable reel systems have a low degree of reliability and component failure would not be readily detectable before damage could occur to hoses or connectors.

Hose configurations utilizing counterweights would require either remotely maintainable rollers to support the hose bundle or sufficient counterweight to support the hoses in tension. Both the weight of the hose catenary and tension loads on the hose would impede bridge movement as it traversed the length of the cell. With the end wall counterweight system, excessive hose length is required, decreasing the sensitivity of control and restricting the approach of the bridge to the end wall. This restricted wall approach can be reduced by recessing the hoses into the end wall, at the expense of both structural simplicity and ease of remote replacement. The hose length can be minimized by a center-wall counterweight; however, the hose bundle in this system interferes with rectilinear manipulator operations and has the same hose replacement disadvantages as above.

A coiled tag line, used with a multihose bundle, would require a large coil diameter, and a horizontal cable to support the coils. The detachment and replacement of the coils from the taut support cable would require complicated, through-wall handling equipment. The bulkiness of the bundle of coils would restrict end-wall approach of the bridge and/or side-wall approach of the trolley. Hose length could be decreased by fixing the coiled tag line to a through-roof conduit at the center of the cell and uncoiling the line from the center of the cell as the crane moved toward each end. However, failure of the tag line coil support wire with either configuration could cause excessive damage to the hoses. Remote maintenance is unnecessarily complicated.

A loop-in-trough system, with hoses bundled side-by-side to form a ribbon, was installed on the mockup crane. With the bridge at one end of the cell, the multi-hose ribbon is supported by an inclined trough. During crane operations at the other end of the cell, the hose bundle is supported and guided by a roller. This arrangement provided adequate hose support and permitted the remote removal of hoses. However, the sag of unsupported hose caused the upper hose to drag on the lower, thereby preventing smooth action; and the installation presented some interference to travel of the rectilinear manipulator. The installation of an additional trough was unsatisfactory, since repeated directional reversals of the bridge caused one hose ribbon loop to form on top of another, with resultant erratic movement of the bridge.

In order to prevent an overlay of the hose loops, a one-way-bend hose-bundle support linkage was devised (Figure 27). The linkage encases a bundle of hoses and limits the bend of the loop to one direction, with a radius large enough to give good hose life. The linkage serves as a beam in the other direction, with sufficient strength to support its own weight plus the weight of the hoses.

Maintenance and/or replacement of the hoses in a PRE hot cell can be accomplished by disconnecting the multihose assembly from the bridge terminal and lowering the hose-and-trough, as a unit, to the cell floor. The replacement of seals in the disconnect can be accomplished with the in-cell manipulators, once the hose unit is lowered to the cell floor. When the hoses require replacement and all the auxiliary equipment, including the crane, is inoperable, crane service can be provided by actuating the crane overrides. The override-operated crane would be used to position the replacement components beneath the through-roof hoist. In order to lower the hose trough to the cell floor (Figure 28) an auxiliary through-roof hoist would be activated. A cantilevered jib attachment on the through-roof hoist would be lowered, rotated to make contact with the bridge disconnect, and lifted to break the pneumatic connection between the multitube hose bundle and the terminal on the bridge. The bridge would be moved by the override system to clear the trough assembly and the disconnect would be lowered to its seat on the trough. The through-wall support mechanism would be actuated, both to disconnect the fixed terminal for the hose bundle from the terminal of the through-wall manifold, and to position the hose-trough assembly out from the cell wall and under the through-roof hoist. In this position, the assembly would be far enough away from the wall to clear all wall obstructions. The through-roof hoist would be used to raise

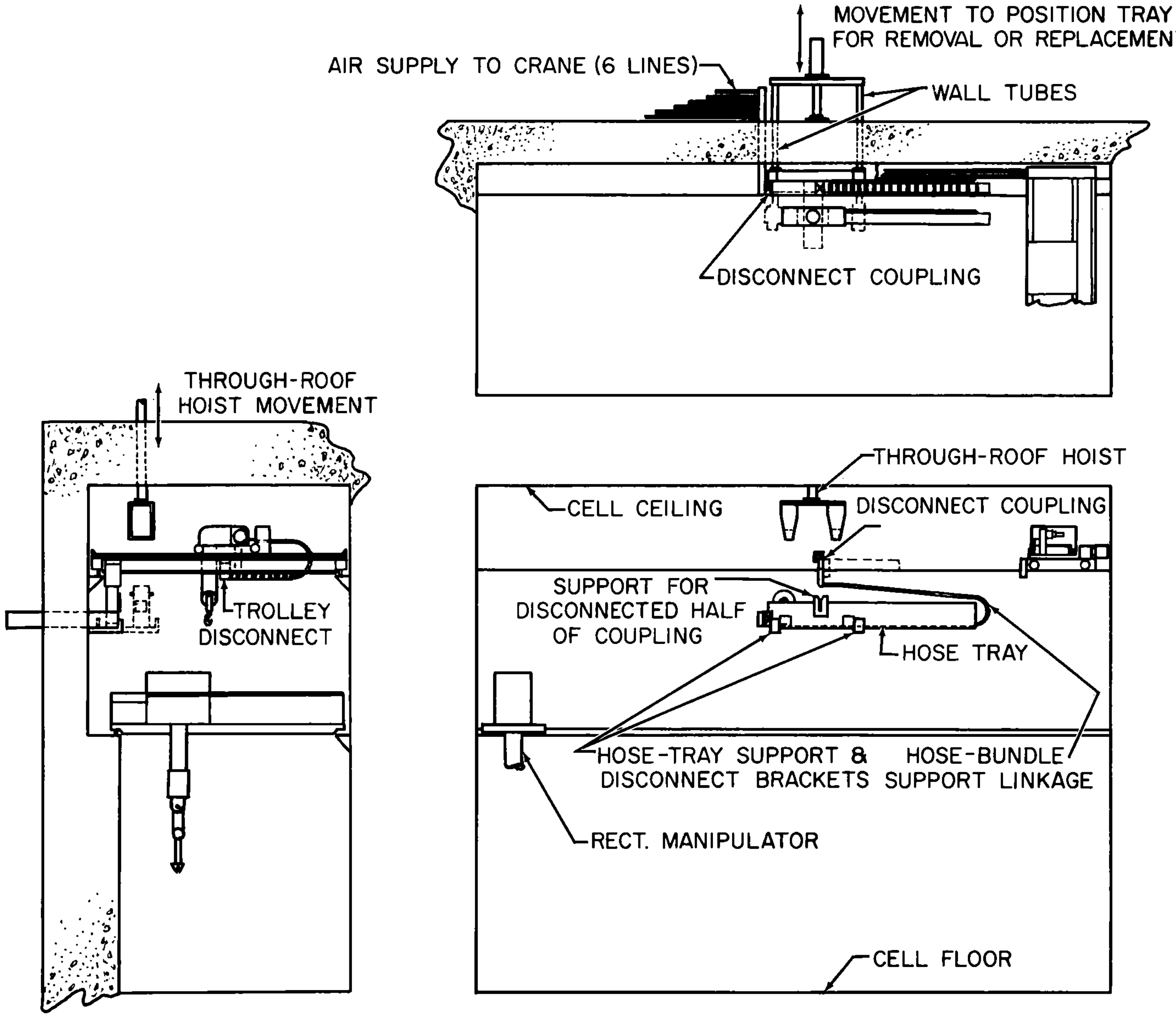

Figure 28. Hose Trough Removal Method

the trough and hose bundle as a unit and allow the support mechanism to be retracted. The loaded trough would be lowered to the floor for the necessary maintenance.

Four different hose systems for the crane trolley were investigated. A coiled tag line presents the same geometric and handling problems as the comparable bridge system. A pantograph support and hose assembly restricts the wall approach of the trolley to an unacceptable degree. A spring-loaded, weighted, or reel takeup attached to the trolley, however, requires a large bend radius in the hoses for good hose life and occupies too much space. A hose-support linkage, similar to the linkage used for the bridge, appears to be the most feasible support for the trolley air-supply hoses.

The trolley-hose system has been mocked up and satisfactorily operated; however, remote removal and maintenance of this system has not been performed. Detailed drawings of the trolley-hose disconnect have been completed. To accomplish hose replacement, the trolley would be positioned beneath the through-roof hoist and the trolley-hose disconnect would be actuated with the through-roof hoist. The trolley, hose, and trough would be lifted above the bridge and the bridge moved out from under the through-roof hoist with the bridge override. The trolley, hose, and trough would be lowered to the cell floor, as a unit, by the through-roof hoist for replacement of inoperable components. The through-roof hoist would lift the repaired trolley, hose, and trough as an integral unit; overrides then would be used to reposition the bridge to permit the trolley to be replaced on the bridge. The through-roof hoist would actuate the remote coupling to connect the crane to its power supply.

(4) Mechanical Overrides

The conceptual design of each remote override was evaluated, with respect to its potential use for the emergency completion of any crane operations and its ability to facilitate the replacement of the inoperable unit it serves.

The mechanical override system for the bridge assembly utilizes continuous double cables, installed parallel to each of the wall-mounted rails. Each of the cables would have a protruding dog attached to it to permit pushing the inoperative bridge in either direction. The cables and dogs would remain stationary, during normal crane operations. A chain-powered left-push dog would be stored at the front and rear rails on the right end of the cell and right-push dogs would be stored at the left end of the cell. The bridge override system incorporates through-roof pulley supports to permit replacement of override pulleys and cables. It is powered by a through-wall drive shaft and a power supply mounted in a glove box on the outer face of the cell wall. Further simplification in maintenance and operating techniques would be achieved with continuous chain and pulleys mounted in the cell wall where they would be accessible by out-of-cell glove box operations. Normal glove box techniques would be used for replacement of both pulleys and chains. The continuous chains should be located between the wall and the wall-mounted rails to minimize mechanical hindrance during remote removal of the bridge and loop-in-trough assemblies. The bridge override system was fabricated, installed in the PRE mockup on the rectilinear manipulator bridge, and satisfactorily operated.

One concept of a mechanical override for the trolley is the through-wall push-pull rod whose line of action intersects the line of action of the through-roof hoist at right angles. The in-cell end of the rod uses a twist-lock device to enable positive fastening to the crane trolley when the bridge is positioned beneath the through-roof hoist. The principal disadvantage of this device is its unipositional capacity for service. This concept has not been studied in the PRE mockup.

A hoist override system with an auxiliary air motor in a secondary drum has a high degree of versatility and permits the continuation of any operation being performed at the time of hoist failure anywhere in the cell. During normal crane operations, the secondary drum is the fixed point of hoist cable attachment. There is no air supply to the auxiliary motor. In case of primary hoist failure, the rectilinear manipulator plugs a two-conduit pneumatic probe into both an in-cell wall receptable and the auxiliary air motor in the hoist drum. The auxiliary drum hoist has sufficient capacity to complete operations from any position in which primary hoist failure occurs. The secondary drum would be pivot-mounted to maintain equal tension on the cables at all times.

e. Future Development Plans

A close examination of the PRE crane requirements reveals an interdependency of many of its associated problems. For instance, the technique of performing remote maintenance on the hose system is dependent on the type of override mechanism used. Consequently, the next effort should be expended on the development of override systems, keeping in mind the possibility of using them to continue crane operations for a limited period after crane component failure. It is proposed to investigate the feasibility of providing two overrides for each motion, one electrical and one mechanical, on the PRE crane mockup.

The redesign to eliminate unnecessary bulkiness of all control components is proposed. The modified console would contain electric switches which would remotely control solenoid-actuated air valves located conveniently on a panel outside of the cell. A signal light system, actuated by the hook's travel-limit valves on a pressure differential basis, would indicate on the control panel the upper limit of crane hook travel. A reliable electrical grid system, which would activate a light panel to indicate the horizontal location of the crane hook at all times, would be developed.

The development of equipment and techniques for remotely maintaining and replacing in-cell components will continue. A great deal of cooperative effort was expended in the development of a remotely operable and maintainable rectilinear manipulator.[32] The designs for compact, readily dismantled components developed therein are directly applicable to the PRE crane.

A dustproof cover for the crane carriage, including insulating material and a cooling system operated by the carriage motor air exhaust, would be devised. The cooling system would be required by the crane since prolonged operation of the crane, when located directly under a cell light, may cause a housing temperature well in excess of 200°F.

The requirements for motor lubrication must be determined. The use of graphitic lubrication and of graphite or other lubricant impregnated parts will be investigated, in an effort to eliminate the possibility of in-cell lubricant leakage. If fluid lubrication is necessary, two possible means of lubricating the trucks of the crane bridge should be considered. In one method, the bridge would be positioned at one end of the cell, where the air intake valve on the bridge would make contact with a supply nozzle on the wall. The tanks for new and used grease would be changed periodically. Development of an in-cell tank-changing technique is required. The second system uses a grease plunger on the end of a pole, which could be handled by the rectilinear manipulator.

Intensive investigation of maintenance and power feed requirements would be initiated to develop a prototype PRE electric crane. The concurrent operational evaluation of an air powered crane and an electrically powered crane, in parallel states of development, is necessary to select the best system for use in a PRE hot cell facility.

2. Rectilinear Manipulator

a. Terminal Status

In order to permit the handling, transfer, and maintenance of processed materials and equipment in the PRE, the development of a remotely maintainable rectilinear manipulator was undertaken. The manipulator, as initially installed, was a commercially available, general purpose, heavy duty, electro-mechanical manipulator. The major components include the track, the bridge assembly, the crane carriage, the telescoping hoist, the arm, the cable takeup, and the control console. Deviations from the manufacturer's prescribed operations are the result of PRE modification of numerous components; these modifications and the resultant operating requirements are described in a separate topical report.[32]

Operational attachments were devised to improve the versatility and reliability of the manipulator. Equipment and techniques were developed for mechanically overriding an inoperable manipulator, to position it for remote maintenance, as well as to complete limited emergency operations after the unit fails. Techniques were devised and the manipulator was modified to facilitate the remote removal and replacement of the carriage and bridge from the wall-mounted rails. Mechanical components of the carriage and bridge were modified to permit the remote removal and replacement of the inoperable components without removing the contaminated manipulator from the shielded cell complex. The manipulator drive mechanisms, modified for remote operation and maintenance, are shown in Figure 29. With these modification, inoperative components can be removed with the in-cell crane and replaced remotely. Mechanical overrides can be driven by a crane-supported impact wrench for emergency operation of the manipulator. Using the methods developed and demonstrated in the PRE

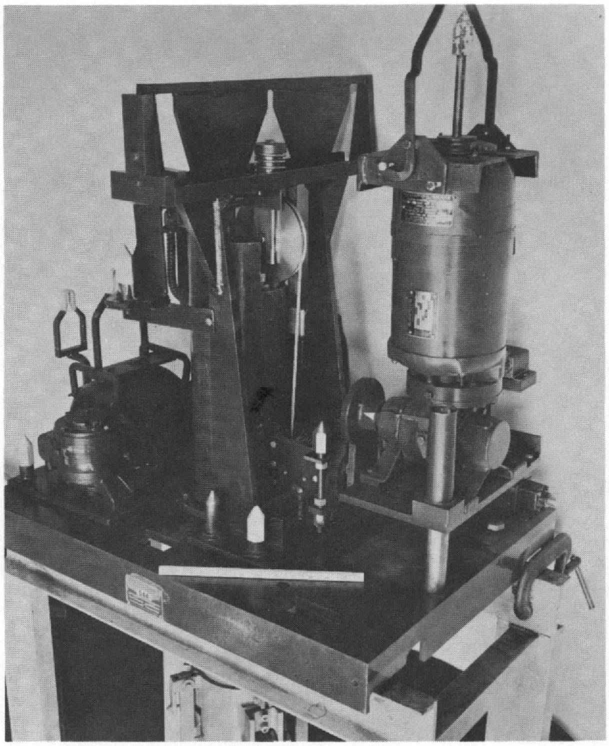

Figure 29. Modified Rectilinear Manipulator

mockup program, it is possible to remove an entire rectilinear manipulator, with the exception of the fixed bridge rails, and replace it from an operating cell, using only an in-cell crane and its attachments.

b. Future Development Plans

Mechanical development of the existing PRE manipulator should include additional modifications to facilitate remote maintenance of the arm assembly, facilitate remote removal and replacement of the main electrical cable servicing the manipulator and supported along the bridge rail installation, and permit booting of the manipulator's arm assembly in order to reduce decontamination required for contact maintenance of small components.

An investigation should be made of the operational and mechanical problems associated with mounting the carriage on the bridge, at right angles to its present position. In its present attitude, the short side of the carriage spans the rails on the bridge. In the proposed attitude, the long side of the carriage would span the bridge rails. Remote removal of the carriage from the bridge could be accomplished readily by lifting the carriage with the through-roof hoist, rotating it 90 degrees, and lowering it between the bridge span members. This method of carriage removal could be performed in a cell whose height is 4 ft less than that required for the carriage removal using the present method. This proposed manipulator geometry should be investigated carefully, prior to the procurement of additional manipulators.

To facilitate the remote maintenance of the arm assembly, a remotely removable two-section shoulder housing should be installed. This would permit access to the drive motor, located in the shoulder housing, for remotely replacing the brushes. Modification to the elbow joint should be made, so that the forearm and wrist joint could be remotely removed and replaced. It is believed that the brushes in the drive motors located on the forearm could be replaced remotely. In addition, a special maintenance jig should be developed to facilitate the remote maintenance of the arm carriage and arm assembly.

The existing step speed control system should be replaced with a variable speed control unit, thus eliminating the irregular motions of the bridge and carriage during startup. Elimination of the need for the travel limit switches on the bridge and carriage, and the associated wiring, should be attempted by incorporating a slip clutch assembly in the respective drive units.

3. Intermediate Duty Mechanical Arm Manipulator

a. Terminal Status

In order to permit the handling, transfer, and maintenance of processed materials and equipment in the PRE shielded facility, remotely operated manipultors must be developed.

The prime function of the manipulators in process cells is that of an auxiliary handling device to augment the in-cell crane in the handling, transfer, and servicing of process equipment. In a maintenance cell, a manipulator will be utilized as one of the major tools for the repair and maintenance of processing, fabrication, and supporting equipment. The installation of a manipulator should not contribute to cell atmosphere leakage, during either remote operating or maintenance procedures.

One of the manipulators purchased for development and possible in-cell use was the first production model of a newly designed and commercially available mechanical arm manipulator. The manipulator is a fixed-mount, air-driven, intermediate-duty mechanical arm, consisting of the in-cell arm and body, a relay box that can be mounted outside of the operating cell, and the out-of-cell operating console. The in-cell arm and the out-of-cell operating console are shown in Figure 30.

The relay box unit requires a 115-v ac supply and 90 psig compressed air. If an individual air supply must be provided, the practical minimum is a 1-hp unit on a 60-gal. receiver.

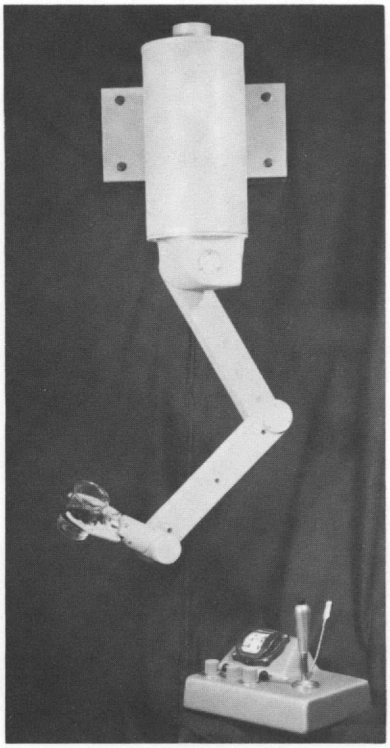

Figure 30. Intermediate Duty Mechanical Arm Manipulator

Grip strength is adjustable at the operating console, from zero grip, which partially closes the jaws, to a squeeze pressure at the jaw tips of 30 lb. The unit will safely handle torque loads of 100 ft-lb about the shoulder joint. With the jaws pointing downward and the forearm and upper arm horizontal, a load of at least 40 lb can be accommodated. The limiting condition is reached when the lower arm is in a horizontal attitude, either with the arm extended full length or with the forearm folded back under the upper arm. In all other positions, correspondingly greater loads can be handled. A vertical lift in excess of 100 lb has been made with the upper arm and forearm folded below the shoulder joint.

The jaw tips will reach any position within a hyperhemisphere, 74 in. in diameter, located about the intersection of the shoulder joint and the vertical axis of rotation when the manipulator is wall mounted. If the manipulator is mounted farther than the arm's reach from the wall, the jaws can cover a whole sphere, except where the body tube and the mounting brackets interfere with the arm motion.

Individual motions by arm components are:

1) Wrist rotation - continuous and unlimited in either clockwise or counter-clockwise direction.

2) Wrist swing - continuous and unlimited about the wrist axis, with the jaws closed. Open jaws will not pass the lower arm in certain positions.

3) Lower arm swing - 330 degrees of arc about the elbow joint, with respect to the upper arm.

4) Upper arm swing and full arm swing - continuous and unlimited in either direction, since the elbow joint will clear the body tube overhead, except for hindrance imposed by the mounting brackets.

5) Rotation of arm - continuous and unlimited in either direction about the vertical axis of the body tube. It should be noted that the body tube does not move. The point of rotation is just above the shoulder joint. Thus, any portion of the body tube can be adapted for attachment to the cell liner, special supports, or the crane.

Motion of the control stick on the out-of-cell operating console energizes relays for the various motions of the manipulator arm. The motion of the stick is spatially as similar to the motion of the mechanical arm as is possible and its use is easily mastered. This unit is right handed; that is, motions on the control stick are oriented as though the operator were sitting to the rear of the hand and wrist, with the arm hanging from the right side of the shoulder. With the arm hanging from the left side of the shoulder, motions of the stick are reversed, with respect to the motion of the arm.

The button on top of the control stick switches the motions energized by the stick from simple motions of one component to compound motions of upper and lower arm combined. Compound motions are obtained by pushing the thumb button on top of the stick, and at the same time moving the stick. When the button is released, single motions are obtained, consisting only of hand, wrist, and forearm motions.

All rotation motions, with the exception of elbow motion, are unlimited about their respective axes, since there are no wires to wind up. The body tube and shoulder mechanically prevent continuous rotation of the forearm about the elbow.

Generally speaking, the manipulator acts to protect itself from damage. The air motors driving all motions other than rotation have unloading slip clutches built into the units. The weakest points in the manipulator are the drive chains in the arms. These will break under shock load without damage to the rest of the unit and they are standard stock items of supply. Single 1/4-pitch chain is used in the wrist drives. Double 1/4-pitch chain is used in the forearm.

The manipulator was installed in the PRE mockup area for component checkout, and test operated to familiarize PRE personnel with the abilities of the unit. Functional checks indicated the unit met or exceeded its lift capacities in all attitudes. The manipulator was installed in the PRE abrasive blast cabinet mockup to determine its reliability in this application.[31]

Operating experience with the air-driven intermediate duty mechanical arm in the PRE mockup indicates that the unit could be utilized to great advantage in any hot cell facility. The relative simplicity of its drive mechanisms and slip-clutch overload protection indicates an extremely high reliability factor.

The unit's versatile application is indicated by its ability to perform overhead manipulations and its relatively small size and weight, which enables it to be transferred through a 9-in. diameter lock. The complete in-cell assembly weighs 60 lb.

b. Future Development Plans

Further plans for the development of the intermediate duty mechanical arm manipulator should include modifications to: (1) provide in-cell mounting, such as an overhead bridge installation, wall-mounted boom, or mobile platform; (2) facilitate the remote removal and replacement of the entire unit from the operating cell; (3) develop special-purpose jaws and a jaw-changing fixture; and (4) permit booting of the manipulator, in order to reduce decontamination required for contact maintenance of small components.

4. Mark VIII Manipulator Boot-Changing Device

a. Introduction

The use of master-slave manipulators is considered feasible for light handling and mechanical maintenance operations in certain shielded cells in the PRE complex. These cells contain air, slightly below atmospheric pressure, and may have radioactive gaseous constituents in the atmosphere in excess of prescribed contaminant tolerances for personnel.

The cells in which master-slave manipulators can be used will contain heavy, highly radioactive, airborne particulate matter. Consequently, every effort will be made, both to eliminate the escape of in-cell atmosphere into the operating gallery and to hold the leakage of air from the operating gallery to the cell to a controlled and acceptable level.

Abrasive particulate matter in mechanical joints of the slave arm would be detrimental, both to the smooth operation and to the useful lifetime of the manipulator. Therefore, the in-cell portion of the manipulator will be enclosed in a flexible boot. The boot will keep the mechanical parts free of abrasive matter and protect the metal surfaces from becoming radioactive, due to the corrosive action of radioactive oxidants in the cell atmosphere.

The PRE philosophy of operation forms the basis for all design and development effort in the program. It is assumed that every piece of in-cell equipment can fail in operation. Consequently, all in-cell attachments and operational hardware for the manipulator must be remotely removable from the slave arm, in order to permit both the removal of the manipulator through the wall and the subsequent out-of-cell decontamination and maintenance of the unit.

Because of the low mechanical capacity of the slave arm, the master-slave manipulator will not be utilized to actuate or load any PRE process equipment, since failure of the unit could shut down the process. All in-cell equipment for handling and transfer operations is being designed for self-sufficient performance, without supplementary service from the master-slave or other types of manipulator. However, use of these manipulators to facilitate in-cell handling and transfer operations is not prohibited.

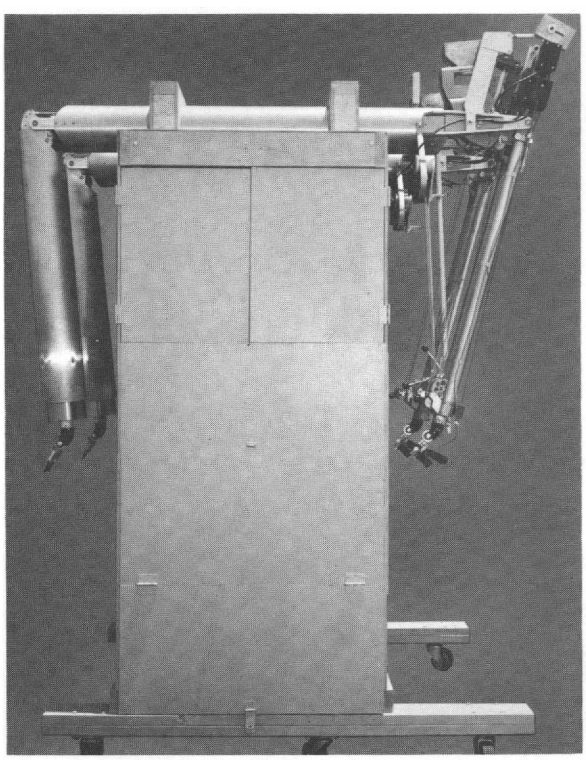

Figure 31. Mark VIII Master-Slave Manipulators

b. Terminal Status

(1) Description of Equipment

A pair of standard commercially available Mark VIII Master-Slave Manipulators is shown in Figure 31. In PRE, these manipulators will be installed in cells permanently inaccessible to personnel. A boot must be used to prevent migration of radioactive gases or particulate matter from the cell to the operating gallery.

The remotely operable device for changing the protective boot on the slave arm of the manipulator must preserve the isolation of the in-cell atmosphere from the operating gallery while the manipulator is partially removed. It must remove the old boot from the slave arm and install a new boot. It must be reliable in operation and readily transferred from station to station in the shielded cell complex. No equipment which is capable of performing these operations is available on the industrial market. Consequently, a prototype device was designed, built, assembled, and test operated in the PRE mockup facility.

This boot changer will permit a one-piece protective sleeve, or boot, on the slave arm of a master-slave manipulator to be replaced by remote control, without exposing the slave arm or the operator to the contaminated environment in which the slave arm operates.

The boot-changing device (Figure 32) consists of:

1) A vertically mounted base platform which (a) supports the working mechanisms of the boot changer, (b) contains an inflatable seal which seals the unit to the through-wall thimble of the master-slave manipulators, (c) serves as one rigid side of the atmosphere envelope which surrounds the two boots during the exchange operation, and (d) supports the mechanism which secures the boot to the rest of the manipulator.

2) A vertically mounted motorized turntable which supports and indexes the boot assemblies which are held in position by spring-loaded detents.

3) A plastic atmosphere envelope which (a) may permit controlled in-leakage of air from the operating gallery through the envelope into the cell, and thereby prevent the contaminated in-cell atmosphere from escaping into the operating gallery; and (b) is transparent, to facilitate full observation of operating and maintenance work performed during a boot change.

4) A grappling mechanism (not shown in Figure 32) which can attach or release the wrist of the boot when the slave arm of the manipulator has been retracted during a boot change.

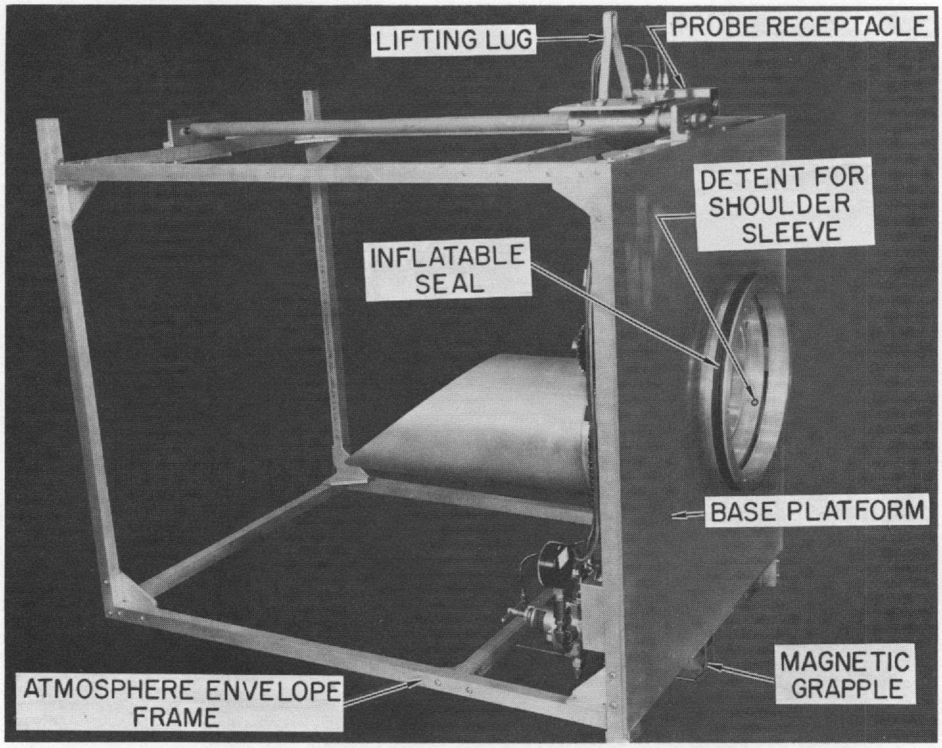

Figure 32a. Boot-Changing Device

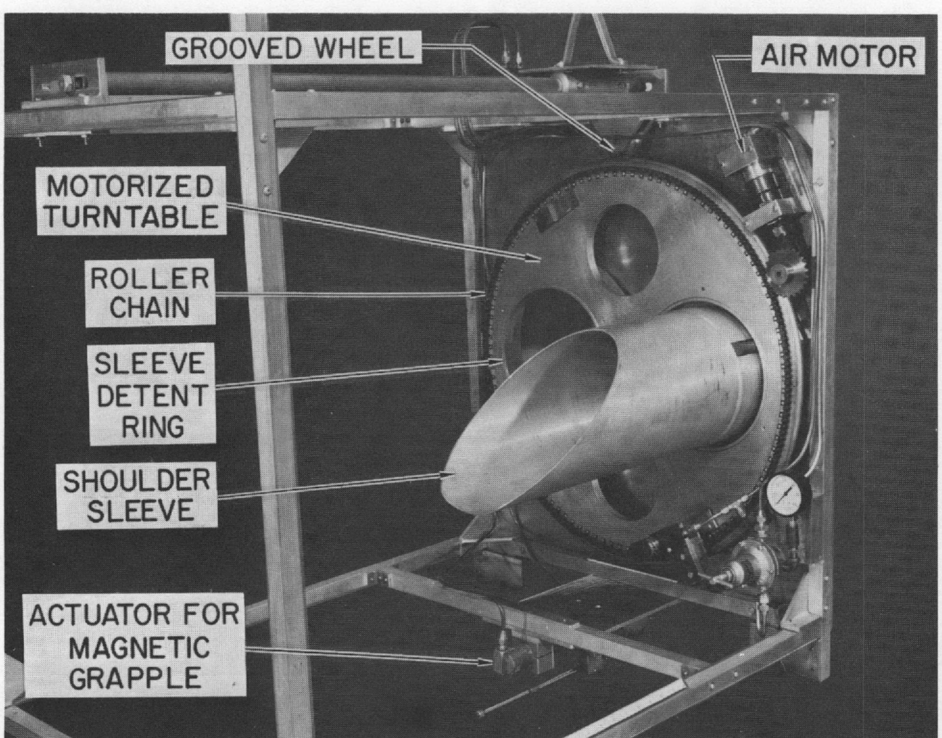

Figure 32b. Boot-Changing Device

5) A <u>shoulder sleeve</u> or boot holder to which is attached the top of the flexible boot and whose flange is sealed to the cell liner during normal manipulator operation by through-wall gas-tight bolts which compress the seals between the flanges of the shoulder sleeve and the cell liner. Detents on the periphery of its flange permit the shoulder sleeve to be engaged with the turntable of the boot changer. When the manipulator and through-wall bolts are retracted into the wall, the sleeve will move with the turntable as the turntable is rotated.

6) A pneumatically actuated permanent-magnet <u>grapple</u> at the bottom of the base platform is used to draw the boot-changing device into engagement with the shoulder sleeve detents and to push it away when disengagement is desired.

The base platform and the atmosphere envelope frame (shown in Figure 32) is made of aluminum plate and extrusion, screwed together with aluminum clips. The frame is not long enough to enclose the full length of the manipulator while changing a boot. The additional length is obtained by attaching a flexible plastic envelope which covers the frame and extends beyond its open end. The envelope is not attached in Figure 32. A lifting lug is attached to the top of the envelope frame near the center of gravity of the changer.

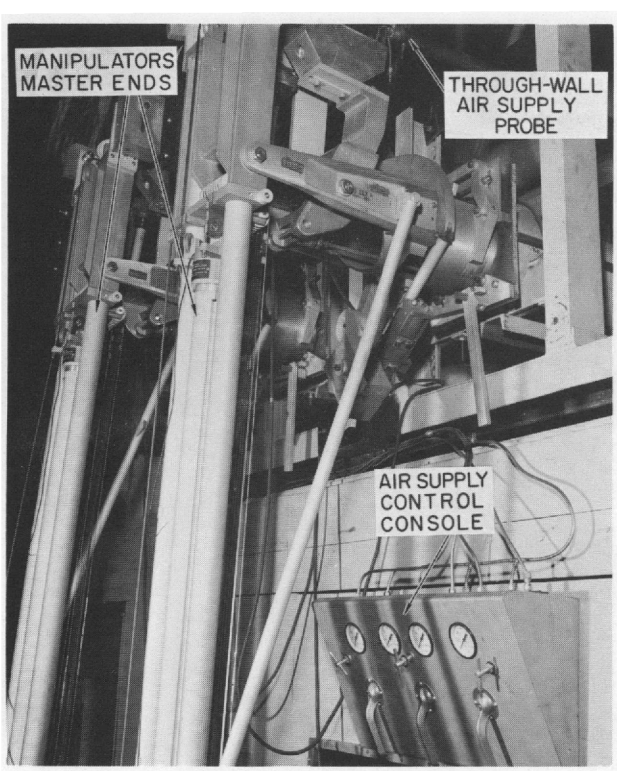

Figure 33. Installation of Modified Manipulators in PRE Mockup

Figure 33 shows the modified manipulators in the PRE mockup, simulating an in-cell installation. The standard slave-side seal-and-roller mount was replaced by a modified flange on the cell liner side. An additional lip was incorporated

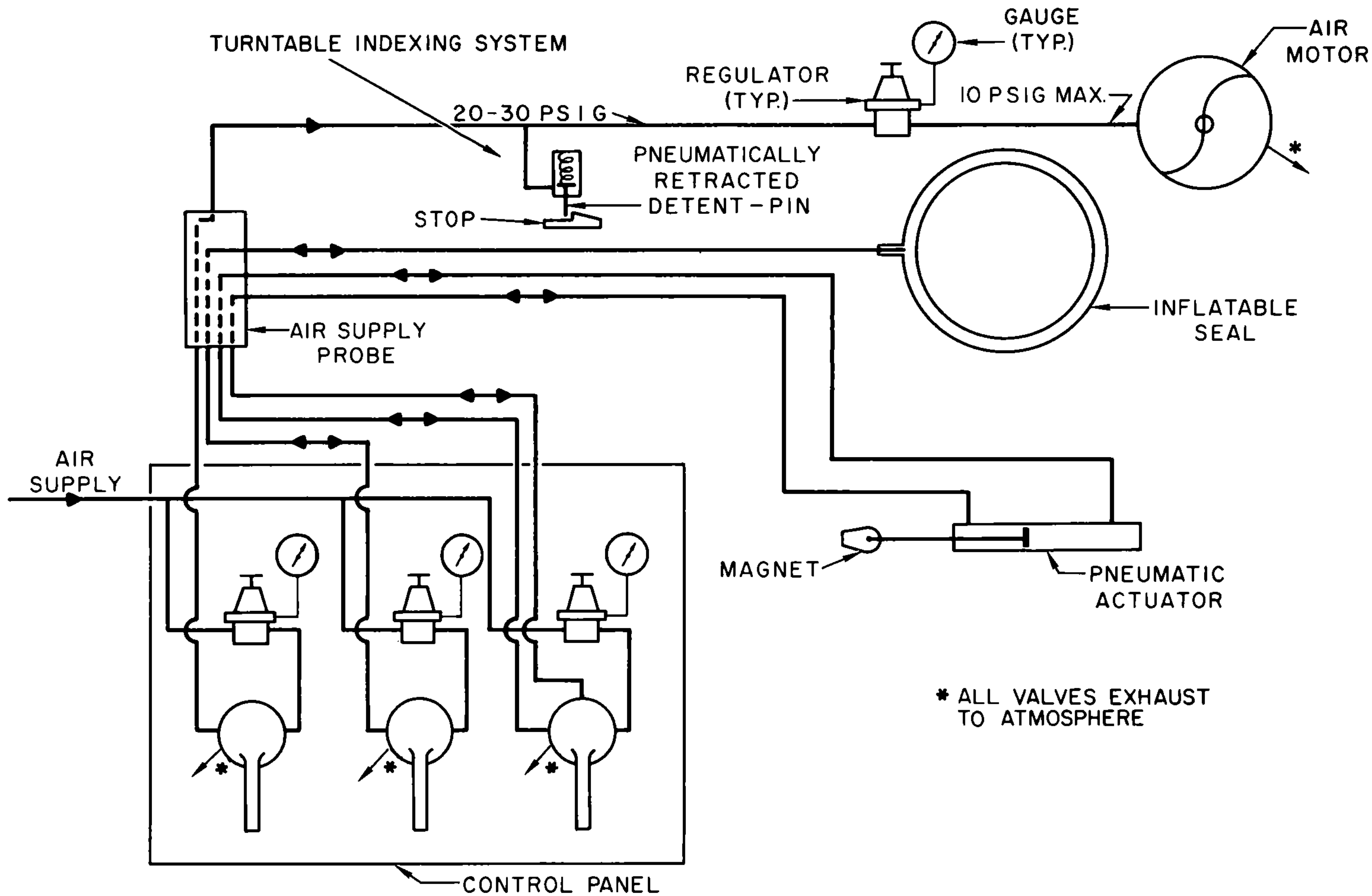

Figure 34. Air Flow Diagram for Boot-Changing Device

to form a cylindrical sealing surface, with which an inflatable seal, mounted on the base platform, could mate to seal the installation port.

Air, for actuating the inflatable seal and the permanent-magnet grapple, is supplied by a through-wall probe, shown in Figure 33. The probe end inside the cell fits into a pivoted receptacle mounted on the envelope frame. The seal is inflated by manual actuation of a valve in the out-of-cell console (Figure 33). A four-way valve in the out-of-cell console controls the grapple. When the grapple actuator is fully extended, an eccentric stop applies a turning moment on the magnet yoke to free the magnet from the cell wall during the disengagement process. A schematic air flow diagram is shown in Figure 34.

A grappling mechanism which swings down from the top of the envelope frame frees the tip of the damaged boot from the manipulator wrist flange and clamps the tip of the boot, as the manipulator is withdrawn. The crane is used to actuate the device.

The turntable disc, made of 5/8 in. aluminum plate, is suspended from the base platform by three grooved wheels (Figure 32a). The grooves fit the rounded edge of the disc to confine the turntable axially, as well as to support it vertically. A roller chain, fastened in a rigid circle around the edge of, and integral with, the disc, is driven at speeds up to 3 rpm by an air motor mounted on the base platform. When the turntable is rotated during the changing operation, a spring-loaded pin indexes the turntable in its desired position. The pin can be retracted pneumatically when continued rotation is desired. The turntable can be indexed so that the shoulder sleeve and the manipulator torque-tube are axially aligned within 1/32 of an inch.

A one-piece boot, shown in Figure 35, covers the sleeve end of the manipulator from the wall flange to the wrist. The boot is collapsible and compact enough for easy handling by the boot-changing device. Convolutions along the full length of the boot afford variable length and compactness in its collapsed condition. If the boot is transparent, the slave-end components are visible and the diagnosis of manipulator malfunction is simplified. Polyvinyl chloride (without filler) is satisfactory for meeting the boot requirements. Its radiation stability and abrasion resistance are comparable to rubber or neoprene.

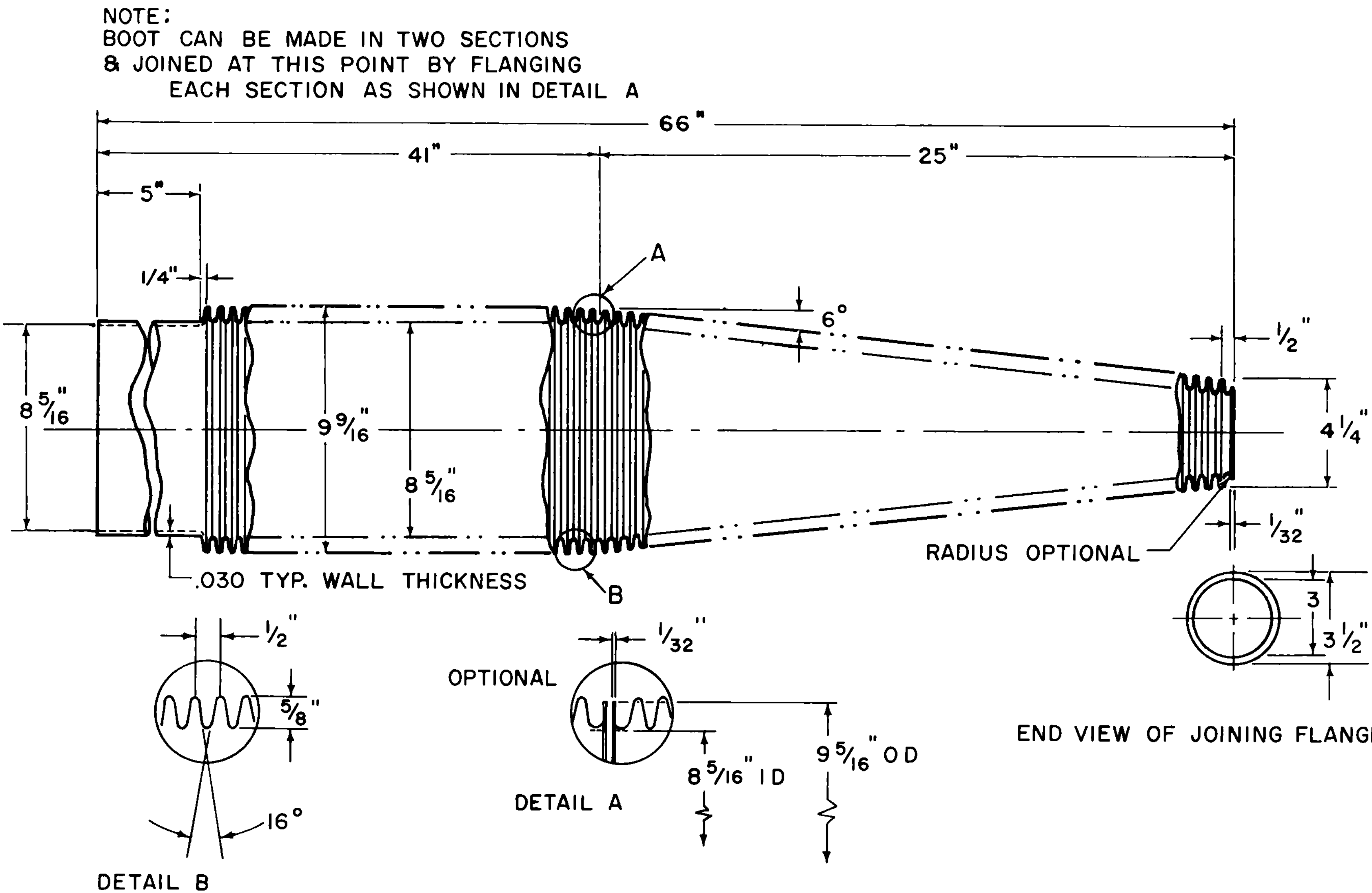

Figure 35. Plastic Boot for Mark VIII Master-Slave Manipulator

Partial removal of the manipulator from the cell is necessary to permit rotation of the turntable. This removal is accomplished with a gantry crane straddling the manipulator outside the cell. The gantry hoist, which travels along a monorail parallel to, and directly over, the axis of the manipulator torque tube, is manually operated. The manipulator is withdrawn on its roller 22 in. before a lifting lug can be installed above the manipulator's center of gravity for further withdrawal by the gantry trolley.

Average radial clearance between the manipulator torque tube and the cell wall through-tube is only 1/32 of an inch; clearance should be preserved throughout the removal of the torque tube from the through-wall thimble to prevent damaging contact between these pieces. The design of the monorail beam on the gantry limits deflection to something less than 0.010 in.; the floor support points for the gantry, and a wall socket for the beam end, are established accurately during installation, to ensure parallelism of the beam with the torque-tube axis. For mockup operations, the gantry was aligned and secured with an improvised clamp arrangement for demonstration of the boot-changing device.

(2) Operational Sequence

The operational sequence is as follows:

a) The boot-changing device is stowed in the PRE maintenance cell when not in use. When a boot requires changing in another cell, the device is moved to that cell through an access lock. A replacement boot, installed on a shoulder sleeve, is introduced into the cell via the same access lock. Once inside the cell, the shoulder sleeve, with the boot restrained in its collapsed position by the boot retainer, is snapped into place in the turntable of the boot-changing device in the empty position, shown in Figure 32.

b) The gantry crane is moved into the operating gallery and the beam end is inserted into the wall receptacle directly over the master end of the manipulator. The rear legs of the gantry are bolted to the floor plates.

c) The manipulator fingers are removed from the slave arm in standard fashion. The lower slave arm is fully retracted and the slave arm is raised to its horizontal position.

d) The in-cell crane moves the boot-changing device horizontally, along the longitudinal axis of the arm, until the two alignment pins mounted on the cell wall guide the device into alignment with the seal and roller mount lip, at a position approximately 1 in. from the wall. The through-wall air supply probe is inserted and screwed into its receptacle (Figure 36). The magnet actuator is extended, so that the magnet contacts the wall, and the device is pulled tightly against the wall with alternate and/or simultaneous applications of both the probe and the magnet actuator. The installed position is shown in Figure 36. The inflatable seal, now opposite the lip of the seal-and-roller mount, is activated to prevent migration of cell atmosphere to the operating gallery during the boot change.

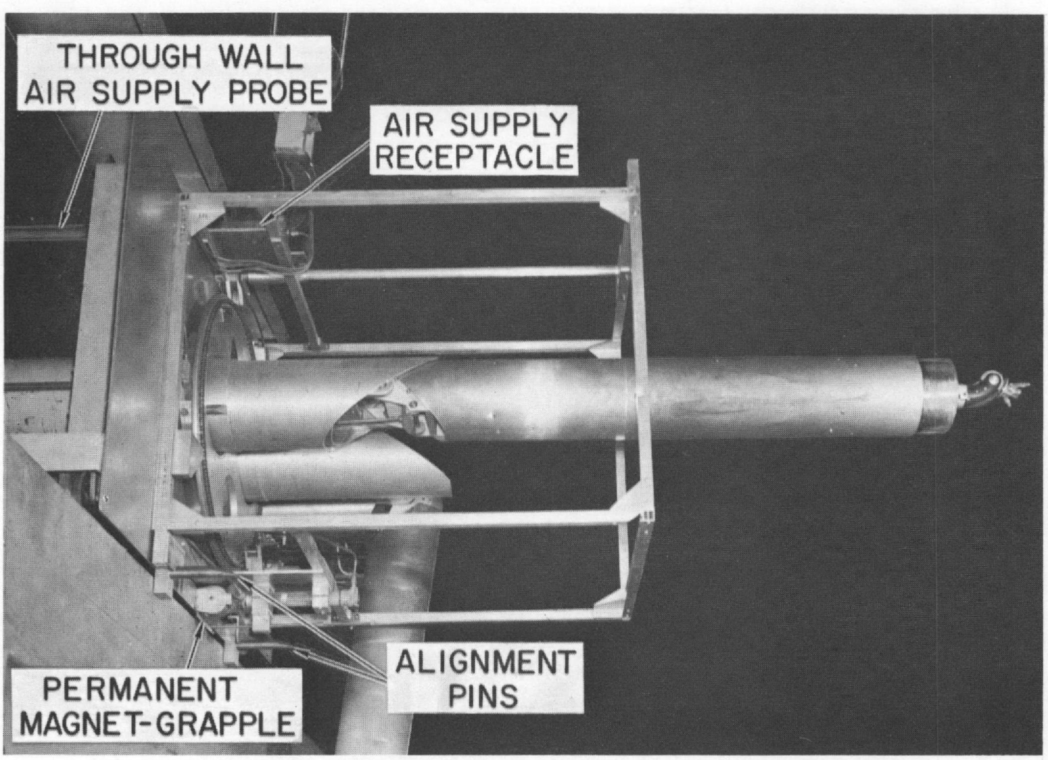

Figure 36. Boot-Changing Device Installed in Mockup

e) After releasing the torque-tube brake and the roller cam lever and disconnecting electrical leads, the manipulator is extracted approximately 22 in., so that the special lifting lug can be installed. The gantry hoist hook is engaged and raised only enough to transfer the manipulator weight to the hoist. Care must be exercised to prevent damage to the torque tube.

f) The manipulator is retracted along the gantry beam to a position where the boot-tip grappling device can release the boot tip from the manipulator wrist. The manipulator is withdrawn until it is free of the boot and the wrist is inside the cell wall.

g) The shoulder sleeve of the old boot is released, by unscrewing the through-wall bolts, and forced into the holding detents in the turntable, by pressure on the through-wall bolts. The bolts are retracted into the cell wall to permit clearance for rotating the turntable.

h) When the turntable rotates 180 degrees to its next index stop, the shoulder sleeve, with the new boot, is in place for boot replacement. The old boot is in the other position. The through-wall bolts are screwed into the new shoulder sleeve, thereby compressing the gas-tight seal and pulling the sleeve free from the turntable detents.

i) The manipulator is reinserted by a reversal of the removal operations. The boot-changing device is taken to the maintenance cell for removal of the old boot and shoulder sleeve.

j) The old boot is removed from the shoulder sleeve and packaged for disposal. The sleeve can be decontaminated, removed from the cell through the access lock, and reloaded with another new boot.

(3) Discussion and Conclusions

Test operation of this device, under simulated in-cell conditions in the PRE mockup, demonstrated its mechanical feasibility. The ease of performing these remote operations varies directly with the degree of visibility permitted. Since depth perception and field of view are limited in each through-wall viewing device, in-cell mirrors, TV cameras, and periscopes should be lined up before initiating in-cell operations. With an operating manual, in which all operations are properly described, in the hands of the operator, the skills required for operation of this device can be acquired by performing a few practice runs in a mockup installation.

c. Future Development Plans

Problems involving the pressure differential between the atmosphere of the cell and the gallery must be investigated, to determine the need for a blower in the envelope of the boot-changing device, the ballooning tendency of an installed boot, and the need for any special atmosphere control that might be brought into use for the duration of the boot-changing operations.

Fabrication of the one-piece, convoluted boots should be completed and the remote changing of these boots demonstrated with the PRE boot-changing device. The characteristics of available plastomers will be investigated for fabrication of boots having maximum transparency, abrasion and turn resistance, and flexibility. A grappling device for removing the boot from the rest of the manipulator and installing a new one should be devised and tested. Numerous operating cycles of the complete boot-changing device should be carried out to demonstrate the reliability of the various mechanisms and their pneumatic supply components.

Remote maintenance of the mechanisms comprising the in-cell device should be investigated and techniques for servicing the assembly developed. Further studies of the gantry crane installation should be made to simplify the requirements imposed by the equipment on the operator during manipulator arm removal operations.

F. IN-CELL DECONTAMINATION

1. Introduction

The primary purposes of the decontamination cell are equipment decontamination and waste disposal operations. Processes and equipment are required which will decontaminate PRE equipment for subsequent contact maintenance or waste disposal. In addition, equipment is required to prepare, can, and seal PRE solid wastes for safe disposal. All equipment must be remotely operable and maintainable, since human access to the cell would not be possible, once the PRE cell complex had begun operations.

2. Terminal Status

a. Decontamination

Both mechanical and chemical cleaning were studied for decontamination processes for PRE. Since particulate matter would obviously be a large contributor to the total activity of most equipment pieces, vacuum cleaning is one of the mechanical cleaning processes to be used.

Another mechanical cleaning process which warranted investigation was abrasive blasting. A process study of abrasive blasting was conducted, to determine the best abrasives and to determine the effect of abrasive blasting on fixed contamination. This study has been reported.[31] It indicated that decontamination by abrasive blasting could be highly successful, on equipment which is to be disposed of or equipment which would not be rendered unusable by the abrasive action. Samples of material having levels of activity of 10^6 counts/min beta-gamma were reduced to or near background (50 counts/min) by abrasive blasting. Facilities were not available to conduct studies at higher levels of activity.

On the basis of this study, a preliminary design[31] was initiated to determine an equipment piece in which abrasive blasting could be accomplished in a hot cell by remote control. As a part of the design study, a preliminary mockup of an abrasive blast cabinet was built to help ascertain remote maintenance techniques and viewing, handling, and space requirements. The conclusions of the study were that, by following the designs developed during the study, an abrasive blast cabinet could be built for installation in the PRE decontamination cell. The blast cabinet would be remotely operable and it could be remotely moved into and out of the cell. All components of the cabinet could be replaced remotely with a crane while the cabinet was in the hot-cell complex.

An investigation of ultrasonic cleaning, as a method of radio-decontamination, was also carried out, as a part of the PRE program. The work was partially completed before the termination of the PRE project. The major effort involved investigation of decontamination with the use of detergents and other mild cleaning agents in water solutions. This part of the program has as its intent a survey of various decontamination agents, in conjunction with ultrasonic cleaning. The results obtained in these experiments, therefore, ranged from ineffectual to excellent under specific conditions. The uncompleted work is outlined in Appendix C, with suggestions for future paths of investigation.

b. Packaging Radioactive Waste for Safe Disposal

The volume and content of radioactive solid waste from the PRE process had not been defined, at the time of phase-out of this project. For this reason, the in-cell waste handling equipment has only been conceptually designed.

The pattern for disposal of in-cell equipment has been envisioned as follows:

1) Any equipment components or other solid waste which can be decontaminated by abrasive blasting will be decontaminated in the abrasive blast cabinet.

2) Any large metallic wastes will be cut, in the blast cabinet, into an appropriate size for disposal, using an electric arc cutter.

3) Refractory wastes, sheet metal, filter media, and other compressible waste materials are crushed, in a hydraulic press, for efficient use of waste container volume.

4) The wastes from steps 2 and 3 are loaded in cans and these cans are sealed, using ring seal lids and a remotely operable closure tool.

5) The sealed cans from step 4 are placed in lead-lined casks and removed from the cell for ultimate disposal.

In the conceptual design, cans 16 in. in diameter and 16 in. high, or cans 24 in. in diameter and 35 in. high (55 gal. drum) are to be used as waste containers. The small can is used for packaging the most highly radioactive ceramic and fibrous materials. The 55 gal. drum is used for waste of larger bulk and lower level of radioactivity. A compression factor of 2 to 1 and an operating pressure of 500 to 750 psi would suffice to compress wastes with the 16-in. diameter ram. The 24-in. diameter can would be used for disposal of most compressible material. A compression factor of about 3 to 1 and a ram pressure of 50 to 100 psi would suffice for the 24-in. diameter ram.

Conceptual design (Figure 37) has been completed on the waste press for PRE mockup demonstration. The press is designed so that all hydraulic components are located outside the cell. Thus, only a minimum amount of mechanical linkage is located in the cell. Pressing is accomplished by a vertical stroke of the press head. The press heads will be interchangeable, so that either a 16- or 24-in. diameter head can be used. The heads can be changed remotely using only the in-cell crane. The press cylinder is located in the basement and the force is transmitted through strain rods which operate in sleeves through the floor. The 1500-psi hydraulically powered press operates by a double-acting, 10-in. bore, 32-in. stroke cylinder, with a maximum capacity of 80 tons.

The press bed is equipped with a movable carriage containing automatically controlled container clamps. When one container clamp is in position for pressing, the other clamp is automatically open for receiving or removal of the other size container. The sliding action of the carriage forces the container clamps against stops, causing them to open or close, depending upon the direction of travel of the carriage. The carriage is moved by linkage through the floor connected to a hydraulic cylinder. This cylinder, located in the basement, has a 3-in. bore and 16-in. stroke. A 15-hp, 18-gpm, 1500-psi pumping unit feeds the cylinders. Solenoid valves, actuated at the cell operating face, are used to control the hydraulic cylinder remotely.

It is planned to use gasketed ring-seal lids for waste can closures in PRE. A standard commercial ring-seal closure device was operated manually in the PRE mockup. The standard device is operated by separating two levers

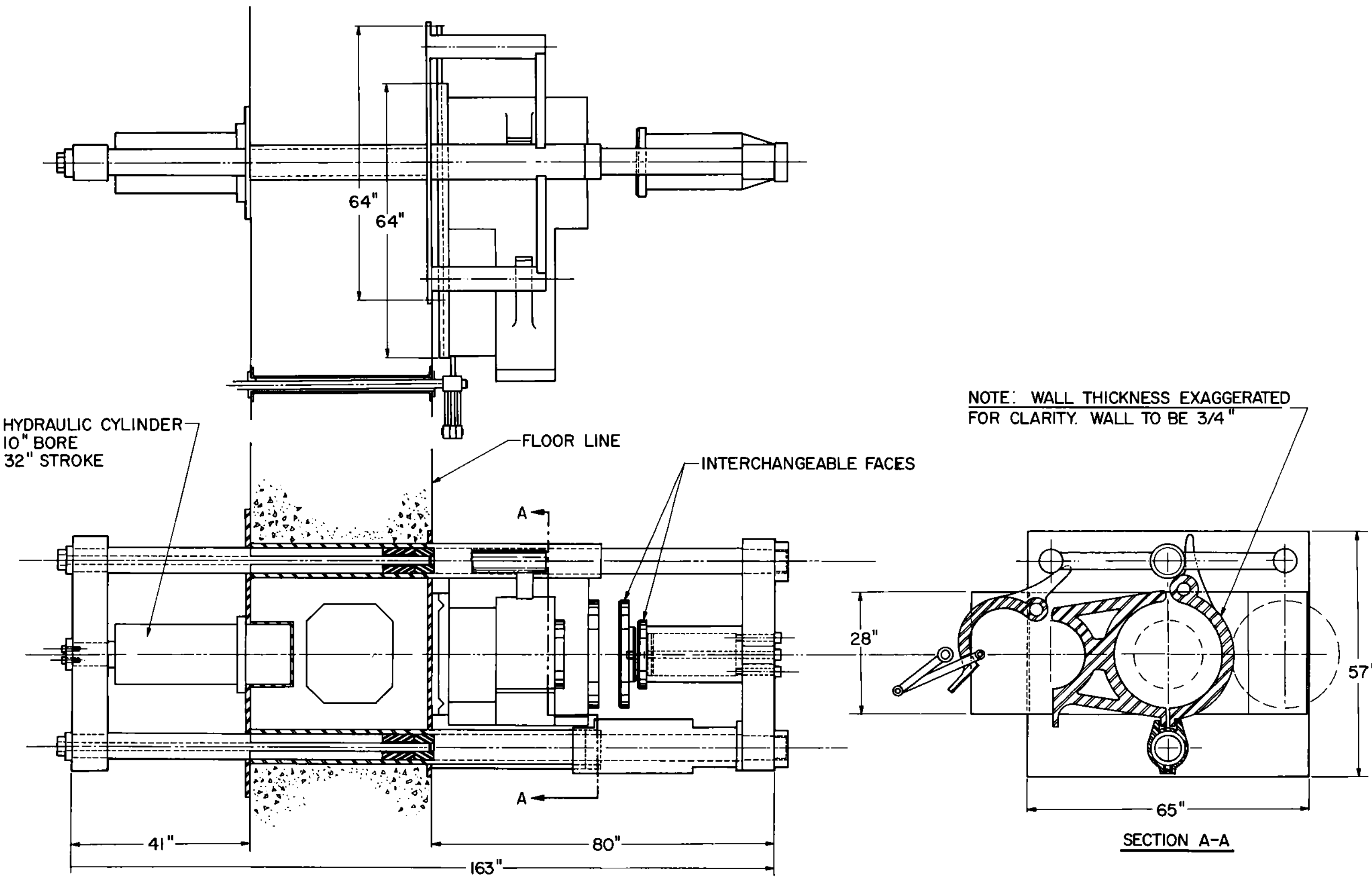

Figure 37. Waste Material Compacting Press

and forcing them downward simultaneously to seal the lid. It can be actuated remotely with only slight modification of the commercial tool. Extension arms are pin-connected to each operating lever and pinned together at the opposite end to form a toggle. The modified seal closure device can be actuated by a weight suspended from the crane hook.

Since the ring-seal closure has an organic gasket to assure leak tightness, it is possible that radiation damage to the gasket will make these closures unsatisfactory for PRE use. In that event, welded closures would be required. A conceptual design for a portable device to seal cans by welding is shown in Figure 38. After waste is placed in a can, a special lid is inserted and pushed into place in the press. The portable can-welding device is placed on the can and power and helium gas connections are made by standard PRE techniques.[29] The welding head is connected to the power supply and the peripheral weld is automatically made around the cap to seal the can. This device was not fabricated in the PRE program.

3. Future Development Plans

a. Decontamination

A remote vacuum cleaner would be developed for in-cell usage.

An abrasive blast cabinet would be fabricated, according to designs presented elsewhere,[31] when all other in-cell equipment sizes had been finally determined. This blast cabinet would be checked again in the mockup and then installed in the PRE facility.

A number of investigations, originally planned for the ultrasonic cleaning study, were not made, because of the project termination. A course of action is suggested in Appendix C for process studies to be performed when the program is reactivated.

Upon completion of the process studies, an in-cell remotely maintained ultrasonic cleaning unit would be developed. The equipment development program would include a design study with a preliminary mockup followed by fabrication and final checkout of an in-cell unit.

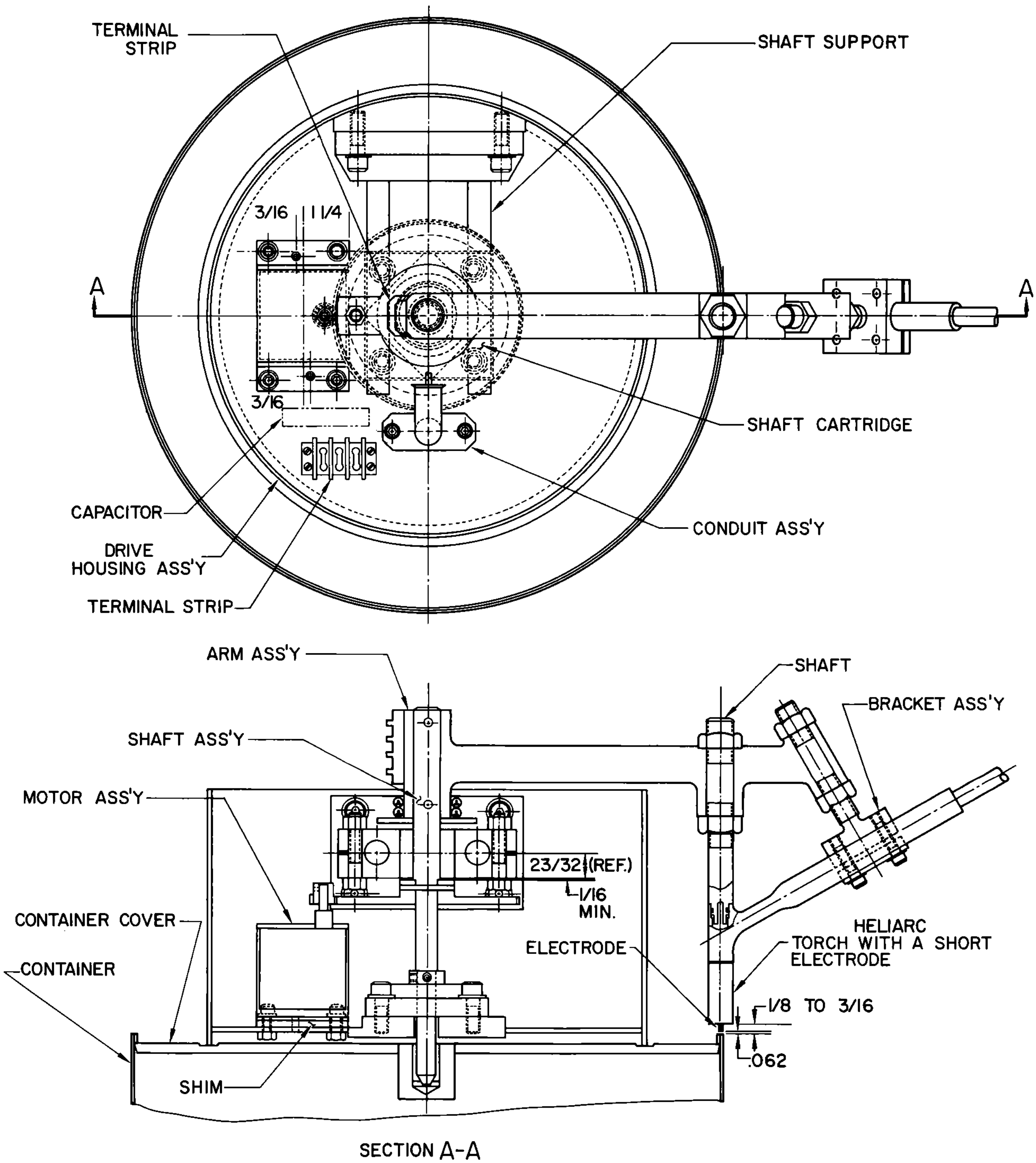

Figure 38. Waste Can Sealing Device

b. Waste Disposal

A waste press would be designed, fabricated, and mocked up, following the conceptual design presented previously, at such time as process and cell wastes had been fully defined. It was believed that the press used in the mockup would be suitable for in-cell installation.

Commercial cans with ring-seal lids are to be tested for leak tightness at various internal pressures. If this type of can is satisfactory, a commercial ring-seal closure tool would be modified for remote operation. If ring-sealed cans prove unsatisfactory, cans with welded lids would have to be used for waste disposal. In that event, a remote can-lid welding machine would be developed. This machine could have either a stationary welding head, with the can rotating, or a rotating welding head, with the can stationary. The first machine to be fabricated for test in the mockup would be similar to the conceptual design of Figure 38. Modifications to this design would be made to incorporate remote maintenance and handling aids, a swivel connection for introduction of helium, and slip rings for welding power connections. It is possible to drive the welding head with a helium-driven motor which exhausts to the Heliarc torch.

G. IN-CELL REMOTE MAINTENANCE

1. Introduction

High temperature processing of irradiated reactor fuel requires equipment designed for operation and maintenance by remote techniques within a shielded cell complex. Some equipment and techniques for remote maintenance developed in PRE have been described elsewhere.[29,30] The routine maintenance of the process equipment components requires some manipulative dexterity of in-cell handling equipment and maintenance devices. To simplify the maintenance of the process equipment components, the maintenance devices and auxiliary tools must be simple, reliable, and applicable throughout the cell complex.

2. Terminal Status

A survey of the torque requirements of operations performed in the process and maintenance cells indicated that an impact wrench with a maximum torque capacity of 150 ft-lb is satisfactory for all operations except for securing large equipment to a mounting pad with 1-1/2 in. bolts. A torque capacity of about 400 ft-lb is required for this operation.

Electrical-drive wrenches were compared with pneumatic wrenches of similar capacity in the PRE mockup to determine their control characteristics and torque ranges. The comparison of performance characteristics indicated a greater operational flexibility for the pneumatic wrench. The compact geometry and the ease and range of control of the pneumatic wrench were major contributing factors. Supply line pressures to the pneumatic wrench can be reduced from the maximum operating pressure to a lower value, which will give the desired torque for a particular application, while an ac electric motor requires a complicated control circuit to give similar variability.

Connecting and disconnecting a flexible air-supply line between a pneumatic wrench and an in-cell service pedestal is more difficult than connecting or disconnecting an electrical wrench. Control of the in-cell atmosphere would likewise become more difficult with a pneumatic wrench because of leakage of pneumatic fluid from the wrench into the cell.

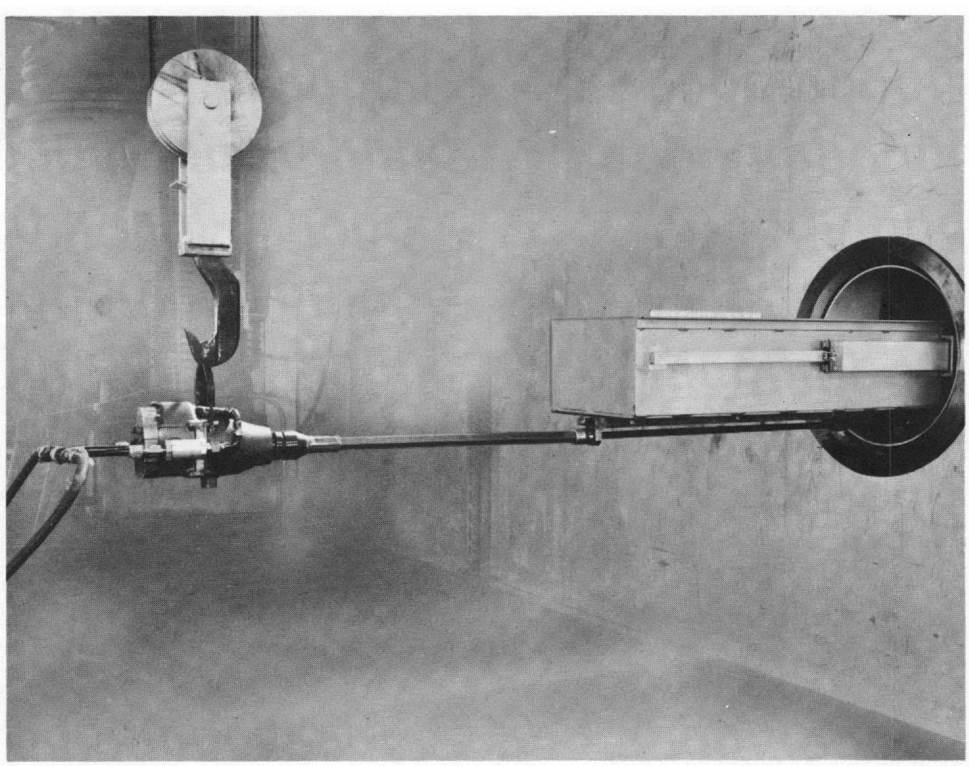

Figure 39. Modified Pneumatic Impact Wrench

Control circuits of the electrical-drive wrench were rewired and the air supply lines to the pneumatic motor were replumbed to permit the operational control of the wrenches from a remote station outside the cell. The motor housings were fitted with bails that could be engaged by the in-cell crane hook. In Figure 39, a pneumatic impact wrench, modified for remote operation in the PRE mockup, is shown operating a prototype of the PRE material transfer lock.

The specifications for and conceptual design of a prototype pneumatic impact wrench for PRE use are shown in Appendix D. Proposed modifications to the motor housing of a commercially available wrench are described to indicate a course of future development.

3. Future Development Plans

Tools for specialized in-cell operations must be studied further in the PRE program. Development of these tools must be carried on concurrently with development of each piece of PRE equipment. These tools include remotely operated hand tools, mechanical manipulators, and special-purpose jigs and fixtures. Storage racks must be designed and installed in the maintenance cell to permit remote selection and installation of special tools at the discretion of the operator. Provisions must be made for removal and replacement of the tools and tool-changing devices in a manner which is consistent with the PRE philosophy of remote maintainability.

Further study is required in the development of in-cell methods for equipment failure diagnosis. Electrical and pneumatic testing stations are required for installation in the PRE maintenance cell.

H. GAS-HANDLING SYSTEMS

1. Introduction

A preliminary flow diagram for cell atmosphere, off-gas, and process stream gas-handling systems for the UO_2 PRE has been described.[20] It was based on mockup experience gained during the development of a PRE for metallic fuels.[27] The functions of the PRE gas-handling system are the filtering of the UO_2 and fission product particulate matter from the cell atmospheres, the containment of gaseous radioisotopes, and the passage of the decontaminated gas to a stack for disposal.

In the PRE for low-decontamination processing of irradiated UO_2, it was proposed to have two process cells, one having an air atmosphere and the other a nitrogen atmosphere. The air atmosphere cell contains equipment for the declustering, decanning, and oxidation operations. It is probable that essentially all of the gaseous fission products, primarily xenon and krypton, would be released in this cell. Since UO_2 is oxidized to U_3O_8 in this cell, there is no necessity for maintaining an inert atmosphere. However, the reduction and reconstitution operations which follow require an inert atmosphere to maintain the O/U ratio of the pellets as close as possible to the stoichiometric ratio of 2.00.

2. Terminal Status

First analysis of the off-gas handling system[20] indicated that the cell atmosphere could be the source of oxygen for the oxidation furnace. The discharge gas from this furnace was to be filtered and xenon and krypton were to be recovered, either by adsorption on silica gel at liquid nitrogen[27] temperatures of by absorption in a liquid hydrocarbon, as reported in unpublished Brookhaven National Laboratory monthly newsletters. An evaluation of this system pointed out the necessity of determining the mode of operation of the oxidation furnace. The effect of the gas from the reduction furnace was not considered in this evaluation because of a lack of knowledge concerning its composition.

Assuming that all of the noble gases are released during the oxidation operation, it would be necessary to store the gas from the off-gas handling system for a period of 30 to 50 days, to permit xenon decay, before the gas could be released to the atmosphere. This requirement indicated that a minimum volume of gas from the oxidation furnace would be desirable, yet this volume should be sufficient to permit processing using conventional equipment.

Three different alternatives, shown in Figure 40, were investigated, based on processing 100 lb/day of UO_2 in a 5 ft^3 furnace. Figure 40A illustrates a method in which pure oxygen is utilized for maintaining the reaction and all the off-gas is totally contained. The furnace is operated by evacuating air purges, in order to control the amount of gas discharged to the off-gas handling system. Eight air purges are required, to lower the noble gas in the furnace to a maximum permissible concentration, before the furnace is opened to the cell atmosphere.

If the 10 SCFD is compressed to 2000-2500 psi and stored in standard (1.67 ft^3) gas cylinders, a cylinder would be good for about 20 days of operation.

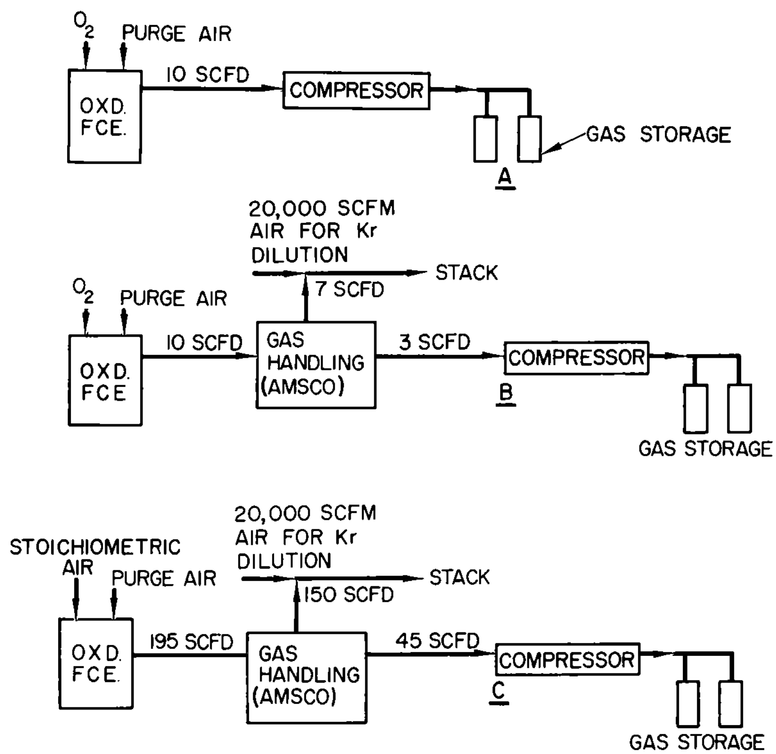

Figure 40. Off-Gas Handling System Alternatives

Operating the furnace according to Figure 40A, but using a liquid hydrocarbon for absorption, results in the system shown in Figure 40B. In using a liquid hydrocarbon for absorption, the volume of recovered gas would be about 25% of the total volume of gas fed to the system. In the case of silica gel, the gas to permanent storage would be less than with the liquid hydrocarbon. Regardless of whether the gas to permanent storage is 1 or 10 SCFD, the compression equipment would be essentially the same. Only the required gas storage capacity would change.

Figure 40C illustrates the volumes of gas evolved from stoichiometric quantities of air in place of O_2 for oxidizing UO_2 and a liquid hydrocarbon for noble gas removal.

Total containment of the off-gases (Figure 40A) makes the gas-handling system simple and inexpensive. Other advantages include: (a) no requirement for large amounts of dilution air, in order to dispose of the residual krypton from the recovery system; (b) no requirement for the removal of ruthenium, iodine, cesium, UO_2 particulate matter, or other fission product matter from the gas stream; (c) operation and maintenance of a recovery system, on a routine basis, would be avoided and a smaller system could be used on a standby basis only. On this basis, a piping and instrumentation diagram was developed (Figure 41) for a system of total containment, by compressing the gas into disposable cylinders.

The off-gas from the vacuum-tight oxidation furnace is pumped through a refrigerated cold trap to remove condensables, picked up by a canned rotary pump, compressed to 20 psi, and stored in the one-day holdup tank.

The dual-stage diaphragm compressor, acting on a fore-pressure range of 14 to 20 psia, compresses the gas to 200 psi and then to 2500 psi, in a two-stage compression cycle. The compressed gas is discharged into the disposable standard gas cylinders, holding 220 ft^3 at 2300 psi.

The storage tank with canned pump, the diaphragm compressor, and the cylinder racks would all require shielding and remote operation. No radiation intensities at any of the components has been calculated.

3. Future Development Plans

The gas-handling system equipment would be designed and construction of a full-scale mockup unit would follow. Operation of the unit, in conjunction with the mockup oxidation furnace, using cylinder krypton, would permit evaluation of the system.

Hot-cave experiments would be conducted on low-irradiated UO_2 to determine the peak rate of gas evolution, the nature, amount, and origin of fission product gases evolved during oxidation and reduction, and the mechanism of carryover of particulate UO_2 matter.

I. LIGHTING AND VIEWING AIDS

1. Introduction

a. Closed-Circuit Television

A closed-circuit television system is required for use in the PRE facility, to aid in the visual observation of equipment and operations in both inert

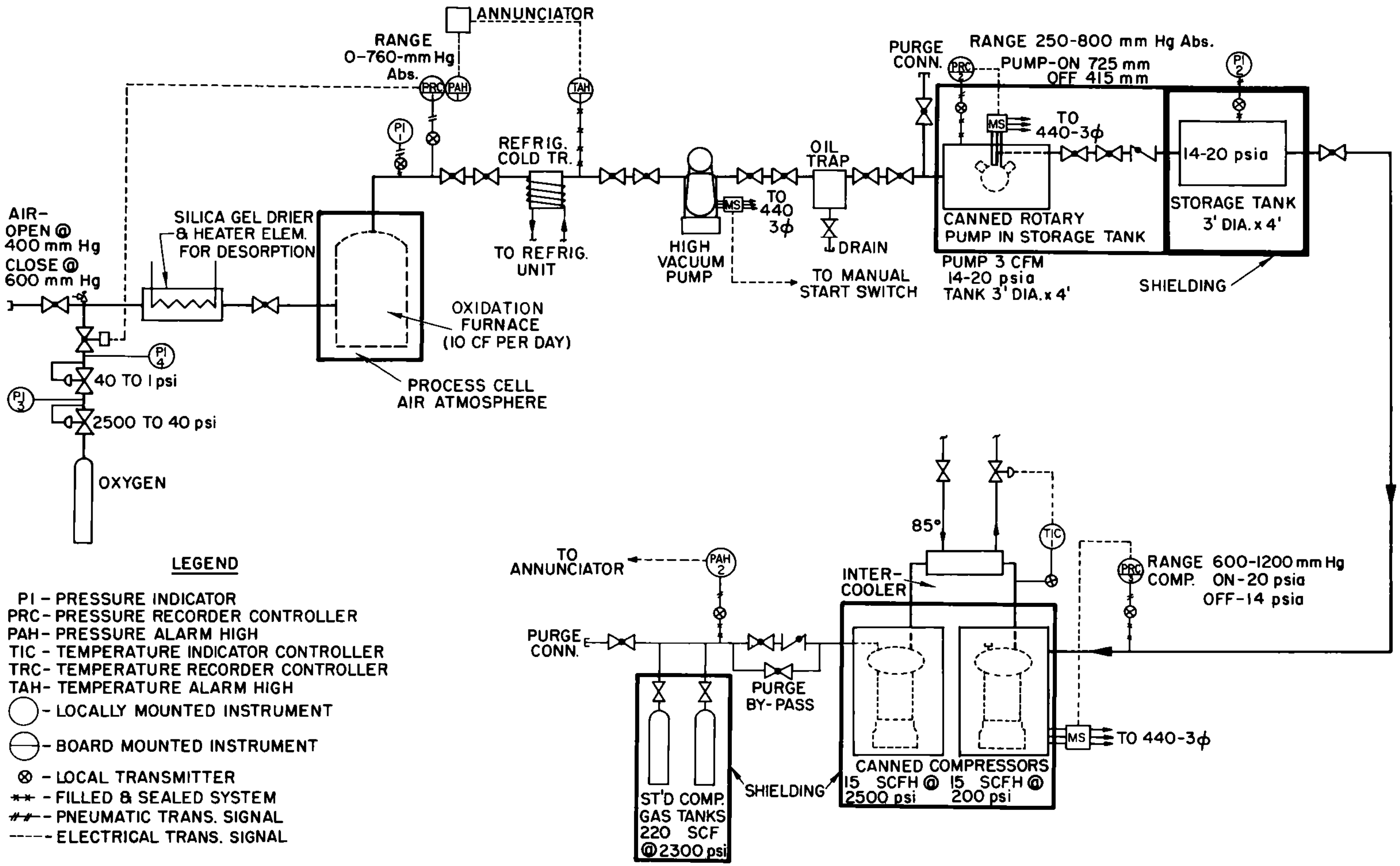

Figure 41. Off-Gas Piping and Instrumentation

atmosphere and air atmosphere cells. In the proposed PRE hot cell layout, viewing windows and periscopes will be mounted on one wall of each cell. Closed-circuit TV is used to observe the remote removal and installation of protective bulb enclosures over the in-cell periscope parts, protective panes over the shielding window, and seals mounted on the operating face and wall. It is also used to view areas behind large equipment such as the vacuum furnace.

The basic requirements for an in-cell TV camera assembly are prescribed by remote operating procedures, cell radiation levels, in-cell atmospheric conditions, and the degree of precision of the work to be observed. The camera system should include:

1) Either a multipurpose lens of good definition or a multilens turret which is capable of general viewing as well as observing minute operations, such as precise alignment operations and detailed inspection.

2) An indicating system to enable the operator to identify the positions of the iris and focus adjustments, and turret position, if a multilens turret is used.

3) An automatic light filter mechanism to protect the lens when the camera is inadvertently directed toward either the high intensity mercury lamps or molten fuels in the furnace or in the ingot molds.

4) An electronic system capable of rendering satisfactory pictures in a cell with an illumination level of 50 to 250 foot-candles. The proposed mercury vapor lights produce considerable infrared rays and are extremely brilliant. They may cause excessive glare and reflection from highly reflective surfaces. Therefore, a "white clipper" light filter or its equivalent must be provided in the camera circuit.

5) A method of controlling the temperature of the camera within safe operating limits. The vidicon tube must not exceed a temperature of 125°F, while operating in a cell whose ambient temperature may reach 150°F.

The camera enclosure must provide:

1) A radiation shield which is capable of protecting the vidicon tube and camera lens in radiation fields up to 250,000 r/hr.

2) A heat removal system which can maintain the temperature of the vidicon tube within safe operating limits. Since the camera may be required to operate in a cell having an inert atmosphere, the coolant should be a similar inert gas.

3) A clean camera atmosphere which is free of particulate contamination and radioactive gases (Xe, Kr, etc.) which might be present in the cell's atmosphere.

4) Physical protection, with a minimum increase in remote maintenance requirements due to the existence of the housing. All electrical and coolant lines must be provided with remote disconnect couplings and installed so as to give maximum freedom to the aiming of the camera.

5) A self-sufficient tilt-pan camera support which can point the camera in all directions.

b. Periscope

A periscope is provided in the proposed PRE facility, in order to permit visual control of the equipment, materials, and transfer and handling operations in the hot cells. The periscope must perform its design function in hot cells which may have radiation levels up to 2.5×10^5 r/hr and inert atmospheres which are severely contaminated with both radioactive gases (Xe, Kr, I_x) and particulate matter. Atmosphere-borne contaminants will be present in quantities which would be lethal to operating personnel if the in-cell atmosphere should escape into the operating gallery; consequently, reliable gas-tight seals are required. A stepped through-wall installation screens the radiation from in-cell materials. The PRE philosophy of operations assumes that in-cell mechanisms will fail during their useful lifetimes; consequently, all in-cell components of the periscope must be designed for both remote maintenance and remote operations.

2. Terminal Status

a. Closed-Circuit Television

A commercially available closed-circuit TV system was purchased and components were modified for simulated remote operations in the cell mockup. The basic components comprising the original TV system are a single lens camera with remotely operable focus and iris, a monitor having a 14-in. viewing screen, a remote control console for lens operation, a standard heavy-duty tilt-pan assembly which was designed for use with the camera enclosed in a conventional acoustic housing, and the necessary electrical cables.

A pedestal support for the camera and tilt-pan assembly and a simulated shielded housing for the camera and lens unit were built and used in the cell mockup. These assemblies and the temporary mobile stand for the monitor and control units are shown in Figure 42. Some components of the TV system were modified and new assemblies were devised to make the closed-circuit system applicable for in-cell operations.

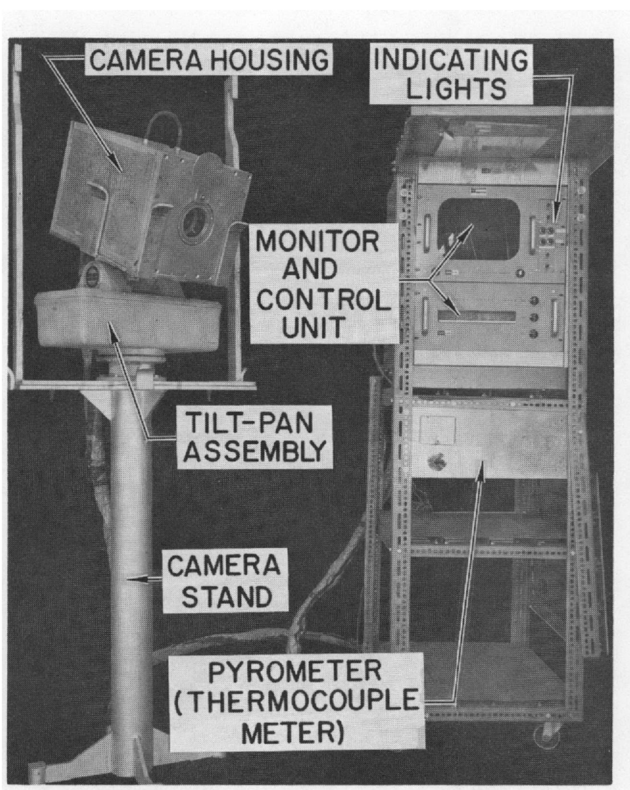

Figure 42. Closed-Circuit Television Assembly

Mobility of an in-cell TV camera increases its utility; consequently, a mobile camera stand with an open base was built. The stand is provided with spring-loaded feet, to give it maximum stability, and a lifting bail attached to the inside of the pedestal. Alignment shoes on the platform top of the stand position and hold the camera, housing, and tilt-pan assembly on the stand. Remote handling of the camera stand was demonstrated in the cell mockup.

The tilt-pan assembly, fastened to to a base plate, has two lifting bails attached to it, as shown in Figure 42. These bails, when engaged with a special lifting yoke held by the crane hook, permit the camera and tilt-pan assembly to be carried as a unit. To simplify camera maintenance, the camera and housing were not secured to the tilt-pan assembly, but just rest on it. The tilt-pan assembly was modified by the addition of alignment shoes which guide the camera housing into position, when lowered by the crane, and hold the camera housing during in-cell operation. Although the unmodified tilt-pan assembly was designed to handle a 40-lb camera and housing, it proved inadequate for this job. The lever arm of the camera-and-housing load on the tilt-drive is too great for tilting loads imposed during PRE mockup operations. A conceptual design was made of a tilt-pan assembly which could handle the load of the camera and housing. This design calls for a tilting axis at the center of gravity of the housing assembly.

A camera housing was designed and built of aluminum plate, to simulate the dimensions of an in-cell shielded unit and yet not exceed the capacity of the unmodified tilt-pan assembly. This housing contains a heat exchanger and its terminal connectors, a porthole window in front of the TV lens, and a movable shutter to protect the window from physical and radiation damage when not in use. The porthole window, simulating a lead-glass shield, and the removable top plate of the housing are provided with remotely replaceable rigidly supported seals[29] to make the housing gas-tight. The housing is provided with dowel pins to locate it on the tilt-pan assembly or any other camera perch. A lifting bail was attached to the camera housing to permit crane transfer of the camera and housing without moving the tilt-pan assembly.

Cooling of the camera housing and remote handling of the camera stand and housing were demonstrated in the cell mockup. The camera housing was installed in a test cubicle and held at 140°F until the temperature of the metal housing reached the ambient temperature. With 3 gpm of 70°F water flowing through a small heat exchanger mounted on the back plate of the housing, the temperature of the metal housing was reduced from 140 to 96°F in 90 min.

The camera, lens-drive assemblies, limit switches for the focus and iris drives, and an iron-constantan thermocouple are mounted on a common base plate attached to the removable top plate of the housing. This integrated system permits the camera and driving system to be removed from the housing by remotely releasing the captive bolts securing the top plate to the gas-tight housing and remotely removing the camera supporting plate from the housing. The bolts can be released by an impact wrench suspended from either the crane hook or the rectilinear manipulator, and the integrated camera support is readily removed by the crane or manipulator. The heat-exchanger assembly is attached to the same removable plate of the housing.

The electrical cables provided in the purchased unit were inadequate for the electrical and electronic circuits required in the PRE prototype TV system. Limit switches for the focus and iris drives and a thermocouple were installed and an auxiliary cable was used to handle their circuits. The standard cable and the auxiliary cable were tied together with zippered plastic tubing for PRE mockup tests.

The original cable connectors were not acceptable for remote operation by the crane hook in PRE. Consequently, an adaptation of a standard PRE prototype coupling[29] was devised for all remote in-cell electrical connections. This prototype unit incorporates rugged self-aligning and locking contact pins and thereby reduces the tolerances imposed on alignment pins during the coupling operation.

The in-cell cable is provided with the PRE prototype male coupling which easily can be remotely connected or disconnected, by the crane hook, from the female couplings on the camera housing and in-cell utilities pedestal. These connectors can be engaged without requiring precise alignment of the male and female plugs. The plugs are mounted so that lifting the camera housing from the tilt-pan assembly disconnects all electrical and electronic circuits from the camera. Replacing the camera reconnects all circuits by plugging in the connector. When the entire tilt-pan assembly and housing are moved as a unit, all connections are made and broken similarly.

In the PRE mockup, indicating lights were connected to the lens focus and iris drives to indicate their relative positions. These indicator lights are located on the control panel in the operating gallery and allow the operator to locate the focus and iris positions rapidly while redirecting the camera with the tilt-pan assembly.

Additional indicator-light circuits were designed to show which lens, in a three-turret lens installation, is aligned in front of the vidicon tube. These indicator lights are located on the same control panel.

A white clipper light filter circuit was added to the camera control system to compensate for the effect of glare and bright lights in a field of normal light. The white clipper circuit reduces the relative brightness of objects on the monitor screen and increases the definition of details in the focused area.

b. Periscope

A standard industrial periscope was installed on a mobile dolly which can traverse the length of the simulated wall in the PRE cell mockup. The periscope was installed and operated in the mockup cell, both to familiarize the operators with its operating characteristics and to facilitate the development and redesign of the assembly to meet the operating requirements of the PRE program. It was used, in other phases of the PRE program, for remote operation of equipment such as the vacuum furnace, the oxide-drossing furnace, and the turntable hoist for equipment maintenance. The optics of the periscope provide the operator with 2X and 10X magnification, in a hemispherical scanning field, with focusing from zero to infinity.

The standard unit was capable of limiting the diffusion of atmospheres through the periscope housing to a few cubic feet per hour; however, a zero leakage rate is mandatory for normal operation of a PRE periscope installation. Therefore, major emphasis was placed on the development of the primary seal assembly, including the protective dome, and techniques for remotely maintaining the seal-and-dome assembly.

The hyperhemisphere dome, seen in Figure 43, was sealed to a dome collar bolted to a dome-mounting plate and installed over the in-cell optics of the periscope to provide both a primary gas-tight seal and some physical protection for the precision-mounted in-cell optical components. The mockup dome is optically ground and does not require the addition of any corrective lens.

In the mockup periscope installation, one face of a stainless steel plate was machined flat, to a total indicator reading of ±0.004 in., to provide a sealing surface for the dome-mounting plate. This wall-mounting plate in the mockup simulates the cell liner and through-wall periscope housing in the proposed PRE hot cell facility. The mockup wall mounting plate is screwed onto the through-wall periscope housing and secured to the mobile dolly supporting the periscope.

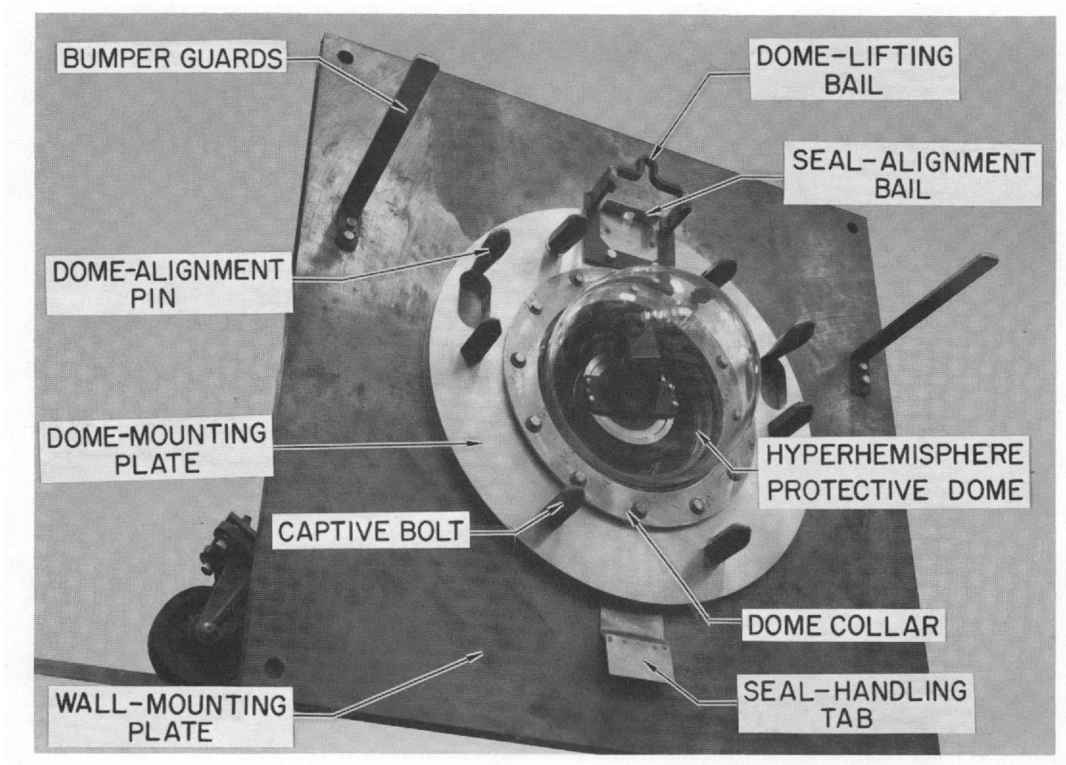

Figure 43. Periscope Dome Installation

Protruding bumper guards are attached to the wall-mounting plate to prevent the crane cable or block from accidentally breaking the protective dome while the crane bridge is being run past the periscope.

A stainless steel dome-mounting plate was machined flat, to a total indicator reading of ±0.004 in., to provide parallel surfaces for sealing to both the dome and the wall-mounting plates. For mockup purposes, the dome was sealed to the dome-mounting plate with a rubber gasket and a bolted-down collar. A cemented dome-to-plate seal would be desirable, if a gas-tight and radiation-stable bond can be made. The seal between the wall-mounting plate and the dome-mounting plate is compressed by the action of holddown bolts which are captive in the replaceable dome assembly to permit remote replacement. A typical captive bolt assembly is shown in Figure 44.

To facilitate remote handling and replacement of the gas-tight seal between the wall- and the dome-mounting plates, the plastomer seals were molded in concentric grooves on each side of a flat metal washer. When compressed, the

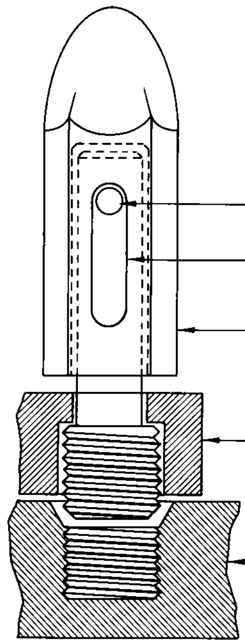

Figure 44. Captive Bolt Assembly

plastomer seal rings flatten themselves in the grooves to make gas-tight seals. The seal plate is provided with an alignment bail which is hooked onto the dome-mounting plate for seal replacement, and a tab for remote handling by an in-cell manipulator.

The remote replacement of the protective dome assembly and of the seal plate were demonstrated in the cell mock-up with only the crane and rectilinear manipulator. The periscope was used to view the positioning of the dome assembly on the alignment pins and the sliding of the dome assembly over the shank of the alignment pins. During remote installation, the pins align the captive bolts and permit the bolts to be threaded easily into the wall-mounting plate.

The seal plate is hooked onto the dome-mounting plate and is readily replaced by removing the dome-mounting plate from the wall, grasping the handling tab of the seal plate with the manipulator, lifting off the old seal plate, installing a new seal plate over the seal alignment pin, and reinstalling the dome assembly on the wall-mounting plate.

These remote operations were performed more easily and more efficiently by the rectilinear manipulator than by the crane; however, both techniques were satisfactorily demonstrated.

3. Future Development Plans

a. Closed-Circuit Television

An automatically operated glass filter should be provided in addition to the white clipper circuit, to protect the vidicon tube from damage when it is inadvertently directly towards either the high-intensity mercury vapor lamps, a welding arc, or molten fuels in a furnace or ingot mold. This filter and its operating mechanisms should be mounted on the camera support, inside of the housing, if space is available. An exterior mounting may permit a somewhat smaller and lighter camera housing; however, it places the glass filter and its operating mechanism in the relatively dirty in-cell atmosphere and probably will require more frequent maintenance.

All components, such as condensers and relay switches, which are vulnerable to radiation damage, should be removed from the in-cell assemblies and placed in the out-of-cell console to eliminate unnecessary maintenance by remote techniques.

A second closed-circuit TV system should be installed in the mockup cell and used to study dual-camera viewing as an aid in performing precision operations remotely. The operator's sense of visual depth is severely altered by viewing through a 3-1/2-ft thick lead-glass window. A substitute for depth perception must be developed, via either dual cameras and separate monitors or an improved form of stereotelevision.

A new prototype camera housing would be built to house the larger camera and turret lens assembly. This housing would incorporate thermal insulation and a cooling system to regulate temperature of the camera atmosphere, a nonbrowning glass window in front of the functional lens position, and the disconnect terminals and couplings developed during mockup test operations. Provisions would be made to weight this prototype housing, to simulate the shielded unit to be used in the high radiation fields encountered in a fuel processing cell. Heat removal studies would be made with this housing and various coolants.

A rugged tilt-pan assembly would be designed and built. The axes of rotation should pass through the center of gravity of the camera housing. This assembly will incorporate the remote disconnect coupling and receive its electrical power through the camera housing which it supports.

Alternate electric motors, insulation, nonbrowning camera lenses, and glass light filters will be investigated, in an attempt to reduce the frequency of maintenance on in-cell TV components.

Remote removal and replacement of the in-cell power cable and coolant lines would be demonstrated with the in-cell crane and rectilinear manipulator. Techniques would be developed to facilitate in-cell movements of the TV camera and housing without snagging the power or coolant lines. Redesign for replacement of inoperable components should be investigated.

b. Periscope

Further development of the protective dome assembly would be pursued. Investigations would be made of the use of a nonbrowning glass dome, cemented dome-to-plate seals, and a remotely operable light filter mechanism which can be positioned over the in-cell optics to permit overhead viewing and reduce the mercury arc glare.

The use of corrective lenses, to compensate for the use of nonbrowning glass in the dome assembly, requires investigation. Cerium-stabilized nonbrowning glass should be investigated for use in the lenses and prisms in the in-cell optics.

The through-wall portion of the periscope would be investigated for modifications which would separate the in-cell and out-of-cell components of the system, thereby permitting the introduction of a secondary seal in the shielding wall. This secondary seal would isolate the in-cell atmosphere and operating gallery during in-cell seal or dome replacement operations. Redesign of the through-wall assembly requires separation of the lens drive mechanisms. Magnetic and servo couplings should be investigated for this purpose. Stepped construction of the through-wall optical arm and installation housing will be specified, if a segmented assembly is developed.

Vacuum purge plumbing should be investigated for installation in the through-wall housing to facilitate safe maintenance of the out-of-cell periscope mechanisms. Glove box equipment and techniques for the out-of-cell removal and maintenance of the periscope system should be developed.

J. INTERCELL TRANSFER DEVICES

1. Material Transfer Lock

a. Introduction

The shielded facility for the PRE consists of several cells with two intercell transfer locks. A large access lock permits the transfer of equipment between cells under controlled atmospheric conditions. A smaller vacuum lock, the material transfer lock, permits the transfer of fuel materials and other small items between the air-filled fabrication cell and the inert-gas-filled or nitrogen-filled process cell without any cross-contamination of atmospheres.

Operation of the vacuum purge system, the shielded doors, and the transfer assembly of the lock will originate in a remote control console in the operating gallery. Switches will control electrically motivated valves for the vacuum purge system and a crane-impact wrench combination to actuate the lock drive mechanisms. The latter arrangement eliminates the need for builtin power drives in the lock and makes the operation independent of manipulator availability.

Although radiation levels in the fabrication cell may be low, techniques for maintenance of the entire lock assembly are based on the possibility that contamination of the lock will prohibit anything but remote maintenance.

b. Description of Prototype

The material transfer lock is cylindrical in shape, 20 in. in diameter and 42 in. long, and is located in the dense aggregate concrete wall separating two cells, as shown schematically in Figure 45. The transfer drawer is capable of supporting a 500-lb load in a space 11 in. by 13 in. by 40 in. The drawer extends 38 in. beyond the surface of the wall into either cell, as shown in Figrue 39. The mockup version of the partially completed material transfer lock appears in Figure 39.

The lock consists of three main components: the cylindrical steel housing or installation thimble with its two doors, the transfer mechanism, and the atmosphere control system. The cylindrical steel housing or installation thimble (Figure 39), which becomes an integral part of the cell wall, has machined flanges to which the lock doors are sealed. Two heavy-walled channels are

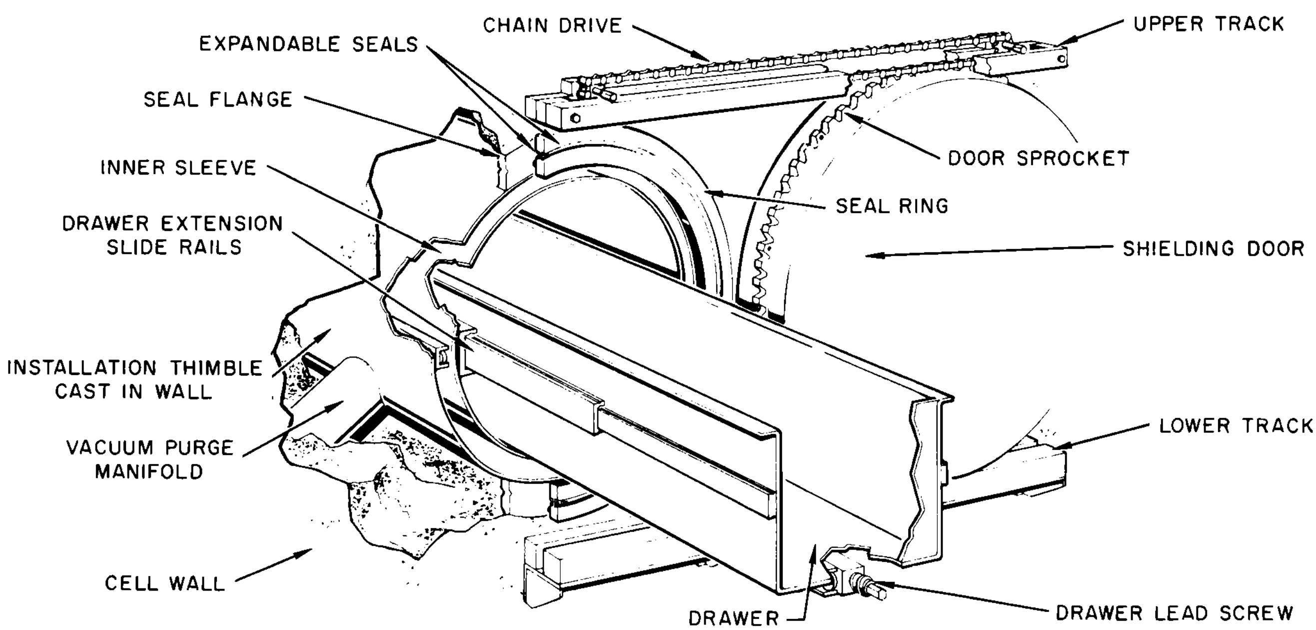

Figure 45. Material Transfer Lock

welded along each side of the housing to support the transfer assembly. Each door is a 5-in. thick steel and lead disc which rolls between horizontal tracks attached to the cell wall, as illustrated in Figure 45. A circumferential sprocket, bolted to the rim of the door, is driven by a top-riding chain which drives the door along the track. The door is sealed to the housing with an inflated circular seal. When deflated, the seal collapses and allows the shielded door to roll free on its track. The seal is mounted on a steel ring which is removable from the inner flange for replacement by the in-cell crane.

The transfer assembly consists of an 18-in. diameter inner sleeve, within which are housed the transfer drawer, its slide suspension, and its drive system. Cam rollers, extending through the sleeve from the slide mounting plates, support and align the assembly along the channels welded to the outer sleeve. This roller suspension allows removal of the transfer assembly from the lock for maintenance of the mechanical components.

A double-ended file drawer, rolling on a commercially available double extension-channel track, shown in Figure 46, permits the drawer to extend into the cell on either side of the cell wall. The design is simple and compact. The load-supporting slide is suspended, on upper and lower ball bearings, in an intermediate member which is suspended similarly in a fixed outer member. These three members are commercially available in heat treated aluminum extrusions. While this material is satisfactory for a mockup prototype, in-cell use may justify having these shapes duplicated in stainless steel. The ball bearings are caged in a strip of steel which has holes to receive the balls.

The purchased slide unit was designed to extend in one direction only. A stop was removed to allow extension in both directions. An automatically retracting stop, designed to arrest the travel of the intermediate member in the slide unit as the drawer is closed, is shown in Figure 46.

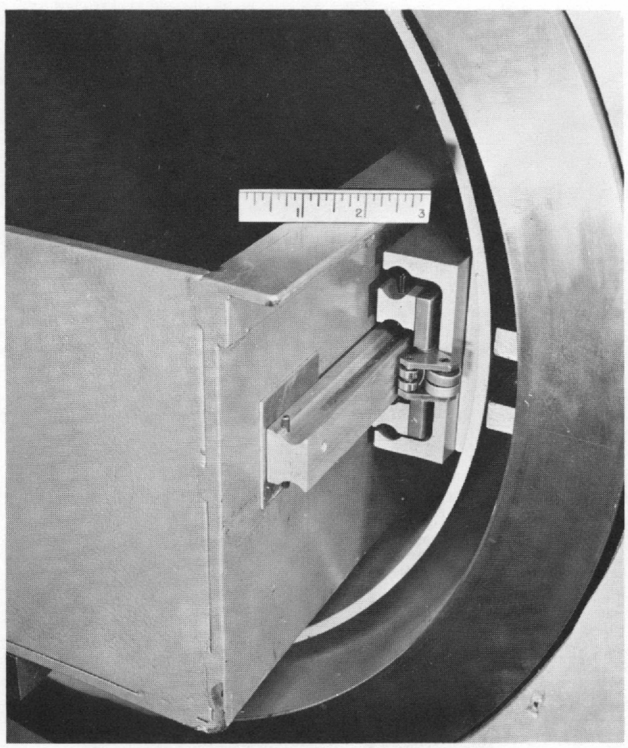

Figure 46. Slide Arrest in Retracted Position

Pins were added to the slides to limit slide travel and drawer extension. In order to allow maximum extension of the drawer, the ball cages must start from the center of the slide when the lock is closed. However, with normal operation of the transfer lock, random slippage of the balls allows the cages to drift from this initial alignment. When the drawer is extended to either extreme, the roll-pin stops installed at the ends of the inner member force the cages back to their proper positions.

The double rack-and-pinio·. drive system is powered, through a lead screw, by an impact wrench suspended from the crane hook, as shown in Figure 39. Two load-bearing wheels, mounted on the same axis as the pinions, share the load in the transfer drawer with the slides. The lead screw is suspended from the bottom of the drawer by two special pillow blocks. Rotation of the lead screw drives a captive nut and pinion-gear assembly along the screw axis. Rotation of the pinion gear, which is meshed with the two racks, causes a relative displacement of the upper and lower racks, which are integral with the transfer drawer and the inner sleeve, respectively. Torque requirements, and their resultant stress applications, are kept at a minimum by transmitting power through a low-friction ball bearing lead screw and nut to transmit force from the spiral grooves on the lead screw to the matching grooves on the nut. Relative motion is imparted to the upper and lower racks by two identical pinion gears which are coaxially mounted on the nut on trunnions normal to the axes of the lead screw.

A latching device, actuated clockwise by an impact wrench, locks the inner sleeve in the outer housing. Full rotation in the counterclockwise direction releases the sleeve-to-housing lock and locks the drawer in the inner sleeve so that it cannot slide out during the removal of the assembly from the housing for maintenance.

To minimize the introduction of oxidizing impurities into the inert atmosphere of the process cell and the migration of highly radioactive gaseous and particulate matter from the process cell to the fabrication cell during a transfer through the lock, vacuum and purging plumbing is incorporated in the lock system. The valving, pumps, and controls are located outside of the contamination envelope.

The forepumps and diffusion pumps are located, below the cell floor, in a limited-access vault area. A manifold of minimum length, embedded in the cell wall, would connect the lock housing to the valve and pumping system. A mechanical forepump backs oil diffusion pumps to pull a vacuum ranging from

1 micron to 10^{-5} mm of Hg in the sealed lock. The vacuum requirements of the lock are dependent upon the relative degrees of contamination of the two cell atmospheres connected by the system.

The power tool used to actuate the shielded lock doors, the transfer drive, and the sleeve latch can be any drill, nut runner, or impact wrench which is available in the cell. Under full load, the transfer drive requires only 2 to 3 lb-in. of torque from a 1/4-in. hexagonal socket.

The horizontal removal of the drawer-and-sleeve assembly from the installation housing to expose the lifting bail is accomplished with the crane, a fixed pulley by which vertical lift can be translated into a horizontal tow, and a sling to connect the sleeve assembly and the crane hook. The sleeve assembly is stable when cantilevered 70% out of the housing, giving free access to the recessed lifting bail. The sling is removed from the crane hook and the crane hook engaged with the lifting bail for complete removal of the sleeve from the housing.

c. Operating Procedure

A transfer of fuel from one cell to the other would entail a procedure generally typical of remote operation in hot cells. Starting with the lock in its closed condition, filled with a clean inert atmosphere, the transfer process is initiated by monitoring the lock atmosphere to determine the levels of radioactive and oxidizing impurities existing in it. The permissible concentrations of radioactivity would vary with the materials being processed and the process flowsheet. It is expected that the contamination levels in the dormant lock, with seals functioning properly, would be low enough to permit one of the lock doors to be opened without purging. If not, an evacuation and purge operation is initiated. An electrically operated valve in the vacuum manifold is opened and the lock is evacuated to a predetermined pressure. When the lock has been evacuated, the vacuum valve is closed and the electrically operated purge valve is opened to allow clean gas, comparable to the atmosphere of the cell to be connected, to bleed into the lock. Then the appropriate door seal is deflated by actuating an electrically operated valve. An impact wrench is picked up with the crane, engaged with the door drive mechanism, and actuated to open the door. The impact wrench then is engaged with the drawer drive mechanism and the drawer is extended, as shown in Figure 39, for loading. After the load is placed in the drawer by the crane, the drawer is retracted, the door closed, the seal inflated, the lock evacuated, and clean dry gas, comparable to the other cell atmosphere, is bled into the lock. Again, the lock is monitored for oxidizing impurities. The lock-unloading procedure is accomplished from within that cell in the same manner as is described above. The drawer is then retracted, the door closed, the door seal inflated, and the lock is evacuated and charged with clean, dry, inert atmosphere to make it ready for the next transfer.

d. Terminal Status

The steel housing and the sleeve-and-drawer transfer assembly were built, installed in the PRE cell mockup, and test operated, to demonstrate remote maintenance techniques. The doors, seals, and atmosphere control system were designed and scheduled for future mockup.

Due to the relatively frictionless suspension and lead screw, the drawer moves very easily in both the loaded and unloaded conditions. After a dozen traverses of the drawer from one extreme to the other, under a light load, the accumulated migration of the ball cages amounted to about 2 in. from their centered positions without any indication that further displacement would not accumulate indefinitely. The tendency to migrate decreased with increased payload. Each full movement in one direction of the original slide assembly, under no-load conditions, resulted in a cage migration of as much as 3/8 in.; however, with the ball cage alignment pins installed, the drawer can be driven out to its extreme position and the migrated cages will be forced against the pin stops to recenter themselves. Although migration can occur on the return trip, recentering occurs each time the drawer is extended in use and significant accumulation of misalignment is prevented. Since the realignment process forces the balls to slide, instead of rool, in their races, realignment operations should be executed in the unloaded condition whenever possible.

e. Future Development Plans

Future development efforts on the material transfer lock should include the experimental investigation of the door and seal operation, the fabrication and test operation of an atmosphere control system, and the demonstration of remote operating and maintenance techniques for in-cell use of the entire assembly.

2. Slug Transfer Chute

a. Introduction

The slug transfer chute is used to load PRE-made uranium fuel slugs or UO_2 fuel shapes into the stainless steel fuel cans, prior to the fuel rod fabrication operations. In addition to this slug loading function, the device also serves to transfer the fuel slugs or shapes from the process cell into the fabrication cell.

Special features of the device protect the fuel from air contact when the fuel is transferred from the process cell, with its helium atmosphere, to the fuel can in the fabrication cell, where there is an air atmosphere.

b. Description of Prototype

The slug transfer chute consists of a fixed, sloping transfer tube through the wall between the process and fabrication cells, a tilting cradle in the fabrication cell, and a remotely replaceable gate valve attached to the wall adit of the trough-tube in the process cell. The cradle can position a fuel can in its support tube, in line with the fixed transfer tube,[7] and seal the fuel can support tube to the through-wall transfer tube housing. Vacuum and inert gas purge lines, with remotely controlled valves, are connected to the fixed transfer tube to control the atmosphere inside the fuel can. Tilting of the cradle in the fabrication cell is actuated by a remotely controlled pneumatic cylinder. Another remotely controlled pneumatic cylinder, installed on the cradle itself, forces the fuel rod support tube against the vacuum seal on the end of the fixed transfer tube when the cradle is in the tilted loading position. Alignment of the cradle to the transfer tube is critical, so that passage of the fuel slugs into the fuel can will be free and unobstructed.

c. Operating Procedure

The operating cycle of this device begins with the positioning of the fuel can in a support tube in the vertically positioned tilting cradle. This handling operation is performed by the crane in the fabrication cell. A remotely controlled cylinder then rotates the cradle on its support trunnion so that the fuel-can support tube is directly in line with, but retracted from, the through-wall transfer tube. Guides, positive stops, and precision fabrication will assure good alignment of fuel can and transfer tube. A remotely controlled cylinder, mounted on the cradle, thrusts the fuel-can support tube against a vacuum seal on the end of the transfer tube. With the support tube in this position, the mouth of the fuel can is in the tapered socket end of the through-wall transfer tube, ready to receive the fuel slugs or shapes.

The transfer tube, fuel-can support tube, and fuel can are evacuated and back-filled with argon to the process cell pressure, so that no air will be present when the fuel is loaded into the fuel can. The vacuum gate valve at the process cell end of the transfer tube is opened, a guide trough is inserted through the valve opening and into the mouth of the fuel tube, and metallic fuel slugs or refractory fuel shapes are started individually into the transfer tube. Tests have shown that metallic uranium fuel slugs will slide freely, by gravity, down a fifteen degree slope.

When the fuel can has been loaded with metallic fuel slugs or refractory fuel shapes, the guide trough is withdrawn from the vacuum valve adit in the process cell and the valve is closed. The closed system is evacuated and purged with clean argon until monitoring reveals the tube is acceptably free of contamination. The air cylinder mounted on the cradle is actuated to retract the fuel can and support tube from the end of the transfer tube, and the tilt-cylinder is actuated to rotate the cradle to a vertical position. The loaded fuel can and support tube are removed, by the crane, and transferred to the rod fabrication device. The argon in the fuel can, being much heavier than air, will remain in the fuel can and exclude the cell atmosphere from the fuel slugs until the rod fabrication operations begin.

d. Terminal Status

The design layout of this device has been completed. Preliminary tests were made to make sure that the fifteen degree slope of the transfer tube and the fuel can would assure complete passage of metallic fuel slugs into the can.

e. Future Development Plans

A full-size mockup of this device should be built and fully tested for remote operation and maintenance. Extensive testing in the PRE mockup is required. Further testing may show the need for a ram of some kind to force the fuel fully into the fuel can. A portable device using a coiled, flexible shaft has been considered for this purpose.

Tests should be made to determine how much air diffuses into the argon atmosphere of the open fuel can during the time the can is exposed to the fabrication cell atmosphere. If required, a small purge stream of argon could be directed into each fuel can after it is lowered into the fuel rod fabrication device until the bell jar of that device is locked in place. An alternate method of protecting the fuel from the air atmosphere would be to flush and purge the loaded cans when they are tilted to the vertical position and install a temporary cap in each open fuel can; these caps would be removed with a manipulator, prior to placing the bell jar on the rod fabrication device.

K. INTERFACILITY FUEL TRANSFER

1. Fuel Transfer Cask

a. Introduction

Both the spent and reprocessed uranium fuels which must be transferred between the SRE and PRE facilities will have radiation intensities as high as 10^4 r/hr at 10 in. with no shielding. This radiation intensity is due largely to gamma emission with energies of ~1.5 Mev. Figure 47 shows the thickness of lead shielding required to reduce the radiation intensity from 10-day cooled metallic uranium fuel to safe levels outside the cask.

A shielded cask, designed to shield for these radiations, weighs about 16 tons and has a configuration which allows the addition of a shielding muff to permit the cask to be used for future fuel transfer involving much higher intensities. Therefore, the special carrier vehicle used to transport the cask between the SRE and PRE facilities, and the overhead crane at the PRE site, were scaled accordingly.

The cask must provide the shielding necessary to reduce radiation intensities to 2.5 mr/hr at the outer surface of the cask, a self-contained manually operated hoist to raise and lower the fuel container into and out of the cask, and a shielded port in the base of the cask.

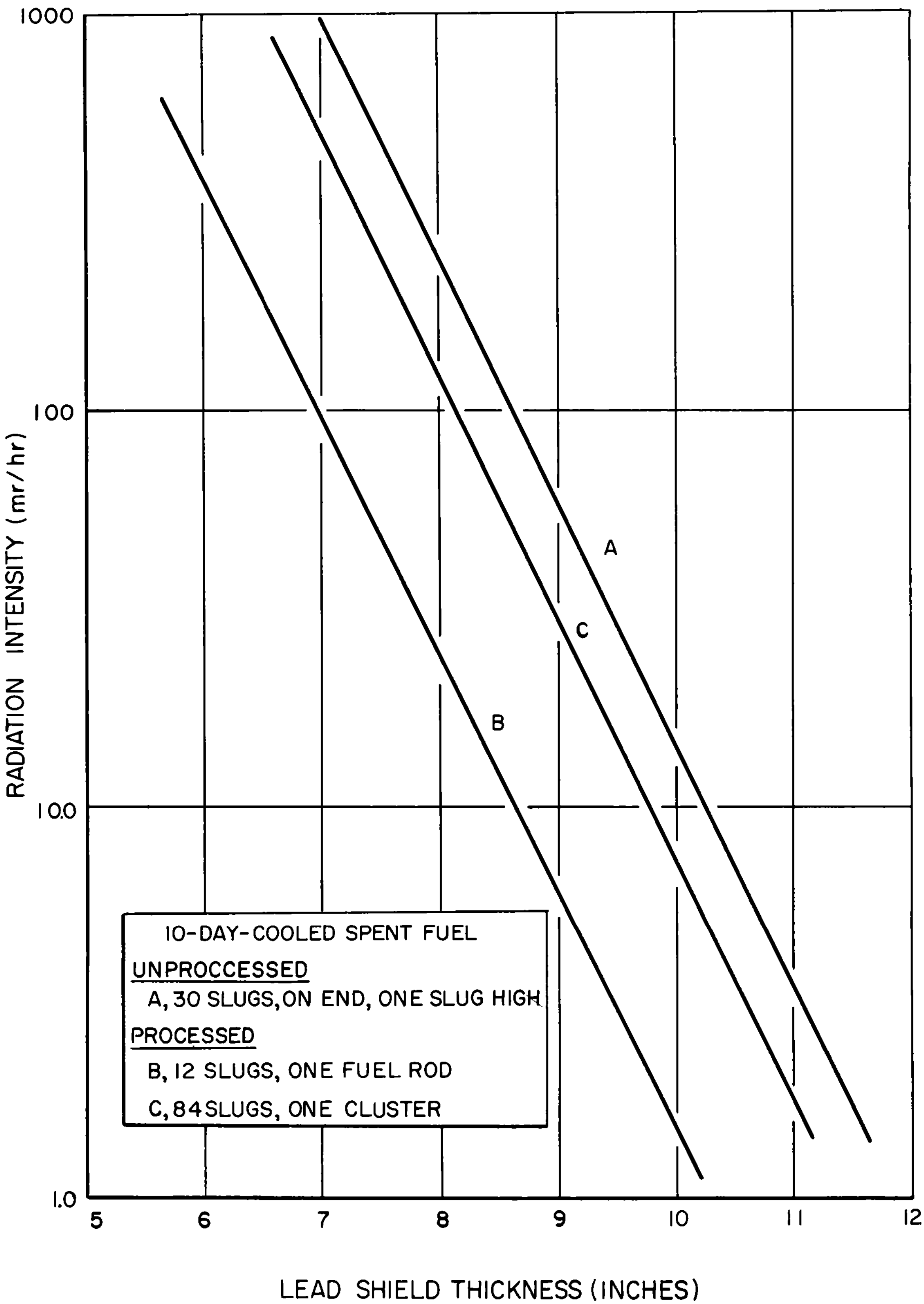

Figure 47. Radiation Intensities vs Shield Thickness

The cask must be capable of carrying up to 30 kg of metallic uranium fuel which has been irradiated to 3000 Mwd/t in the SRE and cooled for 10 days. The spent fuel may be in the form of either a reprocessed and refabricated SRE fuel rod (0.75-in. OD by 8 ft) or irradiated fuel in a cylindrical can (~1-in. OD by 8 ft). Future interfacility transfers of fuel for processing and fabrication in the PRE facility may necessitate the transfer of 70 kg of 3000 Mwd/t 10-day cooled spent fuel in the form of a doughnut-shaped fuel element (2.75-in. OD by 8 ft high).

PRE-made fuel rods must be transported in a pendant, vertical position because the 0.010-in. stainless steel fuel envelopes are strong only in tension; and care must be exercised to avoid the possibility of entrapping gas in the NaK below the fuel level in a metallic fuel rod. The fuel rods will be enclosed in vacuum or inert atmosphere envelopes during transfers. The interiors of these vessels may become badly contaminated; consequently, all surfaces which potentially could be exposed to radioactive contamination will be made of corrosion-resistant materials, in order to facilitate decontamination with ordinary chemical reagents.

b. Description of Equipment

The design of the interfacility fuel transfer cask is schematically presented in Figure 48. In order to utilize the large cask required for the long fuel element (2.875-in. OD by 8 ft long) as a round trip carrier, an enlarged cavity (5.5-in. ID by 8.5 ft high) is provided below the fuel element cavity (3.5-in. ID by 8 ft high) to admit the transfer magazine for the transfer of irradiated fuel from SRE to PRE. The structure is a steel-lined reinforced lead tube with a large steel base which houses the valve and the fuel slug transfer magazine. The upper portion of the cask has an 8.5-in. lead wall, the lower portion has a 14.5-in. steel wall and a stepped base to reduce radiation streaming during loading. Initially, a lead pipe (3-1/4-in. OD by 1-1/4-in. ID by 8 ft long) will be installed in the fuel element cavity to permit the supported transfer of a single SRE fuel rod. The future transfer of a hollow fuel cluster can be accomplished by removing the lead pipe insert and installing a reinforced lead muff around the outside of the cask to provide the additional shielding required by the larger fuel element.

The closure for the cask is a 17-in. OD rotating lead cylinder, located immediately below the fuel cavity. When opened, a 5-1/2-in. diameter orifice is

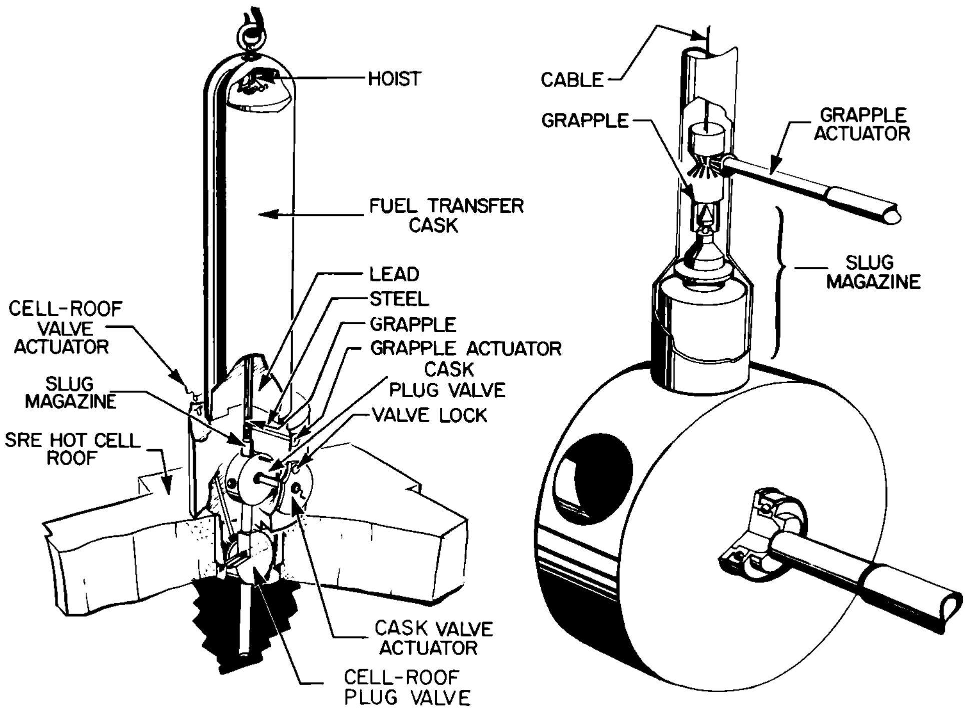

Figure 48. Interfacility Fuel Transfer Cask

concentrically aligned with the fuel rod and slug magazine cavities. The valve is gear actuated through a 90° arc, from the open to the closed positions, by a shaft that penetrates the cask shield.

The hoist inside the cask has a capacity of 175 lb and is motor driven from a push button station at floor level. It is partially shielded with respect to the fuel cavity, enclosed within the atmosphere envelope of the cask, and can be serviced by removing a service plate from the top of the cask.

Attached to the hoist cable is a weighted grapple, shown in Figure 49, which has a mechanical action like a Jacobs chuck; except that, in place of the jaws, two hooks close under the shoulder of the end cap on the fuel rod. It is actuated by a drive pinion attached to a push rod which penetrates the shielded wall of the cask immediately above the slug transfer magazine cavity. When the rod is pushed in, the pinion meshes with the two bevel gears on the upper and lower portions of the grapple and actuates the jaws for grappling or releasing. A ball bearing suspension is used between the cable and the grapple to prevent cable twist during actuation of the gear mechanism. The grapple is self-locking in the closed position.

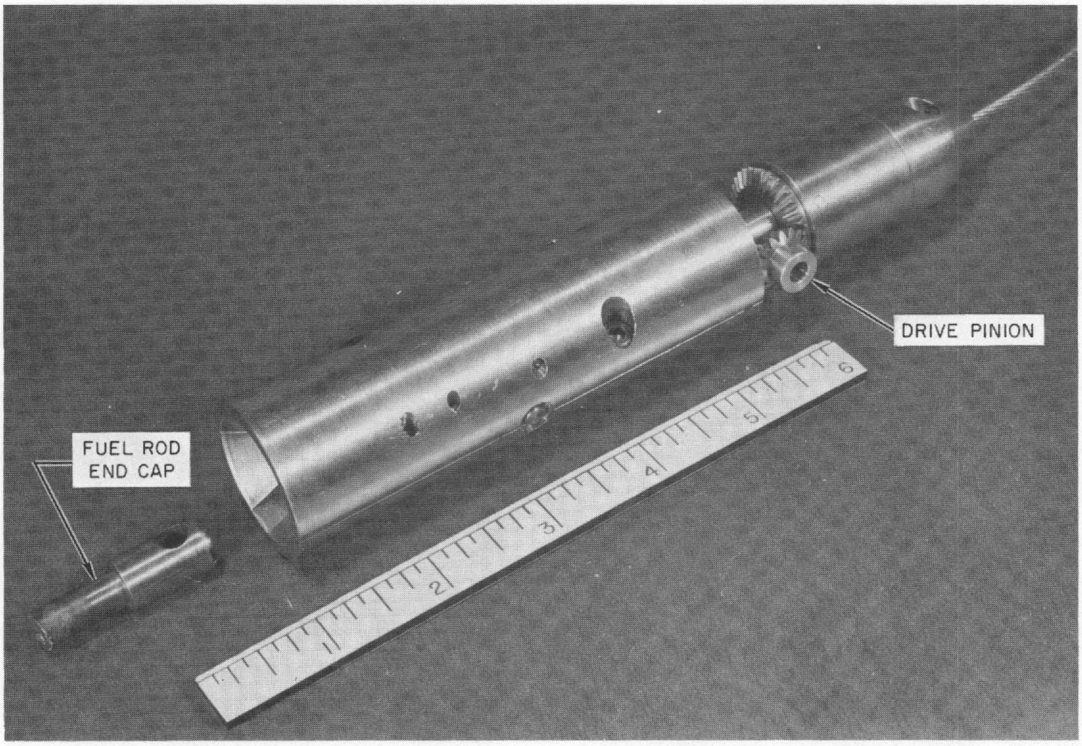

Figure 49. In-Cask Grapple

A special 20-in. diameter roof plug replaces the standard roof plug in the SRE hot cells. The special roof plug, shown in Figure 48, provides access for the cask to pick up spent fuel slugs which have been decanned and inspected in the SRE hot cell. This roof plug is fitted with a shielded valve, identical to the one in the cask. A bevel gear, attached to the cylinder in the vertical plane, is driven by a pinion on a vertical spline shaft which extends through the top of the roof plug and mates with an extension shaft in the cask housing. The valve is manually operated from the extension shaft in the base of the cask, when the cask is in place over the roof plug. To provide maximum shielding, the valve plug is made of steel and is filled with lead.

c. Terminal Status

Temperatures at the inner extremities of the lead shielding were calculated to determine if there is a need for cooling the cask during fuel transfer. Heat radiated from 30 kg of 10-day cooled, 3000 Mwd/t irradiated SRE fuel will cause an increase in the in-cask temperatures during transfer operations. Temperature transients in the fuel containers and in the cask shield have been calculated, on the assumed basis of 4 hr in transit. The calculated maximum temperature on the inside surface of the cask, in the immediate vicinity of the slug transfer magazine, was less than 450°F. Operating temperatures may be significantly lower, since it is probable that transfer time will be less than the assumed 4 hr. However, cooling channels are provided in the shielding.

The first step in mockup of the fuel transfer cask was the construction of the hoist grapple shown in Figure 49. The grapple operates successfully.

d. Future Development Plans

A mockup of the cask and valving should be fabricated and operated under simulated operating conditions. Transfer techniques, equipment, and procedures require development.

2. Fuel Transfer Tunnel

a. Introduction

The uranium fuel materials processed in the PRE program will be irradiated in the SRE reactor and transferred between the SRE and PRE facilities, in the form of either a PRE-made fuel rod contained in a transfer pipe (1.125-in. diameter by 8.5 ft long) or irradiated fuel in a transfer magazine (5.5-in. diameter by 8 in. high). Both the feed and product uranium fuel materials for the PRE process studies have radiation intensities as high as 10^4 r/hr at 10 in. and require the installation of adequate shielding between fuel and operating personnel during all out-of-cell transfer operations.

Fuel containers are transferred between facilities in a shielded fuel transfer cask. Fuel rods or fuel magazines are transferred from the shielded cask to the shielded cell complex via a subfloor tunnel with one access port inside the hot cell and a second access port in the operating gallery. The base of the shielded cask is flanged to mate with the out-of-cell access port and to provide adequate shielding during transfers.

b. Terminal Status

(1) Description of Equipment

In the PRE program, a conceptual design of the transport mechanism in the fuel transfer tunnel has been established. A schematic diagram of the fuel transport mechanism and transfer tunnel is presented in Figure 50.

The subfloor tunnel is roughly 4 ft wide, 11 ft deep, and 14 ft long. The tunnel roof consists of 9 in. of lead shielding, reinforced with structural steel to handle floor loading applied by the fuel transfer cask. It is adequately shielded to protect operating personnel from radioactivity during fuel transfers. The fuel transfer tunnel is provided with a filtered-air exhaust system, vented to the exhaust stack for the proposed hot cell facility.

The out-of-cell port, giving access to the tunnel, is covered with a shielding door which can be actuated while the fuel transfer cask is in place over it. The in-cell access port is covered with laminated shielding which can be handled by the in-cell crane. This cover will be sealed to prevent migration of radioactive particulate matter and the diffusion of atmospheres between the tunnel and the hot cell.

The shoulder-mounted carriage, riding on rails extending the length of the tunnel, carries a lift platform in which a fuel rod (in a fuel rod transfer pipe) or a transfer magazine can be carried. The carriage provides support for an elevator which can raise the lift platform either into the fuel transfer cask or into the cell where transfers can be made with appropriate grappling tools. Power is delivered to the two carriage drive chains through a motor and sprocket installed in the out-of-cell end of the tunnel.

Stops are installed at each end of the carriage rail to limit carriage travel and permit the chain drive to raise the lift platform. At the out-of-cell end of the tunnel, a stop indexes the carriage directly under the cask during a fuel transfer. When the carriage is against the out-of-cell terminal stop, overtravel of the chain drive raises the lift platform 55 in. above its down position (see Figure 50) so that the fuel rod transfer pipe is part way into the cask, where the fuel rod can be grappled. The stop at the in-cell end of the tunnel indexes the carriage directly below the in-cell access port, where overtravel of the chain

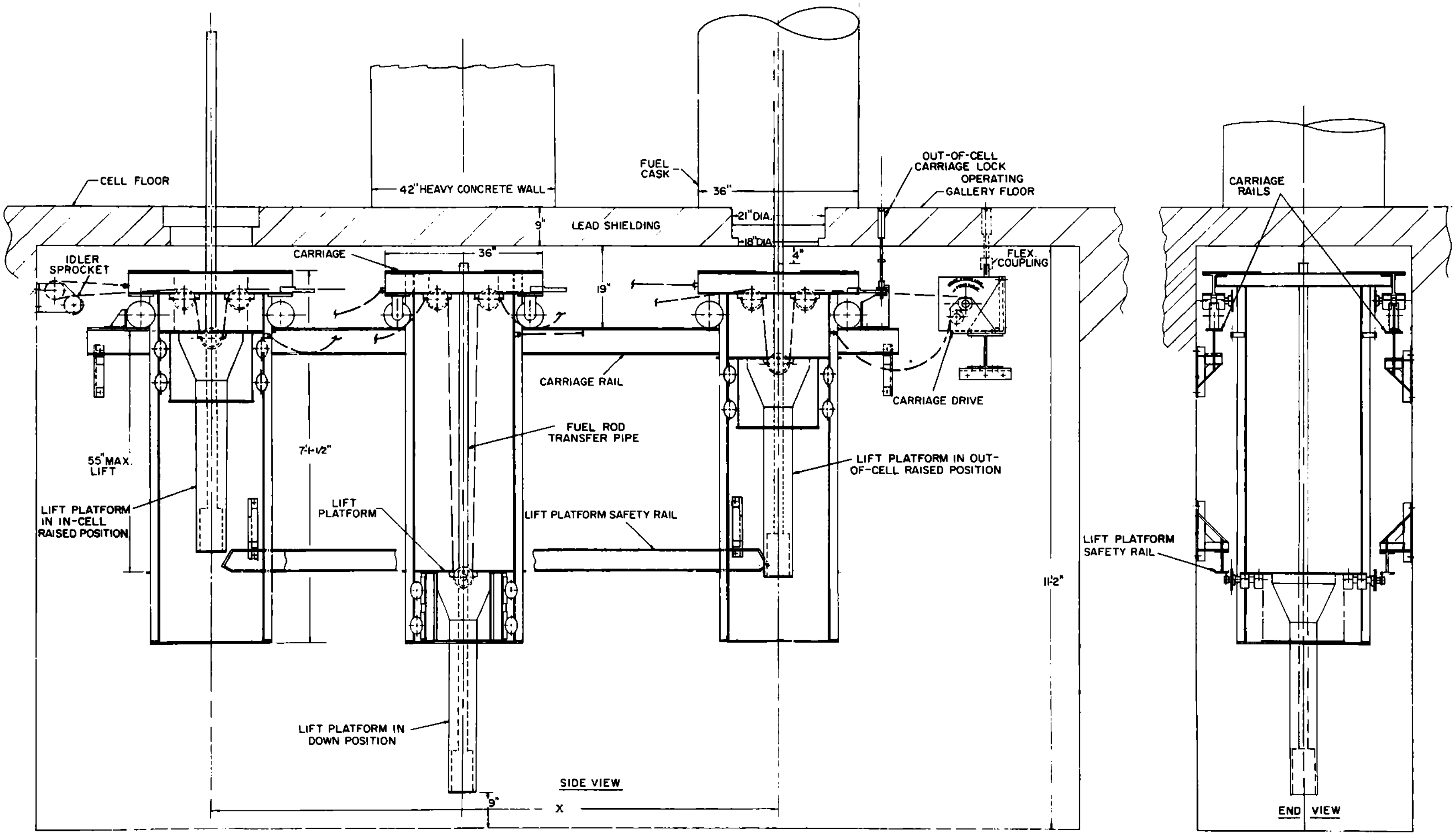

Figure 50. Fuel Transfer Mechanism (Schematic)

drive can raise the lift platform into the cell. Eight cam wheels ride against the vertical members of the carriage framework to align the lift platform while it is being raised.

The transfer magazine can be attached to an empty fuel rod transfer pipe. Small objects, such as fuel rod caps, NaK bottles, welding stingers, and some replacement components for in-cell equipment, can be handled in the 12-in. deep can which can be inserted in the lift platform. Additional buckets and/or fixtures will be provided to handle special transfers of uncontaminated in-cell equipment or to introduce replacement equipment into the cell.

(2) Operating Techniques

The transfer mechanism is normally stowed with the carriage indexed below the out-of-cell access port and the lift platform in the down position. Both ports are closed and sealed. A typical transfer of a PRE-made fuel rod from the shielded cell to the fuel transfer cask is executed as follows:

a) Seal the fuel transfer cask to the out-of-cell access port.

b) Release the out-of-cell carriage lock and drive the carriage to its indexed position under the in-cell access port.

c) Remove the laminated cover from the in-cell access port with the in-cell crane, and stow it on the cell floor.

d) Actuate the chain drive to raise the lift platform above the cell floor level.

e) Pick up the PRE-made fuel rod, in its transfer pipe, with the in-cell crane and lower the fuel rod transfer pipe into the hole in the lift platform. Disengage the in-cell crane hook.

f) Actuate the chain drive to lower the lift platform.

g) Replace the laminated cover on the in-cell access port.

h) Actuate the chain drive to pull the carriage into its indexed position beneath the fuel transfer cask and engage the out-of-cell carriage lock.

i) Open the shielded valve port in the base of the cask and the access port.

j) Actuate the chain drive to elevate the lift platform. Reversing the direction of the carriage drive motor raises the lift platform when the carriage lock is engaged.

k) Raise the lift platform to its upper limit in the cask. In this position, the fuel rod cap is indexed so that the in-cask grapple can be actuated.

l) Actuate the in-cell grapple and raise the fuel rod transfer pipe into the cask with the in-cell hoist drive.

m) Actuate the chain drive to lower the lift platform into its down position.

n) Close the shielded valve port in the base of the cask and the out-of-cell access port to the fuel transfer tunnel.

o) Remove the cask from the access port and transport it to the SRE facility.

(3) Maintenance Techniques

All mechanical components of the transfer mechanism and transfer tunnel are accessible for contact maintenance when the in-cell access port is closed and no fuel is located in the tunnel. The in-cell access port is sealed by the weight of the lid. It can be readily replaced by the in-cell crane.

c. Future Development Plans

The transfer mechanism for the fuel transfer tunnel should be fabricated and assembled, to demonstrate the reliability of the design. Shielded design concepts of a remotely operable shield for the out-of-cell access port should be evaluated and a prototype unit developed.

VII. CONCLUSIONS AND RECOMMENDATIONS

Progress in the PRE program at Atomics International has proved to be a significant contribution to the concept of low-decontamination processing for irradiated nuclear fuels. In the mockup program, equipment development effort has been carried forward to the point where a facility for processing metallic uranium fuel could be designed with some confidence in its remote operability and maintainability.

The study of equipment for processing irradiated UO_2 fuels was well started, at the time of PRE phaseout. In our opinion, another year of mockup effort on equipment development, combined with laboratory-scale processing studies, would advance the art to the point where a facility for processing UO_2 could be designed and built. It is felt that the plant could be operated with a reasonable degree of confidence in its technical feasibility.

A large-scale engineering experiment, such as PRE, is of great significance in the development of low-cost fuel cycles for irradiated nuclear fuels. The remote processing of highly radioactive fuels by low-decontamination methods, in a facility adjacent to an operating power reactor, can be an economically and technically feasible contribution to nuclear technology. It is strongly recommended that engineering experiments of the PRE type be reactivated, in connection with reactor demonstration programs now under way or contemplated.

APPENDIX A

BUILDUP OF POISONS AND FISSIONABLE SPECIES IN SLIGHTLY ENRICHED POWER REACTORS

by

S. Berger

I. STUDY OBJECTIVES

The objective was the determination of the effect on reactivity of operating an SGR reactor for numerous cycles of fuel burnup and reprocessing. The fuel (uranium metal or UO_2) will be processed after 13% depletion of the U^{235}, corresponding to 287 days in-pile operation, at an average thermal neutron flux of 1.5×10^{13} n/cm^2-sec. The processing will consist of re-enrichment of the fuel in U^{235} to its original value and the removal of only the fission product gases, xenon and krypton.

II. SUMMARY OF RESULTS AND RECOMMENDATIONS

For fuels up to 6% enrichment in U^{235} (uranium metal or UO_2), it is possible to operate for 4 cycles with no decrease in reactivity. A cycle is defined as an in-pile time sufficient to deplete 13% of the U^{235} and a process which re-enriches the fuel to its original value.

For fuel of 2.78% enrichment, the reactivity increases by approximately 2%, by the beginning of the sixth cycle. For fuels of 4.4 and 6.0% enrichment, a slight decrease in reactivity, of about 1%, is noted by the sixth cycle.

The results shown above assume no process loss. Introducing a process loss of 10% or less has a negligible effect on the results.

III. METHOD AND SAMPLE CALCULATIONS

A. BASIC ASSUMPTIONS

1) Fuel is irradiated in a sodium graphite reactor, operating at an average sodium temperature of 425°C.

2) A cycle is defined as an in-pile time of 287 days at an average thermal neutron flux of 1.5×10^{13} n/cm^2-sec (13% depletion in U^{235}), 10-day cooling prior to processing, processing the fuel, and reloading into the reactor.

3) All fission product cross sections follow a $1/v$ distribution.

4) The significant fission product poisons considered in this report are listed in Table A-I of this appendix.

5) Processing the fuel consists of the removal of xenon and krypton and re-enrichment of the fuel to its original value.

6) There is no significant depletion of U^{238} during the six cycles of reactor operation considered in this report.

7) The value for the thermal utilization at the beginning of the first cycle is 0.84 for the three different enrichments discussed here. This is not strictly true. However, the variation for different enrichments would probably not exceed 15%.

TABLE A-I

FISSION PRODUCT POISONS CONSIDERED IN THIS REPORT

Fission Product Poison	Cross Section (Barns) (425°C)
Sm^{149}	3.3×10^4
Sm^{151}	4.6×10^3
Sm^{152}	1.0×10^2
Pm^{147}	3.9×10^1
Nd^{143}	1.9×10^2
Nd^{145}	3.4×10^1
Eu^{155}	9.1×10^3
Tc^{99}	6.5×10^1
Rh^{103}	1.0×10^2
Xe^{135}	2.3×10^6

B. THEORY

The value of η (the number of fast neutrons released per thermal neutron captured in the fuel) may be expressed mathematically as

$$\eta = \frac{\sum (\nu_K \sigma_{fK} N_K)}{\sum (\sigma_{cP} N_P + \sigma_{cH} N_H + \sigma_{fK} N_K)}, \qquad ...(1)$$

where

ν = neutrons released per fission,
σ_c = captive cross section,
σ_f = fission cross section,
σ_a = absorption cross section $(\sigma_f + \sigma_c)$,
N = number of atoms,
K refers to U^{235}, Pu^{239}, and Pu^{241},
P refers to fission product poisons,
H refers to U^{235}, U^{236}, U^{238}, Pu^{239}, Pu^{240}, Pu^{241}, and Pu^{242}.

Since the values of N^{25} and the N^{28} are known for a particular enrichment, it is necessary to calculate the poison and heavy isotope buildup before a value of η can be determined. These expressions are shown below. The buildup of a fission product poison isotope is described by

$$\frac{dN_a^b}{dt} = \sum \gamma_{Kb} \sigma_{fK} \bar{\phi} N_K + \sigma_a^{b-1} \bar{\phi} N_a^{b-1} + \lambda_{a-1}^b N_{a-1}^b - (\lambda_a^b + \sigma_a^b \bar{\phi} + \gamma_a) N_a^b, \qquad ...(2)$$

where

a = atomic number of isotope,

b = atomic weight of isotope,

N = number of atoms of isotope,

γ = yield of the b^{th} isotope due to fissioning of U^{235} and Pu^{239},

σ_f = fission cross section,

σ_a = neutron absorption cross section,

$\bar{\phi}$ = average neutron flux,

λ = decay constant,

y = amount of isotope removed during processing.

Equation (2) was solved by an electronic computer for 2.78% enriched fuel, based on one atom of U^{235} originally present. For enrichments other than 2.78%, the fission product isotopes were calculated by applying the appropriate correction factor to the 2.78% values, based on the change in the number of atoms of Pu^{239} being formed.

The buildup of Pu^{239} is described by the following differential equation:

$$\frac{dN^{49}}{dt} = N^{28}\bar{\phi}\sigma_c^{28} + \nu^{25}\epsilon(1-p)e^{-B^2\tau}N_0^{25}(e^{-\sigma_a^{25}\bar{\phi}\bar{i}})\sigma_f^{25}\bar{\phi} + \nu^{49}\epsilon(1-p)e^{-B^2\tau}N^{49}\sigma_f^{49}\bar{\phi} - \sigma_a^{49}\bar{\phi}N^{49}, \quad \ldots(3)$$

where

N^{49} = atoms of Pu^{239},

N^{28} = atoms of U^{238},

N_0^{25} = atoms of U^{235} originally present,

σ_c = capture cross section,

σ_f = fission cross section,

σ_a = absorption cross section $(\sigma_f + \sigma_c)$,

ν = neutrons released per fission,

ϵ = fast fission factor,

p = resonance escape probability,

B^2 = buckling,

τ = Fermi age,

$\bar{\phi}$ = average thermal neutron flux.

The solution of equation (3) is given by

$$N^{49} = \frac{C_1}{C_3}\left(1 - e^{-C_3 t}\right) + \frac{C_2}{C_3 - k}\left(e^{-Kt} - e^{-C_3 t}\right), \qquad \text{...(4)}$$

where

$C_1 = \overline{\phi} N^{28} \sigma_c^{28}$,

$C_2 = \nu^{25} N_0^{25} \sigma_f^{25} \overline{\phi} \epsilon (1 - p) e^{-B^2 \tau}$,

$k = \sigma_a^{25} \overline{\phi}$,

$C_3 = \sigma_a^{49} \overline{\phi} - \nu^{49} \sigma_f^{49} \overline{\phi} \epsilon (1 - p) e^{-B^2 \tau}$,

t = in-pile time.

The thermal utilization, f, is defined as follows:

$$f = \frac{V_u (\Sigma_u + \Sigma_P) \overline{\phi}_u}{V_u (\Sigma_u + \Sigma_P) \overline{\phi}_u + V_m \Sigma_m \overline{\phi}_m}, \qquad \text{...(5)}$$

where

V_u = volume of the uranium,

Σ_u = macroscopic cross section of uranium fuel at any time,

$\overline{\phi}_u$ = average thermal neutron flux in the fuel,

V_m = volume of moderator plus miscellaneous material in core,

Σ_m = macroscopic cross section associated with V_m,

$\overline{\phi}_m$ = average thermal neutron flux in V_m,

Σ_P = macroscopic cross section of fission product poisons.

Let

$$\Sigma' = \Sigma_u + \Sigma_P .$$

Then equation (5) becomes

$$f = \frac{V_m \Sigma' \overline{\phi}_u}{V_m \Sigma' \overline{\phi}_u + V_m \Sigma_m \overline{\phi}_m}, \qquad \text{...(6)}$$

Since V_m, V_u, and Σ_m remain fairly constant during reactor operation, equation (6) can be rewritten as follows:

$$f = \frac{\Sigma' \overline{\phi}_u}{\Sigma' \overline{\phi}_u + C \overline{\phi}_m} = \frac{\Sigma'}{\Sigma' + C(\overline{\phi}_m/\overline{\phi}_u)}, \qquad \text{...(7)}$$

where

$$C = \frac{V_m \Sigma_m}{V_u}$$

$$\frac{\overline{\phi}_m}{\overline{\phi}_u} = \text{disadvantage factor} = F(\Sigma', f).$$

If we let $C' = C(\overline{\phi}_m/\overline{\phi}_u)$, equation (7) becomes

$$f = \frac{\Sigma'}{\Sigma' + C'} = \frac{1}{1 + (C'/\Sigma')}. \qquad \text{...(8)}$$

Calculated values of f are listed in Table A-II.

Previously calculated values of Σ' and f for a sodium-graphite reactor were used to determine C' as a function of Σ'. These are plotted in Figure A-9. The slope of the curve shown in Figure A-9, ($dC'/d\Sigma' = 0.104$), can be used to calculate new values of C', and therefore f for each value of C'. This is done as follows:

$$C' = 0.104\Sigma' + K. \qquad \text{...(9)}$$

TABLE A-II

VALUES FOR THERMAL UTILIZATION

Beginning of Cycle	Enrichment		
	2.78%	4.4%	6.0%
1	0.840	0.840	0.840
2	0.846	0.845	0.847
3	0.851	0.850	0.850
4	0.855	0.853	0.853
5	0.857	0.855	0.855
6	0.859	0.856	0.856

The value of K for any given enrichment can be determined, since both f_0 and Σ_0' are known at the beginning of the first cycle. Equation (8) is used to determine C_0' at the beginning of the first cycle. These values of C_0' and Σ_0' are inserted in equation (9) and K is evaluated.

C. SAMPLE CALCULATION

A sample calculation for the determination of η, for 2.78% enriched fuel, is shown in Table A-III of this appendix. The values for E, p, τ, and B^2 are assumed to be constant throughout the exposure period and have the values:

$E = 1.043$

$p = 0.82$

$\tau = 347 \text{ cm}^2$

$B^2 = 5.05 \times 10^{-4} \text{ cm}^2$

A sample calculation for determining the change in thermal utilization, f, from the beginning of the first cycle to the beginning of the second is shown below.

Assume: 2.78% enrichment,

f (at beginning of cycle 1) = 0.840.

TABLE A-III

SAMPLE CALCULATION FOR THE DETERMINATION OF "η"

(Enrichment = 2.78%)

(Irradiation Time = 287 days at $\bar{\phi}$ = 1.5 x 10^{13} n/cm^2-sec)

		First Cycle		Second Cycle	
		Beginning	End	Beginning	End
1	N^{25}	1.0	0.87	1.0	0.87
2	N^{28}	35	35	35	35
3	$\sigma_f(25)$	350	350	350	350
4	$\sigma_a(25)$	420	420	420	420
5	$\sigma_a(28)$	1.75	1.75	1.75	1.75
6	N^{49}	0	0.046	0.046	0.081
7	$\sigma_f(49)$	850	850	850	850
8	N^{41}	0	1 x 10^{-4}	1 x 10^{-4}	6.5 x 10^{-4}
9	$\sigma_f(41)$	1000	1000	1000	1000
10	$\nu(25)$	2.5	2.5	2.5	2.5
11	$\nu(49)$	3.0	3.0	3.0	3.0
12	$\nu(41)$	3.0	3.0	3.0	3.0
13	$\sigma N(Xe^{135})$	0	13	0	14
14	$\sigma N(Sm^{149})$	0	4.3	4.3	5.2
15	$\Sigma(\sigma N)$ (*misc. F. P.*)	0	3.8	3.8	7.7
16	$\Sigma(\sigma_a N)$ 26, 49, 40, 41, 42	0	56	56	99.8
17	$\nu\sigma_f N(25)$	875	760	875	760
18	$\nu\sigma_f N(49)$	0	117	117	203
19	$\nu\sigma_f N(41)$	0	0.3	0.3	1.2
20	$\sigma_a N(25)$	420	365	420	365
21	$\sigma_a N(28)$	61.2	61.2	61.2	61.2
22	17 + 18 + 19	875	877	992	964
23	13 + 14 + 15 + 16 + 20 + 21	481.2	503.3	545.3	552.9
24	22 ÷ 23	1.818	1.742	1.819	1.743

From lines 20 and 21 of Table A-III of this appendix,

$$\Sigma_0' = \sigma_a^{25} N_0^{25} + \sigma_a^{28} N_0^{28} = 420 + 61 = 481 .$$

Therefore, from equation (8),

$$C_0' = \frac{481(1 - 0.840)}{0.840} = 92.$$

From equation (9),

$$K = 92 - (0.104)(481) = 42 .$$

Thus, for 2.78% fuel, the value of C' at any cycle is

$$C' = 0.104\Sigma' + 42 .$$

At the beginning of the second cycle, the value of Σ' is the sum of lines 13, 14, 15, 16, 20 and 21 in Table A-III:

$$\Sigma' = 0 + 4.3 + 3.8 + 56 + 420 + 61.2 = 545 .$$

The value of C' at the beginning of the second cycle is

$$C' = (0.104)(545) + 42 = 98.6 .$$

Therefore, the thermal utilization at the second cycle is

$$f = \frac{545}{545 + 98.6} = \frac{545}{643.6} = 0.846 .$$

IV. DISCUSSION

Figure A-1 shows the variation of η for successive cycles of reactor operation and fuel processing, using 2.78% enriched fuel. It should be noted that the value of η at the beginning and at the end of the first four cycles are the same. This indicates that, during the first four cycles of reactor operation, it is merely necessary to re-enrich to the original value of 2.78% during the process part of the cycle. No fission product poison removal is assumed, other than Xe^{135}; which, if not physically released during the process, would have decayed during the 10-day cooling period.

Figures A-2 and A-3 indicate similar information to that of Figure A-1, with enrichments of 4.4 and 6.0%, respectively. It is seen that the value of η in both figures changes significantly with each cycle. Therefore, depending upon the particular reactor characteristics and values of f, the enrichment may have to be increased above the original value during processing in order to maintain criticality.

Figure A-4 is a replot of the first four figures, showing the relationship of η with enrichment. The parameters indicate the beginning of each of the first six cycles of operation. It may be seen that the beginnings of cycles 1, 2, 3 and 4 all intersect at about 3.0% enrichment.

Figures A-5, A-6, and A-7 show the variation of the product of $\eta \times f$ with cycles of reactor operation. It will be shown that this product is proportional to the reactivity. Reactivity, ρ, is defined as follows:

$$\rho = \frac{ak - 1}{ak} ,$$

where k is the infinite multiplication factor and a is the nonleakage probability. The value of k is further defined as:

$$k = p\epsilon\eta f.$$

The first two terms on the right hand side of this equation, i.e., the resonance escape probability and the fast fission factor, are quite independent of burnup.

For slightly enriched reactors, their dependence is based almost entirely upon reactor geometry. Thus, for a given reactor design, the values of k and ρ are proportional to $\eta \times f$.

Figure A-8 shows the buildup of Xe^{135} and Sm^{149} and the sum of all other fission product poisons. After about five cycles, the miscellaneous fission product poisons become comparable to the Xe^{135} and Sm^{149}. Therefore, the removal of Xe^{135} during processing is not as effective in increasing the reactivity at the fifth cycle as it was during the second or third cycle.

A 13% depletion of U^{235} per cycle corresponds to the following burnups for the three enrichments considered in this report:

2.7%————————3000 Mwd/t
4.4%————————4700 Mwd/t
6.0%————————6500 Mwd/t.

Consider a reactor designed such that greater burnups (by a factor of 2 or 3) can be accomplished before processing, either by operating at a greater flux or increasing the in-pile time. If processing consists only of re-enrichment, the reactivity changes at the beginning of each cycle can be found from Figure A-5. For example, for twice the burnup of Figure A-5, the reactivity corresponding to the beginning of the second new cycle would be approximated by the third cycle of Figure A-5. The reactivity corresponding to the beginning of the third new cycle would be approximated by the fifth cycle of Figure A-5.

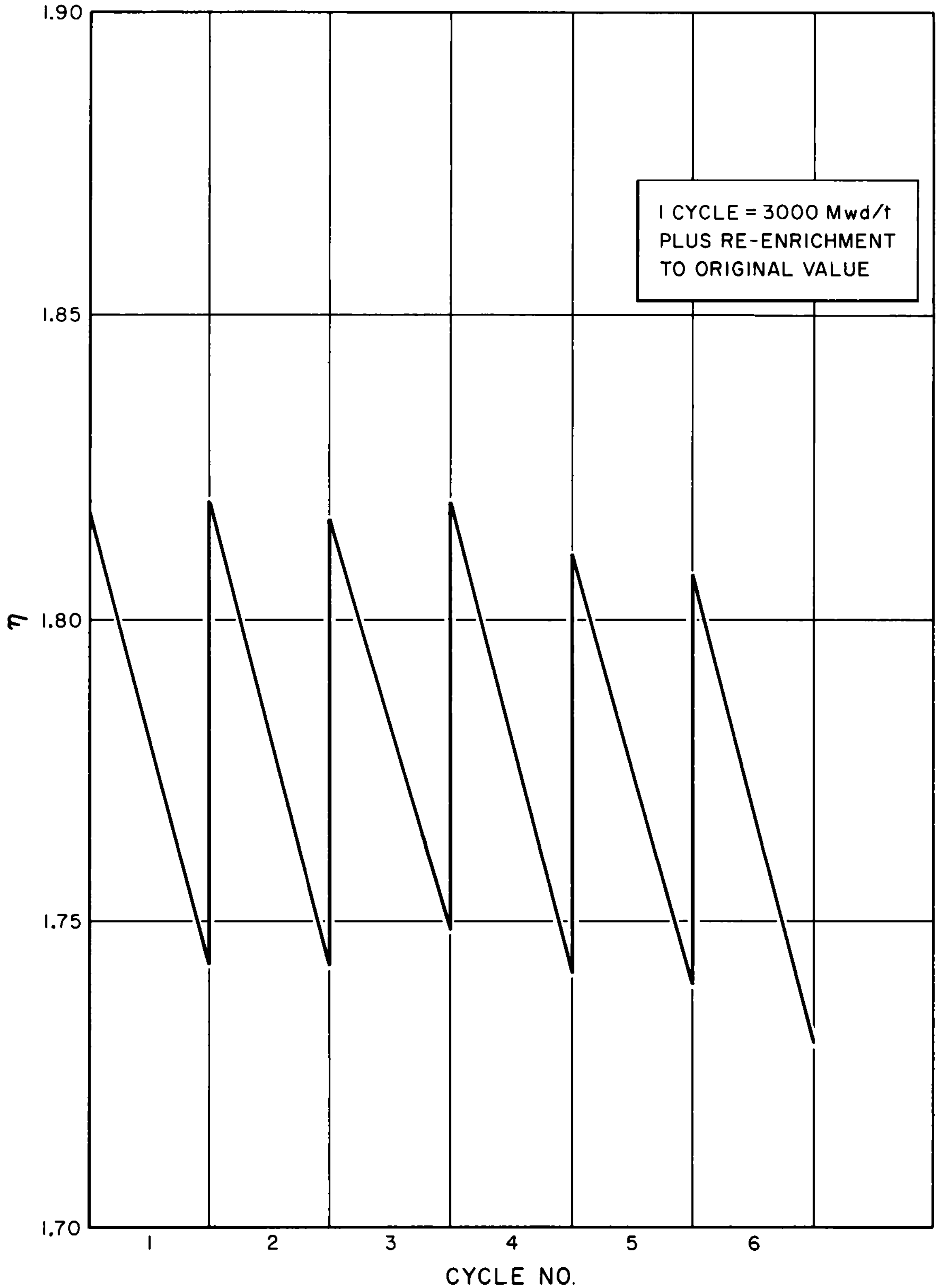

Figure A-1. Value of η for 2.78% Enrichment

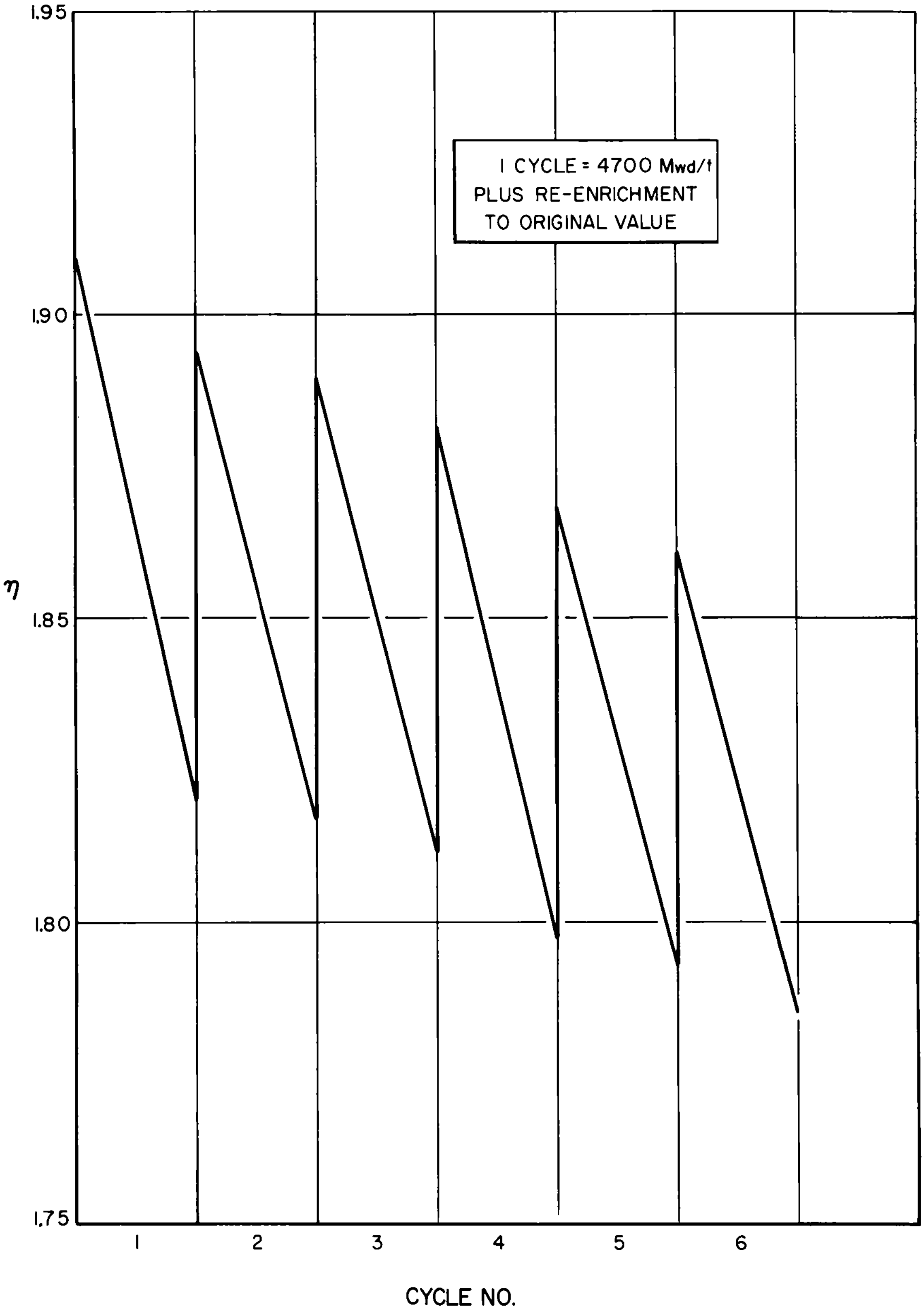

Figure A-2. Value of η for 4.4% Enrichment

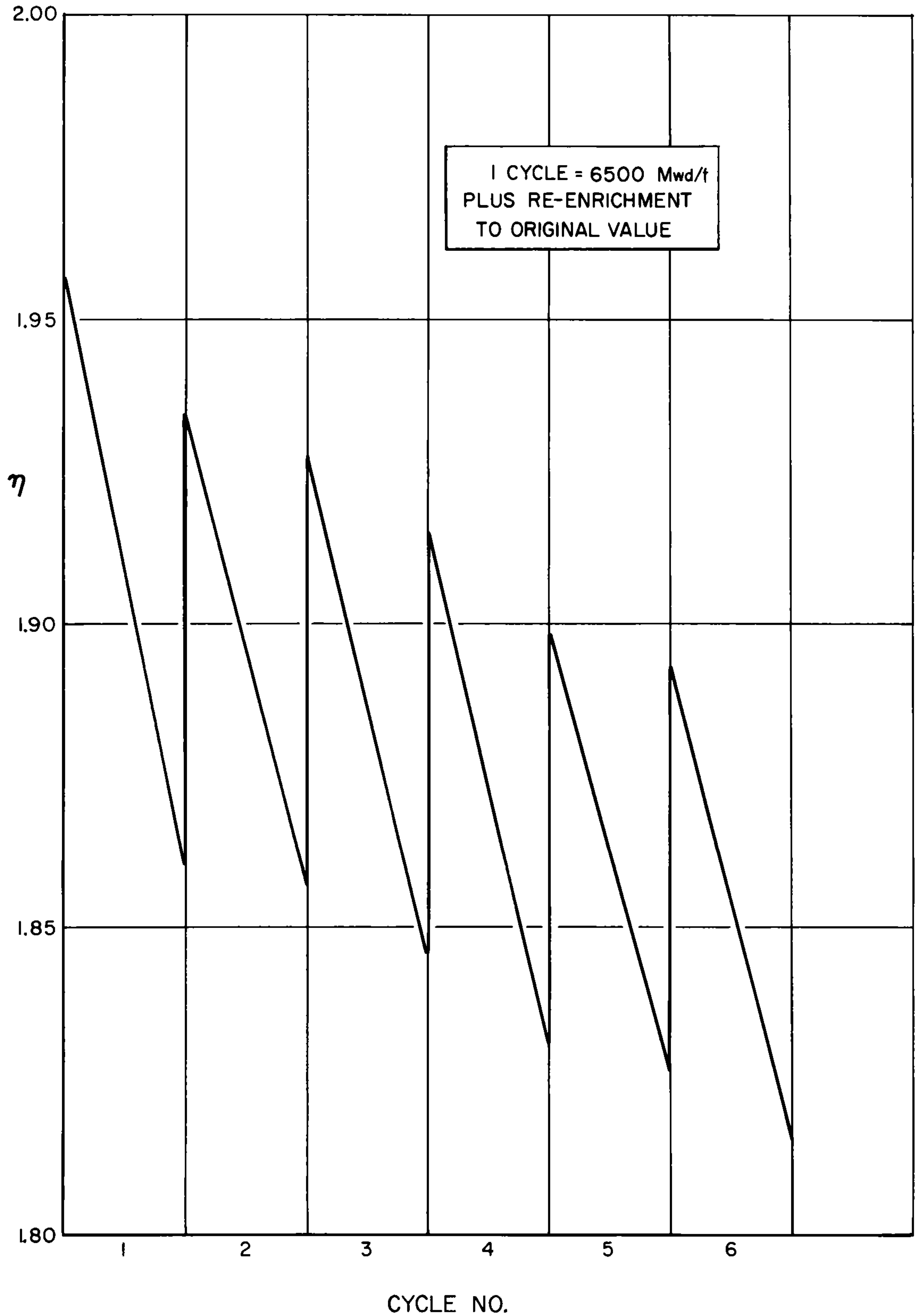

Figure A-3. Value of η for 6.0% Enrichment

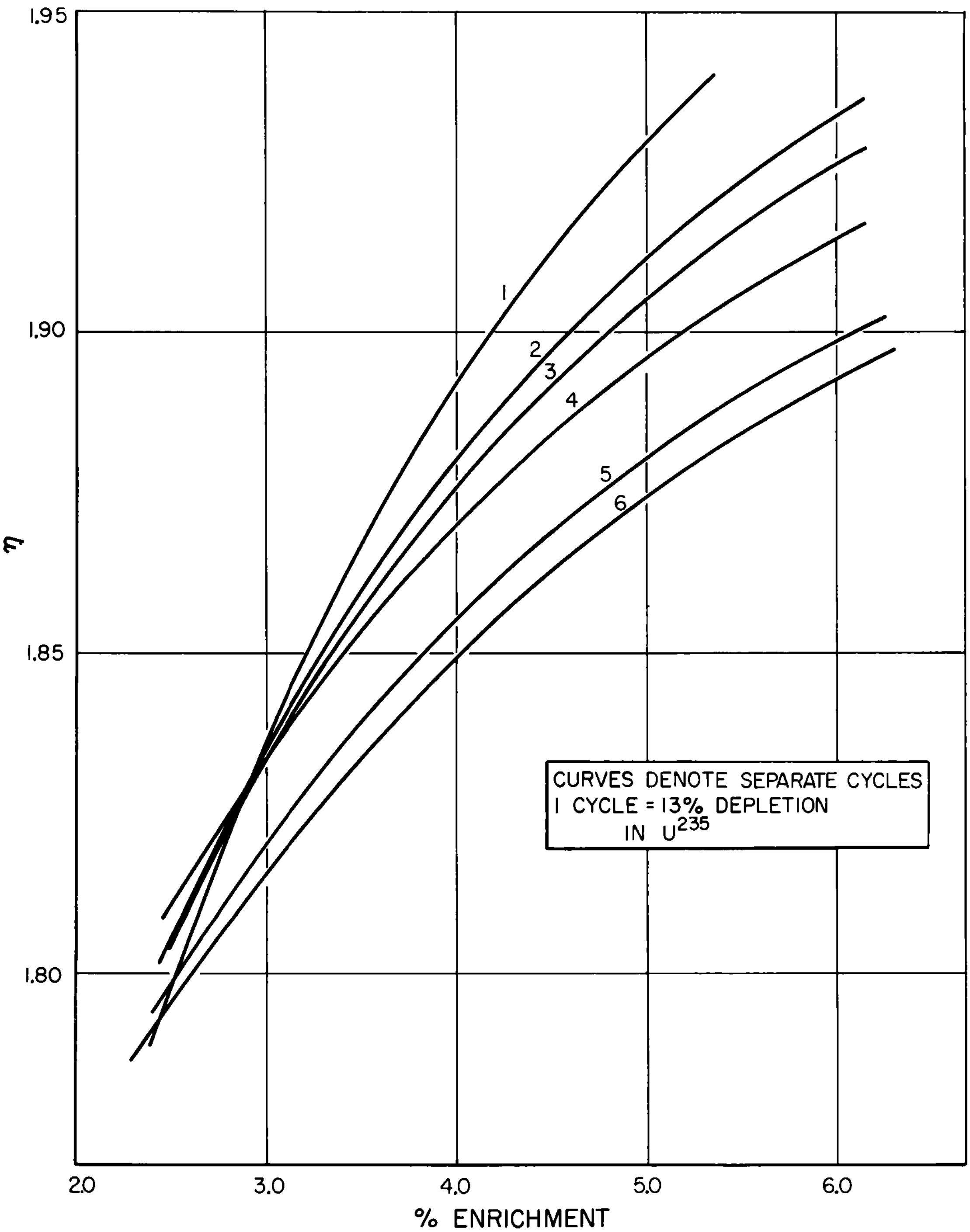

Figure A-4. Value of η vs Enrichment in U^{235}

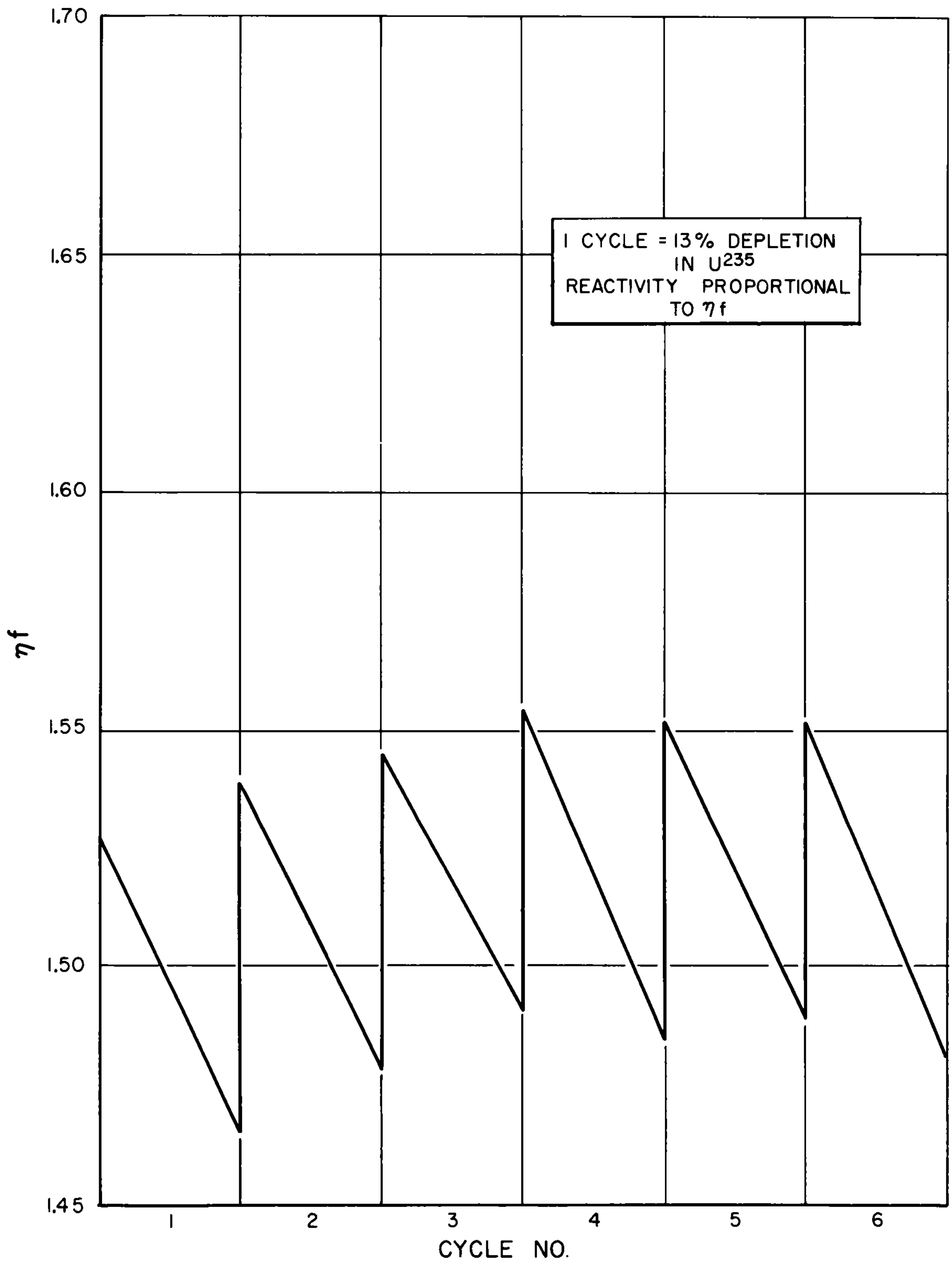

Figure A-5. Change in Reactivity at 2.78% Enrichment

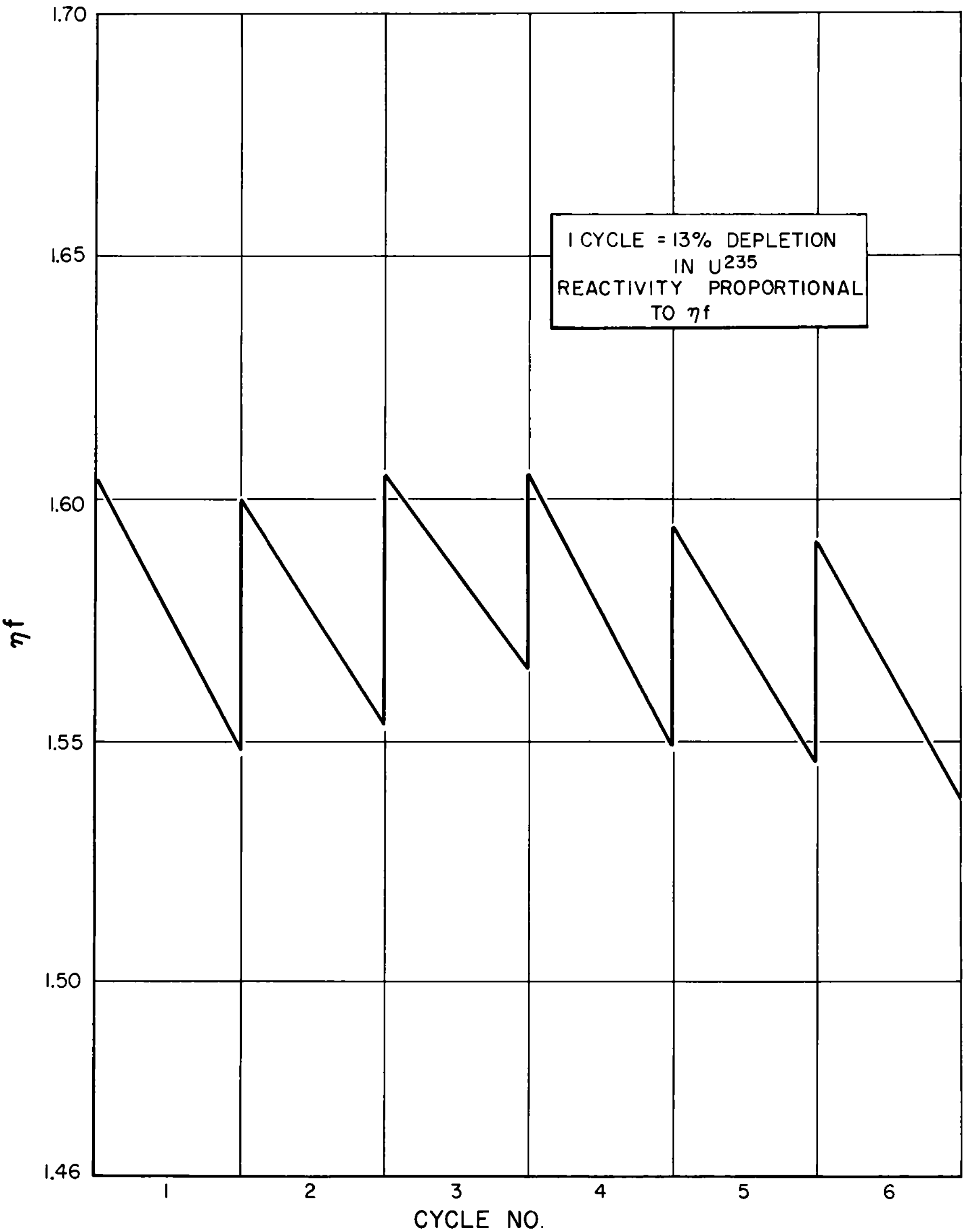

Figure A-6. Change in Reactivity at 4.4% Enrichment

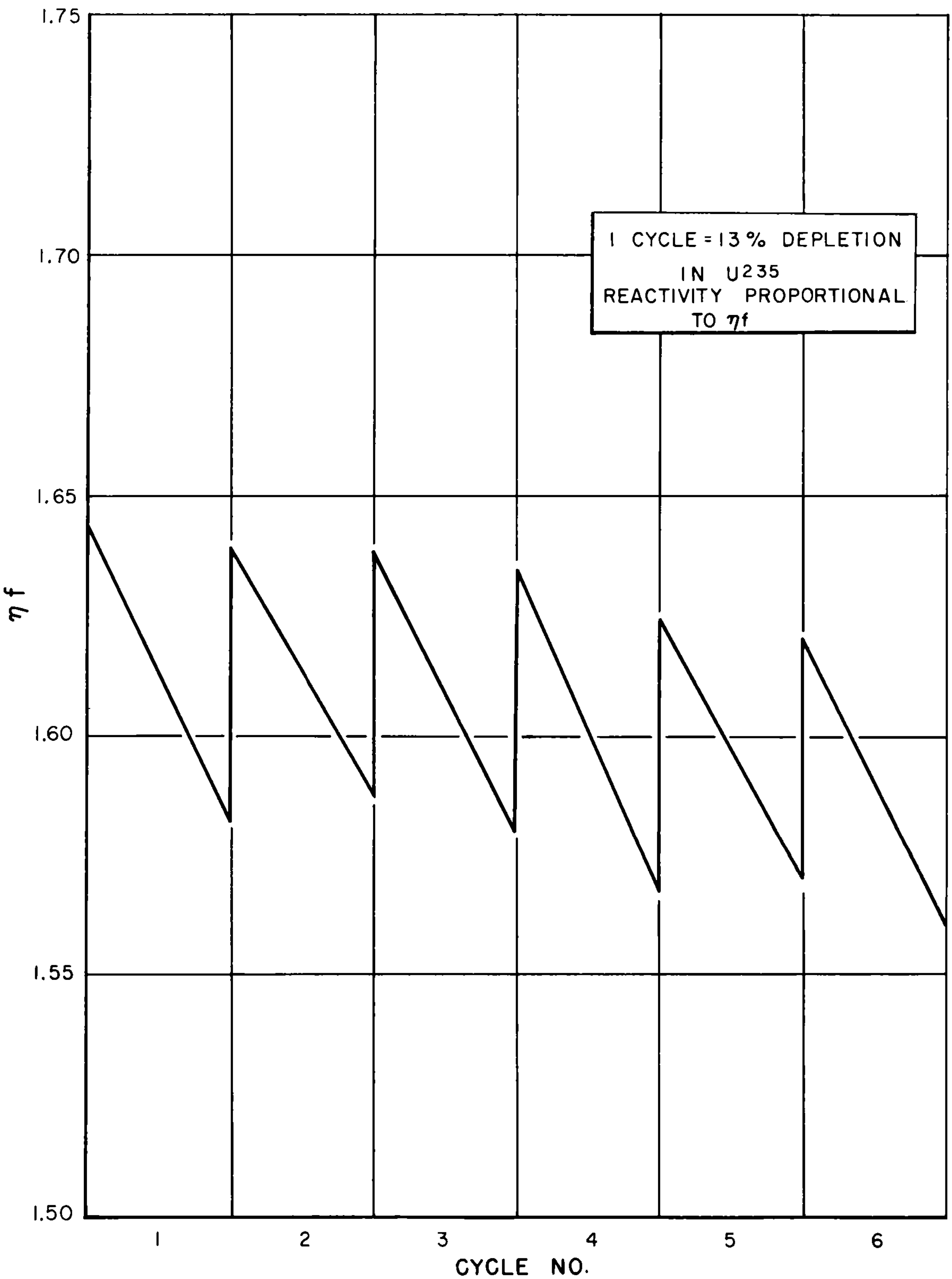

Figure A-7. Change in Reactivity at 6.0% Enrichment

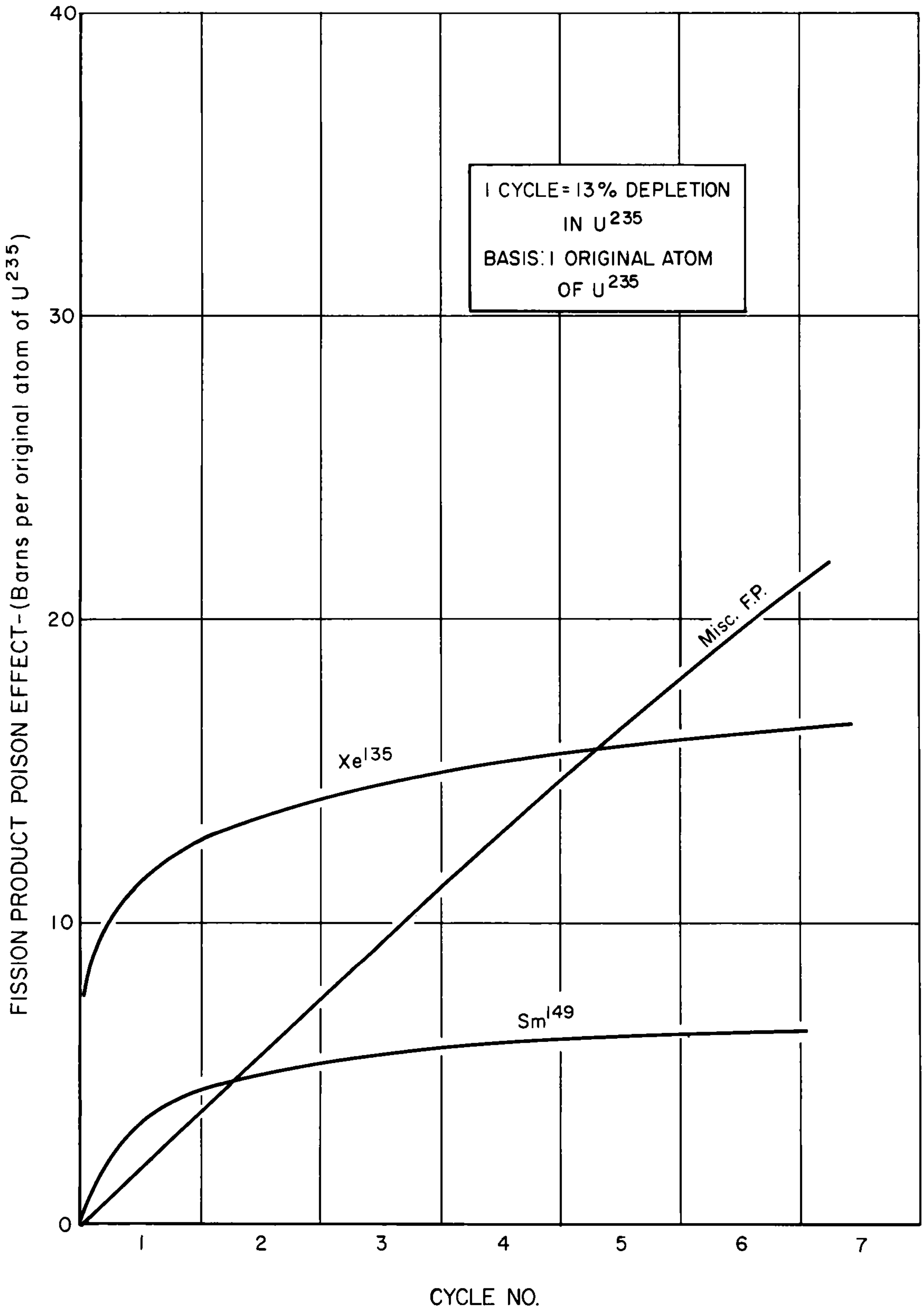

Figure A-8. Fission Product Poisons vs Cycles of Operation

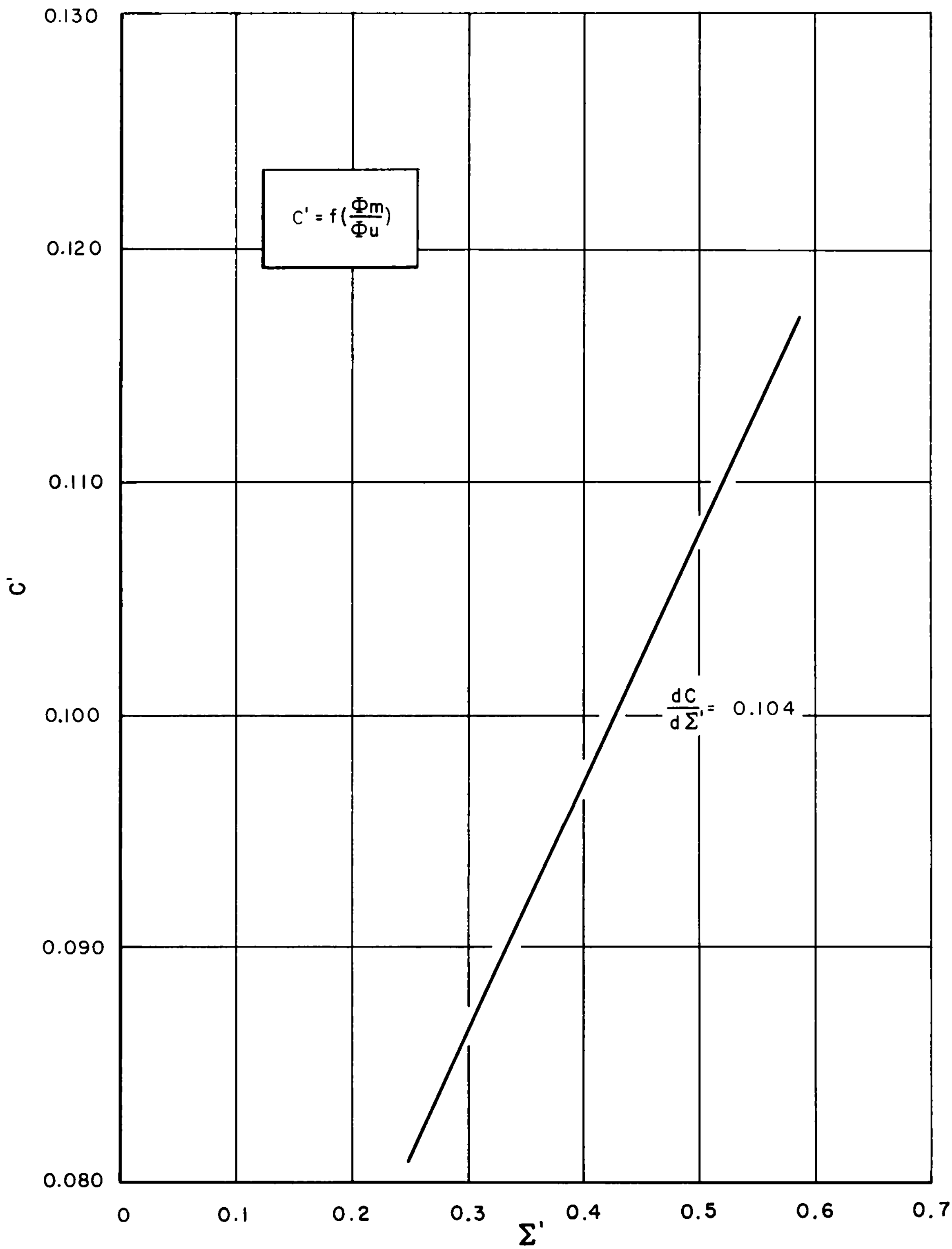

Figure A-9. Effect of Macroscopic Absorption Cross Section of Fuel on Disadvantage Factor

APPENDIX B
POWDER INSPECTION METHODS

by

D. W. Reed

I. INTRODUCTION

The intent of this work was to develop a method of characterizing the resultant particle size of UO_2 powders produced by the oxidation-reduction comminution of massive high density UO_2, in order to predict the behavior of powders during later compacting and sintering.

The method developed in this study was applied to pure UO_2 powders and to normal UO_2 containing calculated amounts of stable isotopes of the fission products to simulate equilibrium composition after one or more cycles of SRE irradiation. The method can provide a standard of reference for the particle size determinations adaptable to control of hot-cell processes. Since the primary emphasis in this study was on information applicable to PRE process control, the results given here refer to aggregates found in UO_2 or U_3O_8 powders passing a 400 mesh screen following oxidation or oxidation-reduction treatment.

Counts were made on a series of samples of UO_2 and U_3O_8 powders. This material represented the fraction of powder passing a 400 mesh screen during 15 min shaking following oxidation-reduction cycles. A polarizing microscope, with a calibrated Porten graticule inserted into the 12.5X eyepiece, was used to perform the size count work. An accessory camera attachment provided a photomicrographic record.

II. PROPOSED METHOD FOR ANALYSIS OF POWDER SIZE DISTRIBUTION

Dispersions of material to be counted were prepared by stirring a small amount of powder into a drop of immersion oil on a glass slide, using a needle as a stirrer to avoid particle breakage. A cover slip was then carefully lowered onto the dispersion and the edges were sealed with clear lacquer. The mount thus produced is quite permanent, does not leak, shows no signs of clumping of particles, and does not show any signs of particle breakage with time, provided no pressure is exerted on the glass cover slip.

Particles in this mount were microscopically measured, using a Porten graticule previously calibrated against a stage micrometer grid. The statistical diameter of all particles within a set width of the field was measured in a traverse in one direction across a slide. Provided enough particles are measured, this method gives a statistically true picture of particle size and distribution because of the cancellation of individual errors in measurement over the range of the larger groups of randomly situated particles.

Since the behavior of this material in a packing is of major interest, the data were converted to volume or mass figures by multiplying the number (n) of particles in each size group by the cube of the average diameter (d^3) of that group and further converting the results to a cumulative percentage basis. These data were plotted as maximum diameter of each size vs the cumulative mass percent less than this diameter. The 50^{th} percentile of this plot on probability-logarithmic paper is the geometric mean mass diameter (d_w) and the standard deviation σ_w of this distribution plot can be derived by taking from the plot the values needed to solve the relation

$$\sigma_w = \frac{84.13\%\ size}{50\%\ size} = \frac{50\%\ size}{15.87\%\ size}\ . \qquad ...(1)$$

A check on this method can be obtained by calculation, using the formula

$$d_w = \frac{\Sigma\,(nd^4)}{\Sigma\,(nd^3)}\ , \qquad ...(2)$$

where n is the number of particles in each group whose average diameter is d.

This information can be used to determine the surface area per unit weight of material (specific surface area) by insertion of the proper quantities in the relation

$$S_w = \frac{6}{\rho d_w}, \qquad \text{...(3)}$$

where

S_w = specific surface or surface area per unit weight,
ρ = density,
d_w = geometric mean mass diameter.

This surface area value is based on the assumption that the particles are spheres. It is assumed that all particles in samples of UO_2 subjected to the same treatment are of like geometry. Therefore, a shape factor can be derived from the relation between S_w calculated from particle size counts and S_w derived from experimental measurements. Equation (3) becomes

$$S_w = C \times \frac{6}{\rho d_w}, \qquad \text{...(4)}$$

where the constant C is a shape factor.

Since the technique of counting described above is both exacting and tedious, a tentative investigation of the possibilities of counts made on photomicrographs was undertaken. Preliminary results were quite discouraging, since magnification to sizes convenient for counting is time consuming and results in photographic grain of an unacceptable size.

During the study, it was discovered that photomicrographic negatives made at low magnification, under polarized light with crossed Nicol prisms, revealed particles outlined in white on a black field. This negative could be projected, in an ordinary enlarger, onto a fine matte surface and sizing performed on the projection with a properly calibrated plastic grid. The advantages of this method are that the work can be performed by relatively unskilled personnel in less time and with less fatigue-induced error. Permanent slides are not needed for rechecking, since the negatives constitute an easily stored permanent record.

The depth of field in the negative, at this lower magnification, gives a more accurate count of smaller particles. The only apparent disadvantage might be a slight exaggeration of particle size, induced by reflection effects at particle margins. Negatives suitable for sizing analysis by this method have been prepared.

III. RESULTS OF PRELIMINARY PROCESS STUDIES

In preliminary process studies, UO_2 and fissia pellets were oxidized to U_3O_8 and reduced to UO_2 for comminution of the pellets to powder under various conditions. The fissia pellets simulated the equilibrium composition of fuel after one cycle of irradiation in the SRE reactor. The process conditions and the resulting powder size analysis are shown in Table B-I. To provide a standard of reference for the counting work in process studies of UO_2 oxidation and reduction, a sample of copper microspheres was prepared by taking the fraction of commercial hydrogen-reduced copper powder passing a 325 mesh screen during 15 min sieving. Data on this material are also listed in Table B-I.

Preliminary results show a generally consistent relation between mean mass particle size and the conditions of the oxidation-reduction reaction. For example, oxidation alone, as in the D-42 run, produces a small average particle size. High temperature vacuum reduction, as in the D-55, -58 runs, results in an average size approaching the nominal opening (37 μ) of the screen used to separate the fraction. Oxidation at low temperatures, followed by slow reduction, as in the D-76 series, gives an average size in the same range as that produced by oxidation alone. The inconsistencies in the size analyses for the preliminary process studies are probably due to unfamiliarity with the method, the loss of depth of field at higher microscopic magnifications, and the disproportionate effect that a small number of maximum size group particles have on the average for the whole distribution. The projection technique with photomicrographs, developed in this study, can improve the accuracy of sizing analyses in other process studies. Further correlation with other methods is warranted, before accepting the method as a standard.

In general, the proposed technique offers more precision than other methods previously attempted on these materials. Its application to powders presently being produced in large quantities by more standardized methods, followed by correlation of the results with compacting and sintering work, should result in a realization of the aims of the work, as originally established.

TABLE B-I.

EFFECT OF PROCESS CONDITIONS ON PARTICLE SIZE

Sample	Process Conditions						Product Characteristics		
	Oxidation			Reduction			% Passing	d_w	S_w
		hr	°C		hr	°C	400 mesh	(μ)	(m^2/gm)
Copper Microspheres	-	-	-	Hydrogen	-	-	100% -325	37.2	0.0181
D42 - U_3O_8	Oxygen	6.0	535	-	-	-	48.6	17.2	0.0437
D55 - UO_2	Air	2.5	375	Vacuum	1.0	1215	59.2	30.2	0.0181
D56 - UO_2	Air	2.5	375	Vacuum	1.0	1100	52.8	33.9	0.0161
D57 - UO_2	Air	2.5	375	Vacuum	0.5	1160	57.1	29.3	0.0186
D58 - UO_2	Air	2.5	375	Vacuum	1.0	1160	59.3	34.4	0.0159
D65 - UO_2	Air	3.0	375	Hydrogen	3.5	650	96.5	24.9	0.0220
D76 - Fissia	Air	5.0	375	Hydrogen	5.0	650	95.0	21.1	0.0259

Note: d_w is geometric mean mass diameter
S_w is specific surface area.

APPENDIX C
ULTRASONIC CLEANING

by

J. W. Savage

I. INTRODUCTION

In the PRE facility, contamination of very high activity levels is anticipated, as a result of facility process operations. This activity will be predominantly particulate in nature, although some material will also be dispersed from the vapor phase during certain operations.

Ultrasonic cleaning appears to be a practical method[36,37,38] for non-destructive decontamination, on the basis of several factors existing in the PRE:

1) Since the use factor of the equipment will be low, reagents will be retained in the system for long periods of time. Ultrasonic cleaning with mild reagents reduces equipment corrosion and liquid handling problems. No equipment replacement due to corrosion is expected.

2) Much of the contamination expected in PRE is particulate in nature. Ultrasonic cleaning will remove contamination as particles which can be filtered from the working fluid by suitable devices, thereby concentrating the contaminant for easier disposal and reducing the activity levels in the fluid.

3) An ultrasonic cleaning system can be externally controlled. In addition, all in-cell components, with the possible exception of the transducers, are simple and nonsensitive to radiation effects. Generator and control units are externally located.

4) Deleterious effects on the objects cleaned are minimized.

Disadvantages of ultrasonic cleaning include:

1) The liquid system is subject to leakage problems and to spillage.

2) A moderately large inventory of fluid is required in the device. Disposal of this fluid is accompanied by the usual hot-liquid waste-handling and disposal problems.

3) The behavior of transducer materials in high radiation fields is not well known.

II. EQUIPMENT

A series of initial investigations were carried out with a small, 100 w, 400 kc, commercial ultrasonic cleaning unit, equipped with a tank of approximately 2 gal. capacity containing a circular barium titanate transducer positioned at the center of the tank bottom. The generator is enclosed in a housing, separate from the tank, with a coaxial lead cable connecting the generator to the transducer. The generator unit operates on 110-v ac. The tank housing contains a centrifugal recirculating pump, and coarse and fine filters for the removal of particulate matter from the working fluid.[39]

In experiments with this device, the size of material to be cleaned was limited, since the transducer area is quite small (approximately 4 in.^{2}), and cleaning effects outside the area of the transducer were found to be negligible. Preliminary study of the mechanisms and effects of ultrasonic cleaning indicates that the efficiency of cleaning decreases sharply with increase of ultrasonic frequency above approximately 50 kc. The preferred range of frequency for cleaning is 20 to 50 kc. Therefore, a much larger ultrasonic cleaning unit was used for the continuation of the study. This unit had more appropriate operating characteristics than the small unit previously used. The unit consists of three separate assemblies:

1) A 500-w average-power (2 kw peak power) generator, operating on 220-v, single-phase ac current;

2) A tank of 15 gal. capacity, equipped with six sealed demountable transducers at the bottom of the tank;

3) A recirculating pump filter and heater assembly, maintained together as a unit. All parts of the system coming in contact with the working solution were constructed of type 304 or 316 stainless steel. Gaskets, valve seats, etc. were of polytetrafluorethylene.

III. SOLVENT SYSTEMS

A. CHLORINATED HYDROCARBONS

The first efforts in ultrasonic cleaning were made with chlorinated solvents as the working fluid, in an attempt to eliminate water from the system. Some preliminary work was devoted to this approach, but consideration of the environmental factors in the PRE indicated that chlorinated hydrocarbons are not suitable for this purpose. Halocarbons were therefore eliminated from consideration for PRE use, since exposure to intense beta-gamma radiation, at the reference levels expected in the PRE, produces the following effects, reported by others:[40]

1) Production of significant quantities of Cl_2 and HCl in the liquid. Levels of 1000 to 10,000 ppm combined Cl_2 and HCl could occur in various solvents, causing an unacceptable corrosion hazard in a system composed primarily of carbon steel and stainless steel;

2) Production of gums, tars, and sludges by radiation-induced polymerization of the solvent base could cause troublesome filtration and removal problems;

3) Possible production of combustible or explosive volatile materials, as degradation products.

B. OTHER SOLVENT SYSTEMS

The function of these solvent systems in ultrasonic cleaning is to remove particulate matter and to solvate firmly attached material deposited in ionic form. Two solvent system types were chosen for consideration. These were:

1) Water-base systems with chelating agents, mild acids or alkalis, and detergents, either singly or mixed;

2) Stable saturated organic solvents, both ionic and nonionic, with suitable additives.

Only the water-base type was explored before termination of the experiments. The organic liquids in water solution used in the experiments include the following:

1) Victamul-115C. This material is a proprietary organic phosphate detergent. In these experiments, it was used in concentrations of about 10 g/gal., as recommended by the manufacturer.

2) Citric Acid. Used at a concentration of 15 g/gal.

3) Thujaplicin. A small quantity of this material was used, in a limited experiment, at a concentration of 10 g/gal.

4) Sodium Metaphosphate. This material was used in a concentration of 25 g/gal.

5) Acoustica-715. This material is a proprietary detergent, and was used in a concentration of approximately 50 g/gal.

6) Versene. A proprietary chelating agent, ethylenediamine tetraacetic acid, used in a concentration of approximately 50 g/gal.

7) Trichlorethylene.

8) Perchlorethylene. This material was used, both alone and with salcylaldehyde. A concentration of approximately 50 g/ℓ was used.

All solutions were prepared in 10-gal. batches. Tap water was used to make up the water-base solutions. The concentrations of active agents were kept dilute during the experiments. During the experiments, time and temperatures for sample exposures were varied, to determine the effect of these parameters upon decontamination. Extension of the program to studies, at other concentrations of organics in water solution, was intended, as part of the program; but the project termination eliminated this work.

IV. TEST SPECIMENS

Experiments were conducted to study the removal of particulate and solution-deposited contaminants from metal samples, similar to those used in abrasive blasting experiments.[31] The samples were rectangular plates of carbon steel, stainless steel, copper, and aluminum, 2-1/2 in. by 3-1/2 in. Variations from this type of sample are specifically noted in the tabulation of data.

Two methods were employed in contaminating samples for these experiments. To simulate the deposition of airborne particulate matter, samples were dusted with gross quantities of UO_2 powder which was rubbed thoroughly into the surface to provide a uniform and relatively heavy degree of contamination. To simulate chemically deposited contamination, more difficult to remove than airborne contamination, samples were activated by dipping the samples into a dilute aqueous solution of mixed fission products, evaporating the residual solution to dryness, and fixing the solids by baking after nitric acid washes. This procedure produces a very tenaciously attached activity.

Several samples were produced by applying solution fission product activity mixed with a heavy grease. The water was removed by evaporation, leaving a grease-borne activity, representing the conditions which can occur upon lubricated surfaces exposed to contamination. The adherence of contaminants to the surfaces of the samples was enhanced to a substantial degree by abrasive blasting the samples before use. The surface condition of the samples and the types of contamination applied to these surfaces are intended to approximate experimentally the "worst case" conditions which can occur in practice. The sample size was dictated by the size of counting chambers available into which samples would be inserted.

V. DISCUSSION OF RESULTS

It is important to note the assumption made in these tests. The removal of fixed activity is presumed to be much more difficult than the removal of particulate material. It is assumed that all particulate activity would be removed if fixed activity is even partially removed. In the preliminary work on removal of particulate airborne matter, there is wide variation in the results. The low level of beta-gamma activity in UO_2 powder contamination made determinations of absolute activity subject to large experimental errors. Within the limits of error, in almost every case, the residual activity remaining, after removal of deposited airborne matter, was reduced to background level. The preliminary tests indicate that visual inspection provides a valid counting technique for detection of particulate matter removal. The contaminant is removed so completely by ultrasonic cleaning that no matter is visible on the sample surface after decontamination.

In a number of experiments, in which the contaminant was solution deposited and fixed to the surface, cleaning efficiency was strongly dependent upon bath temperature. A general increase in cleaning efficiency with increase in temperature is apparent, as is to be expected generally in chemical reactions. The most effective agent found in these tests were the solutions of citric acid and Acoustica-715. Low decontamination factors were observed in these preliminary tests with Versene, Thujaplicin and Victamul-115C.

The maximum decontamination factor achieved in these experiments is approximately 10^3 for the removal of fixed contamination. There is considerable variation in cleaning efficiency in these preliminary tests, due in part to variations in experimental conditions. The variability can be reduced by standardization of operating conditions and further study of process variables.

VI. CONCLUSIONS

Conclusions of this study can be expressed as follows:

1) Preliminary results indicate that ultrasonic cleaning is feasible for radio decontamination of materials and equipment when the contamination is in the form of particulate matter.

2) Removal of firmly fixed activity deposited from chemical solutions is possible but further investigation is required.

3) No satisfactory means was sought or found for removing contaminants fixed to materials by grease or oils. Studies of this problem are needed, bearing in mind that the use of halogenated solvents in high radiation fields is not permissible.

VII. FUTURE DEVELOPMENT PLANS

A number of investigations, originally planned for the ultrasonic cleaning study, were not made because of the project termination. The following courses of action are suggested, upon renewal of this program:

1) More definitive information on minimum effective concentration of additives is needed.

2) No information is available, in this study, on the depletion of additives used in the process. Experiments are needed to determine depletion and makeup for such systems.

3) The survey of nonaqueous solvent additive systems is particularly recommended for this program. Since halogenated solvents have previously been eliminated, the materials to be considered are saturated organic liquids, with such active agents as chelating agents and detergents applicable to a nonaqueous system. Potential advantages of such a system are low corrosion potential, greater compatibility with certain types of equipment (electrical equipment, glass equipment), and greater ability to remove greases and oils.

4) The geometric characteristics of the ultrasonic cleaning bath, with regard to transducer placement, tank geometry, and transducer-to-work piece relationships, require further experiments.

5) Upon completion of the process studies, an in-cell remotely maintained ultrasonic cleaning unit should be developed. The equipment development would follow the approach used in abrasive blasting, namely, a design study with a preliminary mockup followed by fabrication and final checkout of an in-cell unit.

APPENDIX D

EQUIPMENT SPECIFICATION FOR PNEUMATIC IMPACT WRENCH

by

G. L. Schmidt

I. DESCRIPTION

The requirements for a pneumatic, reversible impact wrench and a tool-bit changing device, which will enable maintenance operations to be performed on process equipment that has been subjected to a radioactive cell environment, are discussed in the following paragraphs.

II. OPERATION AND CONTROL OF THE IMPACT WRENCH

The impact wrench will be operated and controlled from a remote station, located out of the cell complex or within the cell enclosure. The impact wrench will be observed by the operator, with the aid of in-cell television monitors, periscopes, and/or through shielded viewing windows, suitable for radioactive cell applications.

The wrench should be pneumatic and reversible, with a torque capacity equivalent to that required to loosen or to tighten a 5/8-11 NC-2A Class A bolt to rated tensile loads. The torque and direction of rotation should be controlled from the minimum to maximum by the operator from a remote station. The free spin torque should be sufficient to perform nut running functions, without impacting, at the discretion of the operator.

The wrench should receive and exhaust its air supply through 30 ft of flexible hose, of sufficient size to give adequate sensitivity and response for remote maintenance operations. Exhaust from the wrench should be ported outside the cell complex and its operation should not alter or affect the cell atmosphere. A schematic view of air flow through the wrench to permit exhausting air outside the cell is shown in Figure D-1. The method of attachment of the hose to the wrench should permit maximum flexibility and should not cause twisting, rotation, or tipping during operation.

The wrench should be supported by the existing in-cell crane hook. After attachment to the crane hook, it should not rotate about the point of suspension. The wrench should be suitable for torque applications which require its axis of rotation to be either perpendicular to or parallel to the plane of the cell floor.

The exterior dimensions should conform to commercially available impact wrenches of similar capacity, and should not exceed 3-1/2 in. in diameter and 16 in. in length. The philosophy of maximum utility of available space and simplicity of housing shall be incorporated into the design.

The materials of construction should be equal to or better than those of commercially available wrenches, with the selection of material influenced by an operational radiation environment of 1000 r/hr within the cell complex.

The fabricated impact wrench should be of symmetrical design, with the quality of workmanship comparable to or superior to that found in commercially available wrenches. The exterior should be free of protrusions or surfaces which may cause locking or jamming, on contact with other in-cell equipment during maintenance of in-cell equipment.

III. OPERATION AND CONTROL OF THE TOOL-BIT CHANGING DEVICE

The tool-bit changing device, shown schematically in Figure D-2, will be located on a table, bench, or stand which can be attached remotely to the floor or wall of a cell and will be operated and controlled from a remote station located outside of the cell. The device should enable remote removal and replacement of the selected sockets, drill bits, and screwdriver bits listed in Section V of this appendix. The device should insure that the tool bit is properly attached to the wrench to prevent inadvertant dropping or loosening of the tool bit during maintenance operations.

Design andfabrication of the tool-bit changing device should permit in-cell disassembly and/or assembly of the major components with a crane. All actuating apparatus should be free of fasteners or securing details, such as cotter pins and snap rings, which make the remote assembly or disassembly of the major components difficult.

The method of supplying power for operation and control of the device should be incorporated with the pneumatic supply for the wrench, to enable the removal or replacement of the device and impact wrench, either as a unit or in the form of major component parts. The operation of the tool-changing device should not alter or affect the in-cell atmosphere.

The method of attachment of the tool bits to the tool-bit changing device should permit removal and/or replacement of the tool bits, individually or as a group, by an in-cell crane.

The controls for the tool-bit changing device should be incorporated in a panel with those of the impact wrench, to provide maximum dexterity by the operator over the wrench and related components.

Materials and commercial devices used in the assembly of the tool-bit changing device should be quality products and should be consistent with the quality of the impact wrench. The appearance and space requirements of the device should be consistent with those of the impact wrench.

IV. GENERAL INFORMATION

The impact wrench and tool-bit changing device should have a nameplate affixed to each major component which should contain the following information:

1) Manufacturer's name

2) Purchaser's part number

3) Purchaser's equipment number

The final acceptance will be contingent on the approval of the purchaser. The purchaser, upon arrangement with the manufacturer, shall have access to the equipment during manufacture, for the purpose of surveillance of the work and/or tests.

V. TOOL BIT REQUIREMENTS

The pneumatic impact wrench and the tool-bit changing device should be capable of handling:

a) Socket wrenches of 4-1/4-in. length, having a depth of socket up to 3 in., and ranging in width-across-flat size from 1/2 in. to 1-1/8 in.;

b) Common screwdriver bits of 4-1/4-in. length, ranging in size from No. 10 to 1/4 in.;

c) Socket head screws of 4-1/4-in. length, ranging in size from 1/8 in. to 1/2 in.;

d) High speed steel drill bits of 4-1/4-in. length, ranging in size from 1/8-in. to 3/4-in. in diameter.

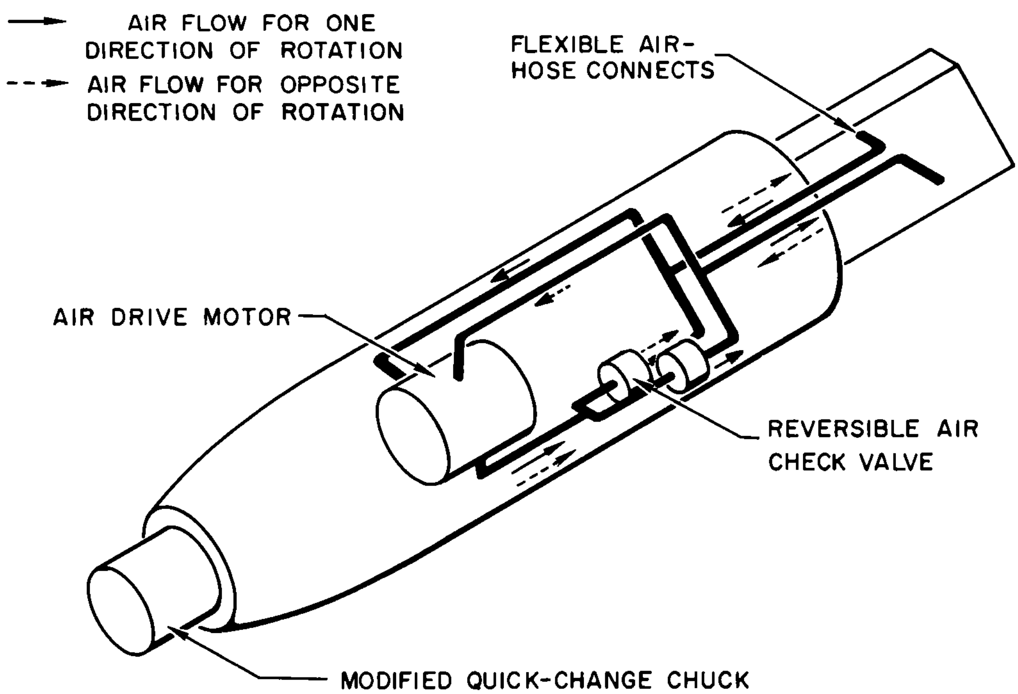

Figure D-1. Modified Pneumatic Impact Wrench (Schematic)

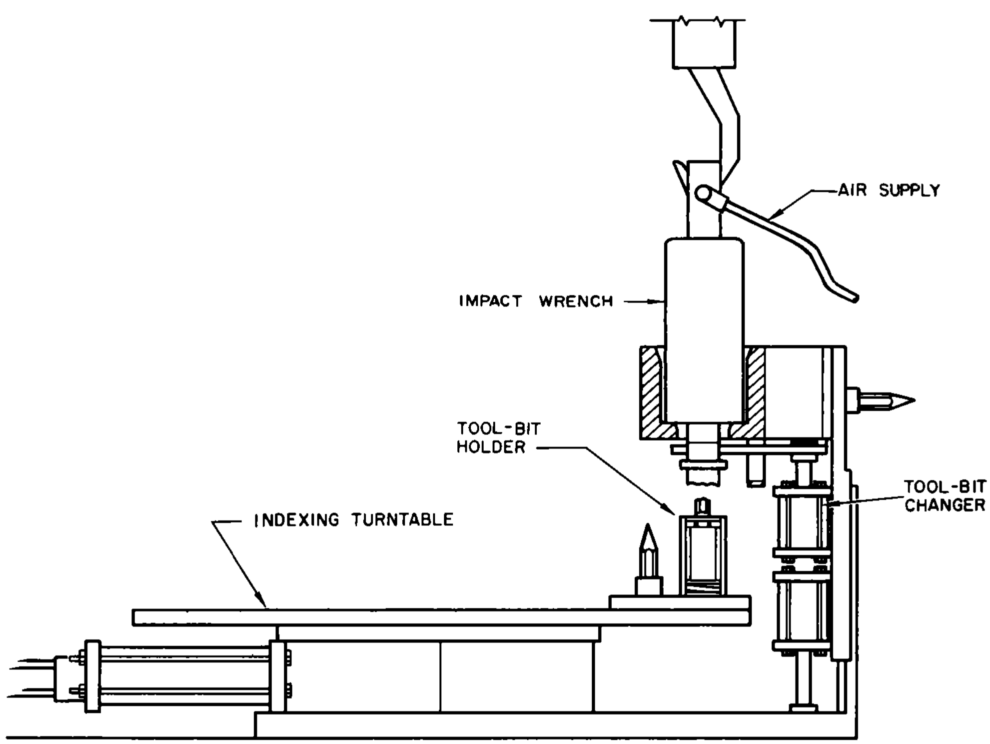

Figure D-2. Tool-Bit and Tool-Socket Changing Table

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