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EXTENDED CONCEPTUAL STUDY OF DISASSEMBLY-REASSEMBLY EQUIPMENT FOR EXAMINATION OF FFTF CORE COMPONENTS AND TEST ASSEMBLIES

R. M. Beckers
W. W. Goolsby

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R. M. Beckers
W. W. Goolsby

prepared for
Pacific Northwest Laboratory
Battelle Memorial Institute
under Purchase Order BOK-S77-61074

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PREFACE

This conceptual study was performed for Battelle Memorial Institute, Pacific Northwest Laboratory, under purchase order BOK-S77-61074. The preparation of this report was completed during May 1970, while the FFTF project was undergoing extensive reevaluation. The details presented in this report therefore reflect the status of the project at the time the report was prepared.

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EXTENDED CONCEPTUAL STUDY OF DISASSEMBLY-REASSEMBLY EQUIPMENT FOR EXAMINATION OF FFTF CORE COMPONENTS AND TEST ASSEMBLIES

Abstract

The results of a supplemental extended conceptual study of the disassembly-reassembly equipment to be located in the Interim Examination and Disassembly Cell at the proposed Fast Flux Test Facility in Richland, Washington, are reported here. This extended study was performed to consider the effects of a reduction in the lengths of core components and test assemblies to be handled with the disassembly-reassembly equipment, addition of equipment capability for remote welding of girth joints in flow ducts of test assemblies, deletion of one set of disassembly-reassembly equipment, and the deletion of performance testing of the equipment at Oak Ridge National Laboratory. The changes to the disassembly-reassembly equipment resulting from these criteria revisions are discussed, and the critical path time-cost schedule and cost estimate are updated to reflect the revisions. Assuming a start date of July 1971, the functionally tested equipment is scheduled for delivery to Richland 36 months later with completion of liaison work scheduled for May 31, 1975. As proposed, the total estimated cost for Oak Ridge National Laboratory participation in this 4-year program is $1,444,000, including escalation.

1. INTRODUCTION

The Fast Flux Test Facility (FFTF) will provide the capability for irradiating reactor core components and test assemblies in a high flux of fast neutrons up to 10^{16} nv, subsequent disassembly and nondestructive examination of these core components and test assemblies, and for reassembly of test assemblies when further irradiation in the reactor is required. A conceptual study of the remotely operated equipment required for these disassembly, examination, and reassembly operations was made by personnel of the General Engineering Division at Oak Ridge National Laboratory, and the results of that study were reported in USAEC Report ORNL-TM-2759 (Ref. 1). This original conceptual study was recently extended to consider the effects of some criteria revisions that primarily involve a reduction in

the length of core components and test assemblies to be handled by the disassembly-reassembly equipment and the addition of equipment capability for remote welding of girth joints in flow ducts of test assemblies. The criteria for and results of this extended study are reported here as a supplement to the original conceptual study report,[1] and the critical path time-cost schedule and cost estimate are updated to reflect the criteria revisions and work involved for further design, development, fabrication, and testing of the equipment.

Except for certain significant points, only the revisions in criteria and their effects on the disassembly-reassembly equipment as originally conceived are discussed in this report. Valid data contained in the original conceptual report[1] are not usually repeated, but the outline of this report is in general the same as that of the original report so that a comparison and consolidation of information may be easily made. The design criteria for shortened core components and test assemblies are summarized in Appendix A, alternate welding methods are discussed in Appendix B, and the conceptual drawings of the shortened disassembly-reassembly equipment and its characteristics and capabilities are given in Appendix C.

2. SUMMARY

The basic function of the FFTF disassembly-reassembly equipment to be located in the Interim Examination and Disassembly Cell is unchanged. This function is to provide a reliable means under controlled environmental conditions by which irradiated core components and test assemblies may be remotely positioned, disassembled, examined, and reassembled when required. The revised disassembly-reassembly equipment consists of one positioning machine with its accessory tooling and controls that can be operated and maintained from one operating station.

The features and general capabilities of the disassembly-reassembly equipment and its modes of operation are essentially the same as presented in the original conceptual study report[1] except that only shortened core components and test assemblies with a nominal length of 12 ft can be handled. As before, these assemblies may contain either top-supported or bottom-supported pin bundles and instruments, but they must have length increments within the limits outlined in Appendix A.

The structural frame of the positioning machine, upon which three slide assemblies move up and down, has been shortened so that the machine is now 33.5 ft tall. The grip and drive subassemblies on the lower slide have been interchanged, and the length of the middle slide has been reduced from 10 to 8 ft so that shorter core components and test assemblies can be handled more easily. The features and functions of the three slide assemblies are unchanged, including the provisions for induced argon cooling of the pin bundle during all modes of operation.

A major change in the accessory tooling is the addition of computer-directed welding equipment for the remote welding of girth joints in the hexagonal flow ducts of reassembled test assemblies. This equipment will control the welding operation from start to finish and will automatically regulate the various welding parameters to ensure a reliable weld. Devices to inspect the completed weld or to record operating values of the welding parameters are not included in this equipment. A complete evaluation of the potential equipment for in-cell welding was not made in this study, and further evaluation of the equipment described herein will

be necessary. A brief investigation was made of the principles that might be used to align the welding fixture on the positioning machine and to align the duct pieces for welding. The use of a self-aligning slip joint in the flow ducts of reassembled test assemblies is recommended for further consideration.

The critical path time-cost schedule for ORNL participation in the design, development, fabrication, and testing of the FFTF disassembly-reassembly equipment has been revised to reflect the changes in the equipment and program requested by FFTF project management. The network of activities in the revised schedule remains similar to that presented in the original schedule. The preliminary design and development work will proceed jointly, followed by the final design, procurement, fabrication by outside contractors, and shipment to ORNL. The integrated functional testing of the positioning machine and tooling will complete the major portion of ORNL participation in the project. The performance testing, welding development, and final acceptance testing of the equipment will be performed by FFTF representatives in the Fuel Examination Cell Mockup at Richland, Washington; followed by installation in the Interim Examination and Disassembly Cell and pre-start-up testing. Adequate engineering liaison is scheduled during the course of the project.

Assuming a starting date of July 1, 1971, the project is scheduled for completion on May 31, 1975. The estimated cost for ORNL participation in this 4-year project is $1,444,000, and this figure includes a cost escalation factor.

3. FUNCTIONS AND DESIGN REQUIREMENTS

The functions of the FFTF disassembly-reassembly equipment and the design requirements for the equipment given in Chapter 3 of the original conceptual study report[1] are considered baseline data. Revisions to the data for the extension of the conceptual study are presented in this chapter.

3.1 Functions

The basic function of the disassembly-reassembly equipment is unchanged. It is to provide a reliable means under controlled environmental conditions by which irradiated core components and test assemblies may be remotely positioned for examination, disassembly, and reassembly when required. The equipment will still be used to perform limited interim, extended interim, and final nondestructive examinations.

The operations involved in these examinations that are to be performed either directly or indirectly with the disassembly-reassembly equipment are also unchanged. These remote examination operations include measurement of the overall dimensions of the assembly, removal of the pin bundle from the flow duct, visual inspection, photography, measurement of inter-pin spacing, disassembly of the pin bundle, testing and repairing of instrumentation, and reassembly of test assemblies for further irradiation.

3.2 Design Requirements

The design requirements for the FFTF disassembly-reassembly equipment include those that are basic and those that are concept related. Revisions to these requirements are given in the following two subsections. There are no firm design choices since no portion of the extended conceptual design is considered definitely fixed at this time.

3.2.1 Basic Design Requirements

The design requirements included in this subsection are applicable regardless of the design details. Those basic design requirements given in the original conceptual study report[1] that are not affected by the following revisions are still valid design requirements.

(a) One complete set of disassembly-reassembly equipment shall be installed in the Interim Examination and Disassembly Cell.

(b) The disassembly-reassembly equipment shall provide for the disassembly and examination of FFTF core components and test assemblies. The reference shortened driver fuel assembly illustrated in Fig. 3.1 and on Pacific Northwest Laboratory drawing SK-3-14718, first issue dated August 14, 1969, shall be used in sizing the equipment.[2]

(c) Drawings of other shortened core components and test assemblies are not currently available. Specific changes in length increments of representative core components and test assemblies to permit their handling with the disassembly-reassembly equipment shall be identified.[2] The representative assemblies to be used in this extended study include

1. the inner reflector assembly shown on Pacific Northwest Laboratory drawing SK-3-14636, first issue dated March 14, 1969, except modified as shown in Fig. 3.1 so that the lower shield section is a separate component, thereby reducing the total pin length;
2. the control safety rod poison tip shown on Pacific Northwest Laboratory drawing SK-3-14732, second issue dated August 26, 1969, except modified as shown in Fig. 3.1 so that the length of the integral hanger rod and duct above the girth cut does not exceed 10 ft 6 in.;
3. the open test assembly with an overall length of 12 ft and a 7-ft-6-in. length of top-supported internals that must be exposed, as illustrated in Fig. 3.1; and
4. the closed-loop test assembly with an overall length of 10 ft 3 in. and an 8-ft-6-in. length of top-supported internals that must be exposed, as illustrated in Fig. 3.1.

(d) Other non-fueled core components must be accommodated by the disassembly-reassembly equipment, but configuration and size data for shortened versions of these components are not currently available.

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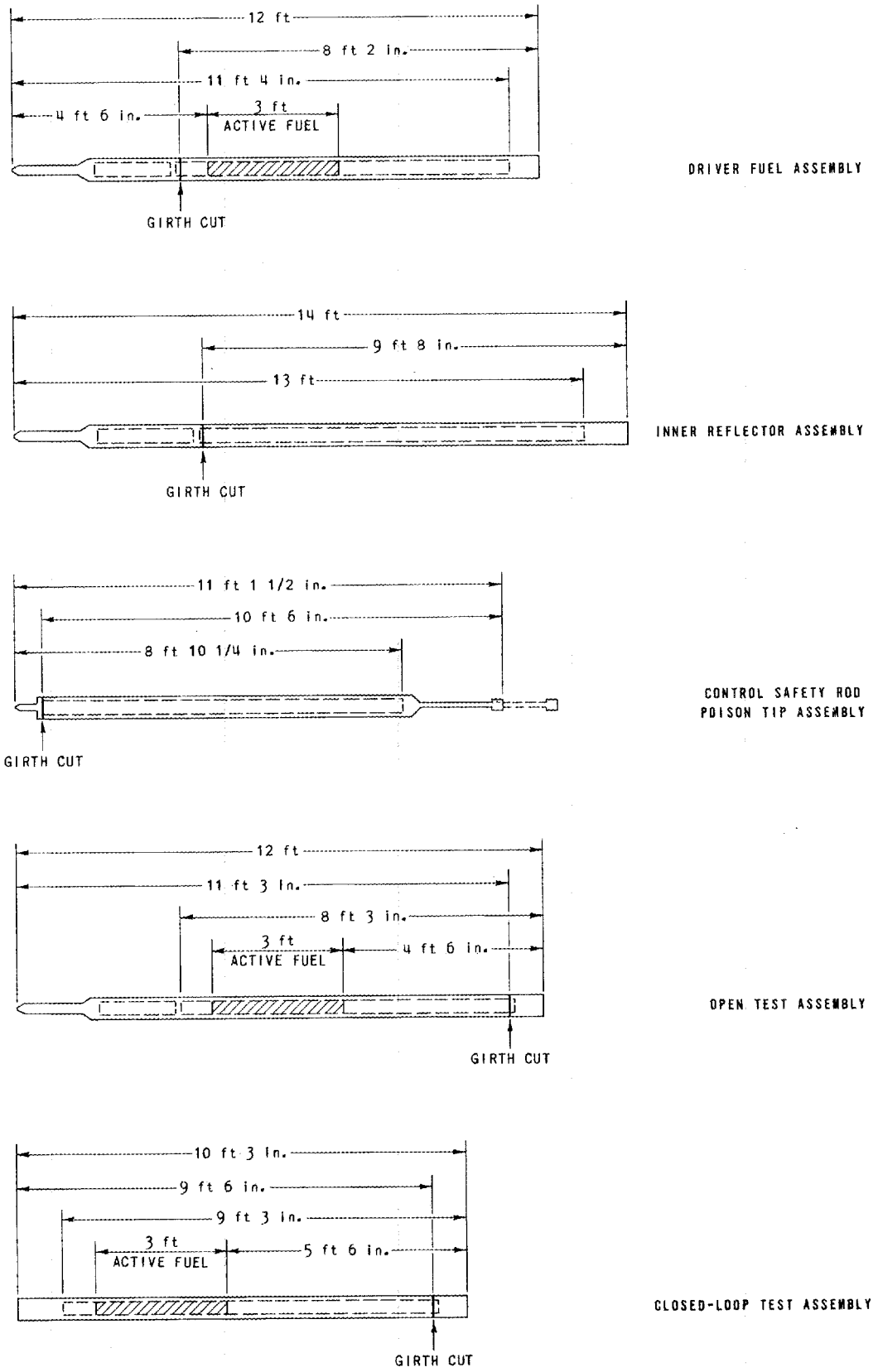

Fig. 3.1. Core Components and Test Assemblies Specifically Related to Extended Conceptual Study of the FFTF Disassembly-Reassembly Equipment.

These components include outer reflector assemblies and shield assemblies. Closed-loop tubes cannot be handled because of their length.

(e) The disassembly-reassembly equipment shall provide for reassembly of test assemblies designed specifically for remote reassembly. Girth joints may have mechanical or welded closures. Axial joints must have mechanical closures.

(f) The disassembly-reassembly equipment shall provide for remote welding of girth joints in the hexagonal flow ducts of test assemblies. Only test assemblies with top-supported pin bundles need be considered for welding at this time. Welding of test assemblies with bottom-supported pin bundles may be considered during later phases of the design work if required.

(g) No specific provisions shall be made for inspection of welded joints during this phase of conceptual study. Inspection requirements and the necessary equipment shall be considered during later phases of the design work.

(h) The floor of the hot cell housing the disassembly-reassembly equipment shall be located 7 ft below the center line of the lower window to facilitate handling of individual pins about 8 ft long and to facilitate other operations required at this level of the cell.[3]

(i) Since the length of all assemblies is limited to 12 ft, there is no longer a need for a winder for instrument leads as part of the disassembly-reassembly equipment. The instrument leads will be coiled or removed from the assembly when the hanger rod is removed prior to transfer of the assembly from the reactor containment.

3.2.2 Concept-Related Requirements

Those design requirements resulting from the reference designs for the core components and test assemblies and from the conceptual design for the disassembly-reassembly equipment are considered concept-related data. There are no changes in the concept-related requirements given in the original conceptual study report[1] except that these requirements now apply to the core components and test assemblies specifically related to the extended conceptual study reported herein.

4. PHYSICAL DESCRIPTION

Shortening of core components and test assemblies has permitted a reduction in the height of the disassembly-reassembly equipment. This reduction in height results in corresponding changes in the hot cell requirements that will reduce the costs of the cell. Various equipment components have been either shortened or rearranged to further enhance the capability for handling shortened assemblies. In addition, the capability for remote welding has been added so that girth welds can be made in the hexagonal flow ducts of reassembled test assemblies. Except to account for these revisions, the physical description of the disassembly-reassembly equipment presented in the original conceptual study report[1] is still valid. The revisions made to the equipment and the new requirements related to the hot cell and support equipment for this extended conceptual study are discussed in this chapter.

4.1 Summary Description of Changes in Disassembly-Reassembly Equipment

The functions, features, and general capabilities of the disassembly-reassembly equipment and its modes of operation are essentially the same as presented in the original conceptual study report[1] except that the equipment will now accept only shortened core components and test assemblies that are nominally 12 ft long. The equipment required for the Interim Examination and Disassembly Cell now consists of one positioning machine with one set of accessory tooling and controls. The second set of disassembly-reassembly equipment that was to have been installed in this cell has been deleted by the criteria for this extended conceptual study, and the space and services for the equipment will not be allocated. The installation and service requirements for the required equipment are discussed in Section 4.4 of this report.

The positioning machine still basically consists of a structural frame upon which three slide assemblies may be moved up and down, but the

column portion has been shortened so that the overall height of the machine from the cell floor is now 33 ft 6 in. The length of the middle slide body has been reduced from 10 ft to 8 ft so that shorter core components and test assemblies can be handled more easily, and the positions of the lower-grip and motor-drive subassemblies on the lower slide body have been interchanged. The functions and other features of the three slide assemblies, including the provisions for induced argon cooling of pin bundles during all modes of operation, remain unchanged. A detailed description of the changes made to the positioning machine is given in Section 4.2.

Except for the addition of remote welding equipment, the accessory tooling required for disassembly, examination, and reassembly operations is essentially the same as that described in the original conceptual study report.[1] One retractable worktable will still be required at each window serving the positioning machine, but the reduction in the length of core components and test assemblies to be handled and the corresponding reduction in the height of the positioning machine have obviated the need for a middle viewing window in the cell. The provision of a lower viewing window is considered optional for reasons discussed in Subsection 5.5.1. Winders for instrument leads will no longer be a part of the disassembly-reassembly equipment because the instrument leads will be coiled or removed from the assembly prior to its transfer from the reactor containment. The philosophy of emphasizing the use of master-slave manipulators and operator judgment rather than highly automated and interlocked in-cell equipment will still be followed for all accessory tooling as much as is practical.

The major change in accessory tooling is the addition of a welding fixture and special automatic welding equipment to provide for remote welding of girth joints in the hexagonal flow ducts of test assemblies. The equipment described in Section 4.3 will completely control the welding operation from start to finish and will automatically regulate the various welding parameters to ensure a reliable weld. The equipment uses a small computer, sequence timers, and feedback-type servo control systems for control purposes. The welding torch and wire feeding components

will be mounted on a portable welding fixture that can be installed and removed remotely in accordance with need as can other items of accessory tooling.

4.2 Detailed Description of Changes to Positioning Machine

The disassembly-reassembly positioning machine has been modified to accept only shortened core components and test assemblies with a nominal length of 12 ft. As before, these assemblies may contain either bottom- or top-supported pin bundles and instruments, but they must have length increments within the limits outlined in Appendix A of this report. The modified positioning machine is shown on conceptual drawing M-11325-EM-080-F in Appendix C as it will be installed in the Interim Examination and Disassembly Cell. Only one operating station is required to serve the machine because of the shorter length of the core components and test assemblies to be handled. This station is equipped with a viewing window, two master-slave manipulators, and a retractable worktable. An overhead crane and a wall-mounted electromechanical manipulator are required as support equipment. The provision of a lower viewing window in the cell is considered optional for reasons discussed in Subsection 5.5.1.

Very few changes were made to the positioning machine. Its design is based upon the same operating philosophy discussed in the original conceptual study report,[1] and the functions of the various components of the machine and the features of construction remain the same. However, the overall height of the positioning machine is reduced in this extended conceptual study, and several components are modified or rearranged. Except to account for these changes, the detailed description of the positioning machine presented in Section 4.2 of the original conceptual study report[1] is still valid. The changes are discussed in detail in the following subsections, and the motion studies used to derive the overall height of the machine and the arrangement of its parts are discussed in Section 5.1 of this report.

4.2.1 Structural Frame

The structural frame of the positioning machine still consists of a modular column attached to a square base, as illustrated on conceptual drawing M-11325-EM-080-F in Appendix C. The column has been shortened so that the overall height of the frame from the floor of the cell is now 33 ft 6 in. The column now consists of two modules with the upper module being 15 ft long and the lower being 16 ft long. The base is still 2 ft 4 in. high and 6 ft square, and it is still anchored to 2-in.-high floor pads. The constructional details of the column and base are the same as described in the original conceptual study report.[1] The joint in the column is located slightly below the operating window where it is accessible for viewing and manipulation of bolting if the worktable is retracted against the cell wall.

Since the height of the machine column is reduced and its cross-sectional size is unchanged, the deflection at the top of the column caused by operational loading will be less than that originally reported for the tall column. Deflections and stresses for the shortened column were not calculated since their values are not significant.

High bolt loading at the column joints and base anchorage brought about by accidental bumping of the column is still a problem, but the magnitude of the problem has been reduced somewhat because of the lessened height of the crane hoist from the cell floor. This new relationship causes a reduction in the total impact energy and, after correcting for the reduced weight of the column, results in a net reduction in bolt loading. For an impact elevation 20 ft above the cell floor, the anchor bolt loading is reduced from 43,800 lb for the tall column to 35,400 lb for the shortened column. This indicates that bolt loads at column joints and anchor points caused by impact loading of the type described in the original conceptual study report[1] will generally be less for the shorter positioning machine.

The vibrational characteristics of the shortened column were not determined. Since the tall column was satisfactory in this respect, the shortened column with the same cross-sectional size should also be satisfactory.

4.2.2 Slide Bodies and Subassemblies

The need to handle shortened core components and test assemblies made necessary a reevaluation of the size and arrangement of components of the three slide assemblies. Two factors had to be considered with the slides assumed to be closely spaced. These were (1) the distance between the upper grapple on the upper slide and the lower adaptor on the lower slide and (2) the location of the transverse cooling shrouds on the middle slide with respect to the upper grapple and the lower adaptor.

As a result of this reevaluation, the length of the middle slide body was shortened from 10 to 8 ft and the positions of the subassemblies on the lower slide were interchanged to place the motor drive beneath the lower-grip subassembly. The shortened middle slide is of adequate length to handle pin bundles up to 8 ft long, and slightly longer bundles may be handled if special tooling is provided. Relocation of the motor drive below the lower-grip subassembly on the lower slide necessitated two minor changes to allow the lower slide to travel down the machine column a sufficient distance. These consisted of altering the position of the idler gear on the motor drive and extending the rack on the column. The upper-grip subassembly on the upper slide was not relocated to a position below the motor drive because this would have required an additional 2 ft of cell height at the top of the cell.

The advantages resulting from the repositioning of subassemblies on the lower slide are that

1. space for tooling above the lower-grip subassembly is not restricted by the motor-drive subassembly as it was in the initial arrangement,
2. the motor drive is better protected from both thermal and gamma radiation emitted from the fuel section of pin bundles,
3. more space is available for the return bend of the cooling hose attached to the axial cooling plenum, and
4. a greater span between the middle guide and the lower adaptor is possible and this span is within the manipulative range.

This fourth advantage improves the stability of an assembly during loading operations, as is discussed in Subsection 5.5.1 of this report. The net result of the changes described in this section is the capability

for handling the shortened reference driver fuel assembly and all the representative core components and test assemblies related to this extended conceptual study with a minimum use of adaptors and an efficient use of cell space.

4.3 Detailed Description of Changes in Accessory Tooling

Accessory tooling is required as part of the disassembly-reassembly equipment to perform the disassembly, examination, and reassembly operations. The typical tools discussed in Section 4.3 of the original conceptual study report[1] are indicative of those required for work on the shortened core components and test assemblies. They include a retractable worktable, girth cutters, longitudinal cutters, and tools for the disassembly and reassembly of pin bundles. Only one retractable worktable is required as part of the accessory tooling since only one operating station is now required to serve the positioning machine. It will be a large table with a cutout to allow part of the lower slide assembly to pass through it, as illustrated on conceptual drawing M-11325-EM-080-F in Appendix C.

Tools for winding instrument leads are also mentioned in the original conceptual study report,[1] but they are not discussed in detail. These winding devices are no longer a part of the accessory tooling for the disassembly-reassembly equipment because instrument leads will be coiled or removed from the assembly prior to its transfer from the reactor containment.

Special measuring equipment not a part of the accessory tooling may be used with the shortened positioning machine to measure shortened core components and test assemblies and their pin bundles. The same considerations of machine accuracy, disadvantages, and limitations discussed in Subsection 4.3.5 of the original conceptual study report[1] are applicable in this extended conceptual study.

Equipment for fusion welding a girth joint in the hexagonal flow ducts of test assemblies is now a part of the accessory tooling for the disassembly-reassembly equipment. This equipment consists of a special

in-cell welding fixture upon which the necessary welding components will be mounted and complete controls, power supply, and auxiliary equipment. Devices to inspect the completed weld or to record operating values of various welding parameters are not included. The welding equipment and in-cell welding fixture are discussed in the following subsections.

4.3.1 Welding Equipment and Controls

The criteria for remote welding of the stainless steel flow ducts of reassembled test assemblies have not been formulated, but high-quality fusion welding of a circumferential butt joint may be required because this is the type of weld specified for flow ducts of driver fuel assemblies. The tungsten-inert-gas (TIG) welding process appears to be the most applicable for welding these flow ducts when the required weld quality, dimensional tolerances on the welded assembly, and the limitations of the welding equipment are considered. Multiple welding passes using filler wire would produce a weld that would be least likely to crack.

An alternate method of joining the flow ducts of reassembled test assemblies would utilize fusion spot welding. Similar TIG welding equipment would be used, but the welding time would be accurately controlled to produce a fused spot in the flow duct. This method would require a slip joint in the duct, and the spot-welds could be made in either the body of the joint or at the outer edge. The application of fusion spot welding is discussed further in Appendix B.

Assuming that a circumferential fusion type of butt weld will be required, the most important objectives to be met by the duct welding equipment required as accessory tooling for the disassembly-reassembly equipment include

1. the production of a continuous girth weld in a hexagonal stainless steel flow duct with rounded corners,
2. the maintenance of close dimensional tolerances on the welded assembly,
3. the minimization of overall heat input and localized hot spots to prevent damage to the pin bundle,

4. the production of high-quality welds with no cracks and a minimum of porosity and distortion, and
5. the capability for accommodating flow ducts of different sizes.

These objectives can be met by using optimized welding techniques that assure smooth continuous welds with minimum heating for the task. Translated into welding terms, these objectives dictate that the welding speed be constant and that the axis of the tungsten welding electrode be maintained normal to the surface of the flow duct at all times. To achieve constant welding speed, the rotational speed of the duct must be varied continuously so that its surface speed will be constant with respect to the electrode, and the welding torch must pivot at the surface of the duct directly under the electrode tip. In addition, the angular position of the torch must vary as a function of the angular position of the duct; and the welding current, arc voltage, and filler wire speed must be variable throughout the weld cycle.

The duct welding equipment needed to attain these objectives can be defined to a large extent from information resulting from a developmental effort currently being undertaken at Pacific Northwest Laboratory (PNL). This task* being performed for the FFTF project involves the development of automatic welding equipment to weld unirradiated flow ducts in the horizontal position. It will serve as a good source of information relative to vendor qualification, fixture design, deviation of welding parameters, and equipment reliability. For this program, a welding fixture being built at PNL will be integrated with a computer-directed welding system being supplied by Sciaky Brothers, Inc., of Chicago, Illinois. This integrated welding system will be used initially at PNL for development of flow duct welding procedures and practices and later in a pilot line role for the assembly of flow ducts.

A complete evaluation of potential welding systems for in-cell welding was not made during this study because of the need for welding criteria for test assemblies, funding limitations, and the advisability of obtaining further information from the FFTF development program for

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*Cladding and Duct Development Task 189a-121 CD.

duct welding being conducted at PNL. Whether this Sciaky welding system will actually be used for the remote welding of flow ducts on reassembled test assemblies will depend upon possible acceptance of an alternate welding method of joining the ducts, the permissible deviation of welding parameters, and further investigation of other methods of servo control that might require in-cell devices that are less complex or less subject to the environmental hazards of the hot cell.

However, the description of the duct welding equipment required as accessory tooling for the disassembly-reassembly equipment is based on the Sciaky welding system to be used for the FFTF duct welding program at PNL. It should be considered tentative and subject to extensive review when more information is available. Such a review can be performed during the preliminary design of the disassembly-reassembly equipment. The duct welding equipment required as accessory tooling consists of welding components, a power supply and auxiliaries, servo and slope controls, sequencing controls, and a digital computer system. The main features and some of the modifications necessary for in-cell use of this equipment are briefly described in the following paragraphs.

The welding equipment consists of

1. a special water-cooled TIG welding torch with a current capacity of 400 amperes and provisions for remote replacement of the tungsten electrode, electrode collet, and gas cup and
2. a special wire feeder with a direct-current servomotor and integral tachometer and provisions for remote replacement of wire feed rolls, nozzles, conduit, and wire reel.

These welding components are mounted on a special welding fixture, which is discussed in Subsection 4.3.2.

The welding power supply will provide a constant preset current with low ripple and variable open-circuit voltage that is required for TIG welding. The primary alternating-current power is converted into direct-current power by water-cooled silicon-controlled rectifiers. The unit is equipped with a current pulsing feature, and the welding current is maintained at its preset value during welding by a proportional plus integral servo control system. The operating range of the current is from 6 to 400 amperes at 100% duty cycle, and the open-circuit voltage is

adjustable by steps from 80 to 150 volts to permit reliable arc starting for the entire current range.

Auxiliaries to the welding torch and power supply include

1. a closed-circuit water coolant system with radiator and interconnecting hoses to cool the welding torch and power supply;
2. a shielding gas system for regulating, starting, and stopping the flow of argon shielding gas to the welding torch; and
3. an arc starting system that imposes high-frequency energy on the welding circuit and ionizes the gas in the small gap between the tungsten electrode and the workpiece, thereby creating a path for the welding current.

The length of welding cables and the problems involved in shielding the high-frequency radiation produced by the type of arc starting system described in item 3 above sometimes prevent its use in hot cell work. If this should be the case for this proposed application, an impulse arc starting system may be used to apply a momentary surge of high voltage to the welding circuit. A touch-and-retract starting method is not recommended because of possible electrode damage or metal pickup that would be difficult to detect in the hot cell.

Appropriate position or velocity servo control systems that utilize proportional plus integral control action are provided for precise regulation of the various welding parameters. Proportional control action provides correction of position or velocity proportional to the error signal, and the integral control action tends to eliminate any steady-state system error. The proportional action also provides sufficient "damping" to produce a stable system. Highly accurate proportional response to the input reference signal is claimed for these servo systems, and this makes them ideal for use with numerical or computer control systems. The welding parameters controlled by these servo systems are the welding current, arc voltage, wire feed speed, duct rotation, and angular position of the torch. Controlled starting and stopping of all of these parameters except the angular position of the torch is provided by linear time-defined initial and final slope controls. These controls permit each parameter with this feature to be varied from an initial value at start-up to a run value and then from the run value to a final value at

shutdown. The rate of response of the arc head, which holds the welding torch, can be set so that the arc voltage system is operating at maximum sensitivity. In operation, the arc head will move the torch in and out to follow the contour of the hexagonal flow duct, thereby keeping the arc voltage constant.

Sequencing controls provide programmed starting and stopping of the welding operation. Shielding gas flow, arc initiation, wire feed, and rotation of the flow duct are automatically initiated and terminated in a predetermined sequence. The duration of welding may also be set.

The digital computer system proposed by Sciaky is composed of components and accessories manufactured by the Digital Equipment Corporation of Maynard, Massachusetts. The system essentially consists of

1. a Model PDPS/L basic computer with 4K core memory that will act upon a part definition program through an executive program provided by Sciaky Brothers, Incorporated,
2. a Model ASR35 teletypewriter that provides the means for communicating with the computer,
3. a Model DM01 data channel multiplexer that allows up to seven different devices direct access to the computer memory,
4. a Model KDS/L data break that facilitates the access to core memory for one- and three-cycle data breaks, and
5. two Model AA01A digital-to-analog converters (one 3-channel and one 2-channel) that convert the digital output of the computer to an analog voltage for use as a reference signal by the servo control systems.

The computer system provides the capability of automatically programming the run values for welding current, arc voltage, wire feed speed, rotational speed of the flow duct, and the angular position of the torch during the complete welding cycle. The welding cycle may consist of as many as four revolutions of the hexagonal flow duct with the run values being preset by the computer to suit conditions during each revolution. A run value for each of the computer-controlled welding parameters may be set at each of 264 change points which will be available for the four revolutions. This allows 66 change points per revolution or as many as 11 change points for each side of the hexagonal flow duct. The duration

between each of these change points may be set to suit the required welding schedule as a function of the rotational position of the duct. A digital tachometer (shaft encoder) will establish 720 duct positions per revolution and transmit this position information to the computer. Up to 66 of these 720 duct positions may be designated as change points for each revolution. Within the limits of any two successive change points, the computer will interpolate the run values for each of the welding parameters as a linear function of duct position based on the run values set at these successive change points. Sciaky indicates that the welding speed along the flat of the flow duct will be theoretically correct, but the welding speed at the rounded corners of the duct will be a series of close approximations of theoretical values.

The welding cycle is controlled jointly by the sequencing and slope controls and the computer system. The starting position of the computer is set by positioning the torch with respect to the flow duct and pushing the reset button. When the sequence-start button is activated, the arc will be initiated and all welding parameters will be operated as programmed under the command of the sequence-start and initial-slope controls. Command signals from the computer begin with the initiation of duct rotation with full linear interpolation of run values between change points during the welding cycle. Welding can be terminated manually by the operator or automatically. In either case, all parameters will be terminated in logical order by the programmed final-slope and sequence-stop controls.

The reasons for selecting a computer-directed system for the FFTF welding program at PNL are reported in a feasibility study.[4] Manual welding, simplified mechanical and/or electrical control, numerical control, and small-scale computer control were considered. Only numerical and computer control were adequate to handle the complexity of the problem caused by the shape of the flow duct. The computer-directed system was considered more flexible than the numerical system because it does not require a completely new control tape when parameter changes are made. The computer system was also considered more reliable because it uses a shorter control tape and it reads this tape prior to actual welding so that errors can be detected and corrected before welding is begun.

A definite advantage of using the same type of Sciaky welding control system for the PNL-FFTF duct welding program and for in-cell welding in the Interim Examination and Disassembly Cell is that the same computer programs can be used. Slight changes in the set values of welding parameters will be required because of the difference in the welding positions. Welding of reassembled test assemblies must be done with the duct axis vertical because of assembly criteria and the vertical orientation of the positioning machine. A small development program will be required to determine the optimum values for welding parameters, and this work can be done during the performance testing of the disassembly-reassembly equipment.

The disadvantages associated with the use of this Sciaky equipment for in-cell welding in the Interim Examination and Disassembly Cell are its complexity and utilization of direct-current electrical systems. The equipment is inherently complex from the standpoint that feedback devices such as tachometers and encoders will be required in the cell in addition to the drive motors. This means that more electromechanical devices will be subjected to radiation and brush wear, with the resultant remote maintenance problems. Brush wear may be alleviated by using special brush materials, but their effectiveness will depend upon the rotational speed of the device, the type of special brush material used, and the dryness of the argon cell atmosphere.[5,6] The effects of the argon atmosphere on brush arcing and on the ability of motors to dissipate heat must also be considered.[5]

4.3.2 Welding Fixture

A welding fixture will be required within the Interim Examination and Disassembly Cell to perform the girth welding of hexagonal flow ducts on reassembled test assemblies. This fixture must accommodate open test and closed-loop test assemblies that have different size flow ducts, and if possible, it must be suitable for making the girth weld at both the upper end and the lower end of these assemblies. The location of the

weld in the flow duct is determined by the location of the support grid for the pin bundle, the weld being made near the support grid.

The conceptual work on the remote welding fixture that was performed during this study consisted mainly of identifying the components which would be required on the fixture and a brief investigation of the principles that might be used to align the duct pieces and to align the welding fixture on the positioning machine. Conceptual drawings were not prepared, and a complete conceptual analysis was not performed because of funding limitations and the need for a better definition of the welding requirements. The work performed should therefore be considered tentative and subject to extensive review when more information is available.

The functions of the welding fixture include rotating the flow duct, moving the welding torch as required to maintain the correct relationship with the duct, and providing a mounting place for the wire feeding devices. Depending upon the alignment philosophy followed, the welding fixture may also provide all alignment for the flow duct pieces. The necessary mechanisms and components will be constructed as replaceable modules on a structural frame to facilitate remote maintenance. Like other items of the disassembly-reassembly equipment accessory tooling, the entire welding fixture will be portable and capable of being moved with the cell crane when the service lines have been disconnected.

The major components of the welding fixture will consist of a chuck to rotate the flow duct, an arc head to maneuver the torch, and an elevating mechanism to adjust the elevation of the torch. The welding torch and wire feeding devices are considered part of the welding equipment, as discussed in Subsection 4.3.1.

A special low-inertia chuck with six jaws will be used to rotate the flow duct. The jaws will clamp the corners of the duct to minimize possible duct distortion. These jaws may be operated with a manipulator using a spanner wrench, or the chuck drive system may be used in conjunction with the spanner wrench for final tightening and for opening the chuck. The chuck jaws will be remotely replaceable to accommodate a wide range of flow duct sizes and shapes. The chuck will be driven by a servomotor with integral tachometer through a gearbox and spur gear drive

train. A shaft encoder will be driven by the bull gear on the chuck to transmit the rotary position of the flow duct to the computer system.

The arc head that holds the welding torch will be located to one side of the flow duct, and it must move the torch toward and away from the flow duct to maintain the correct arc voltage as the duct rotates. It must also pivot the torch through an angle of about 27° on either side of the center line of pivot motion to keep the torch perpendicular to the surface of the duct. The mechanism controlling the arc voltage will consist of a horizontal ball-bearing slide assembly driven by a geared servomotor through a ball screw. A tachometer integral with the servomotor will provide feedback data to the servo control system. A horizontal curved track will be mounted on top of the slide, and a roller-mounted carriage will run on this track. The carriage will support the welding torch, and it will be driven by a geared servomotor with integral tachometer through a pinion and gear segment. A potentiometer driven by a pinion off the gear segment will be used to transmit carriage position to the servo control system. The axis of the welding torch will pass through the theoretical pivot point of the carriage and the axis of the flow duct. The torch will also be located axially on the carriage so that the pivot point will be at the surface of the duct when the torch is at the correct arc distance.

The entire arc head will be mounted on a vertical ball-bearing slide to allow the torch to be moved up and down for alignment with the weld joint. This adjustment will be manipulator operated and will have a positive lock to prevent drift.

The wire feed positioner or nozzle must move with the torch, so it will also be mounted on the roller-mounted carriage that supports the welding torch. The best relationship between the nozzle and the torch will be determined experimentally for each size flow duct to be welded. The torch and nozzle alignment on the carriage will then be fixed to prevent misadjustment within the cell, and specific nozzles will be used for each size flow duct if required. The filler wire will run directly from the enclosed wire reel to the adjacent wire feeder and thence through a wire feed conduit to the nozzle. The wire feeder must be located so that the wire will not bind in the conduit as the nozzle moves with the

torch. The best location for the feeder appears to be above and to the near side of the torch with the feed axis vertical. The feed rolls on the wire feeder would also be accessible in this location.

The operator will be able to see the tip of the welding electrode directly through the operating window because the arc head and torch will be to one side of the flow duct. However, the filler wire will have to be retracted to view the electrode since the nozzle will be on the near side of the torch. The alignment of the electrode and the filler wire with respect to the weld seam can be checked with a telescope.

One of the critical operations involved in the joining of the flow duct is aligning the two portions of the duct so that they are on the same axis and evenly spaced from each other at a suitable distance. The duct pieces must also be oriented so that the corners on one piece are aligned with the corners on the other piece. Ideally, this alignment should be maintained during welding while the duct pieces are being rotated in unison because relative movement between these duct pieces would develop stresses that could induce cracking of the weld. Two approaches may be used to essentially meet these alignment requirements.

In the first approach, the duct pieces would be held in separate chucks to provide alignment. The alignment of the axes of the two chucks and the accuracy of the chuck bearings would be critical if relative movement between the duct pieces at the joint is to be minimized. Relatively rigid fixture construction and machine-tool accuracy would probably be necessary. It would also be necessary to provide a means for adjusting the phase of the chucks so that the corners of the adjoining duct pieces could be aligned. This type of welding fixture would permit conventional butt welds to be made without back-up pieces, and the fixture would provide all the alignment of the welded joint. It would be necessary to align this type of welding fixture very accurately with the axis of the positioning machine to prevent any tendency to strain the flow duct that could in turn affect alignment of the unwelded joint.

The second approach that may be used to meet the duct alignment requirements is based upon the principle of the duct pieces being self-aligning. This approach would require redesign of the flow duct to provide a slip joint, as illustrated in Fig. 4.1. The resulting weld would

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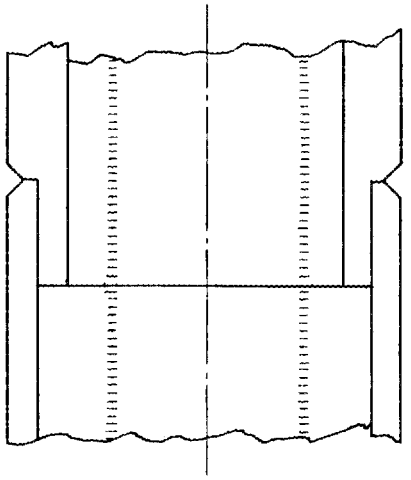

Fig. 4.1. Slip Joint in Hexagonal Flow Duct.

be the same as for a butt joint with a back-up piece, and no filler wire would be used on the root pass. The shape of the ends of the duct pieces would provide the necessary alignment. The clearance between the pieces would, of course, permit some lateral misalignment and the axial runout or squareness of the abuting ends would determine the axial alignment. If this joint is a reasonable distance from the end of the assembly, as would be the case for test assemblies with top-supported internals, the resulting accuracy of the welded assembly should be satisfactory.

In this second approach, the welding fixture would provide no alignment of the duct pieces. The upper and lower grips of the positioning machine would apply an axial load to the assembly to keep the duct pieces together tightly. The relative motion between the duct pieces would be negligible, if not zero, because the grips of the positioning machine are self-aligning. The amount of wandering of the joint under the welding torch would depend upon the accuracy of the ends of the duct pieces. This effect would have to be investigated by using the proposed dimensions of the duct to determine whether the welding would be unduly affected. A chuck would be provided on the welding fixture to align the torch with the flow duct and to provide duct rotation.

Either of the two approaches just described could be used to satisfactorily align the duct pieces for welding. However, the second alignment approach that involves the use of a slip joint in the flow ducts of

reassembled test assemblies and a welding fixture with only one chuck appears inherently better for hot-cell work. This welding fixture would be more simple, its components would be more accessible for maintenance, and it would require less accuracy of setup. It is therefore recommended that the use of a slip joint in the flow ducts of test assemblies be considered for their reassembly.

Another important operation to consider is the alignment of the axis of the welding fixture with the axis of the positioning machine. Any misalignment has the potential for straining the flow duct and thereby affecting the alignment of the unwelded joint. There is also a need to consider methods of supporting the reassembled test assembly as it is being loaded into the welding fixture and whether this support is also needed during welding. The requirements that both open test and closed-loop test assemblies be accommodated and that their internals may be either top or bottom supported present further complexities in the selection of alignment principles and increased potential for interferences with components of the positioning machine. It was not possible during this study to consider these problems in enough detail to make firm recommendations, but certain principles are apparent at this time.

A brief investigation to determine the requirements for aligning the welding fixture with respect to the positioning machine revealed that the problem is resolved into accurately aligning three bearings or providing some means by which one of these bearings can self-adjust laterally so that only two bearings determine the axis of rotation of the flow duct. All the bearings also should be capable of adjusting to the axis of the duct by self-aligning their plane of rotation to minimize strains in the system.

Consider a reassembled test assembly that has a self-aligned joint ready for welding. The assembly is held in the upper and lower grips of the positioning machine and the welding fixture with a single chuck is in place. End thrust by the grips keeps the unwelded joint tightly closed. Alignment of the welding fixture at any point along the axis of the flow duct is not as critical if the fixture can float laterally and if its chuck is self-aligning or if the chuck jaws are very short. If the

fixture cannot float and it is not accurately aligned with the axis of the grips, there will be a tendency for the unwelded joint to buckle and the joint will then open and close as the duct is rotated. Slight tipping of the welding fixture will not affect the welding operation because all points on the joint will pass under the welding torch. However, gross misalignment is to be avoided since this could change the shape of the weld produced by the programmed welding operation.

Allowing the welding fixture to float and thereby seek the axis of the duct is feasible if sufficient end thrust can be applied to the assembly to make the joint stable during welding. It should be emphasized that the straightness of the assembly will depend upon the machining of the ends of the duct pieces and the effects of weld distortion. This method will produce the best results when the weld joint is close to the end of the assembly, as will be the case with top-supported internals. Fortunately, most test assemblies are expected to have top-supported internals to permit the use of contact instrumentation.

4.4 Installation and Service Requirements

The revisions in the basic design requirements for this extended conceptual study permit the use of a shortened positioning machine in the Interim Examination and Disassembly Cell that in turn results in a reduction in the height of the cell. This and other changes in facility-related requirements for space, services, viewing, and handling that are necessary for remote installation, operation, and maintenance of the disassembly-reassembly equipment are discussed in this section. The interfaces for this equipment presented in Appendix D of the original conceptual study report[1] are still valid.

4.4.1 Cell Requirements

Only one positioning machine with its accessory tooling and controls will be required for the Interim Examination and Disassembly Cell. The

spatial relationships required for the installation, operation, and maintenance of this equipment are illustrated in Fig. 4.2. The transfer space required above the top of the worktable provides about a 6-ft-wide aisleway adjoining the back and side of the positioning machine column to be used for loading operations and transfer of machine components and large accessory tooling items. Since the required amount of floor space is smaller than the required amount of transfer space, it will be possible to perform other work in the space adjoining the positioning machine at the lower level of the cell. The final location of the machine with respect to the inside wall of the cell must be determined during the

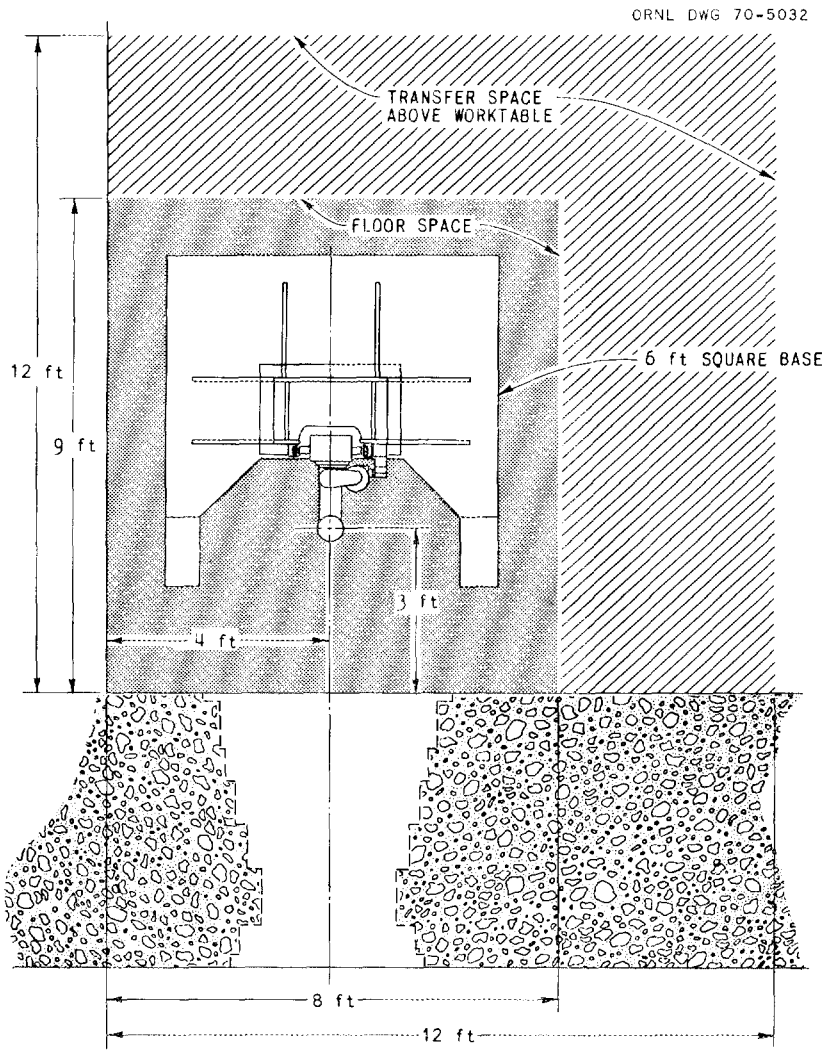

Fig. 4.2. Spatial Relationships Required for Installation, Operation, and Maintenance of Disassembly-Reassembly Equipment in the Interim Examination and Disassembly Cell.

developmental work to assure the best compromise among viewing coverage, master-slave manipulative operations, and maintenance work with the wall-mounted manipulator.

It is still planned to anchor the positioning machine to floor pads which are concrete embedments seal welded to the floor liner. The location and elevation of these floor pads remain unchanged. The uplift and bearing loading of 25,000 lb for each floor pad is still considered valid if accidental bumping of the machine column can be adequately controlled. This problem will be considered further during the preliminary design.

The reduction in the length of core components and test assemblies to be handled has required the establishment of new relationships between the shortened machine, the hot cell, and the operating window, as is illustrated on conceptual drawing M-11325-EM-080-F in Appendix C. The inside height of the cell has been reduced to 40 ft, and only one operating station, which has been relocated, with its viewing window, master-slave manipulators, and retractable worktable is now required to serve the positioning machine. Provision of the lower viewing window in the cell is considered optional since its presence is not an absolute necessity for installation, operation, and maintenance of the disassembly-reassembly equipment, as is discussed in Subsection 5.5.1. However, this lower window would provide convenient viewing for certain operations if it could be justified for other purposes.

4.4.2 Service Requirements

Specific details of the services required for the disassembly-reassembly equipment remain uncertain at this stage of the conceptual design work. The service requirements specified in the original conceptual study report[1] are still valid, but additional electrical service will be required. The power unit for the welding equipment requires a nominal 220/440-volt 3-phase 60-cycle electrical supply, and cell service plugs to feed the welding torch must have low-voltage high-current disconnects. A closed-circuit water-cooling system will be supplied as part of the welding equipment, so a water source and drain will not be needed.

4.4.3 Window and Master-Slave Manipulator Coverage

The viewing range and master-slave manipulator coverage described in the original conceptual study report[1] were assumed for this extended conceptual study, and other details pertaining to the location of the window and manipulators with respect to the operating floor are also unchanged. The CRL* Model J master-slave manipulator with powered indexing in the vertical, lateral, and frontal directions and special lengths of master and slave arms discussed in the original report is still recommended as the best commercially available unit for the job. Only two master-slave manipulators are needed since only one operating station is now required to serve the positioning machine.

4.4.4 Other Support Equipment

The need for and the specific details of the wall-mounted manipulator, overhead crane, overhead manipulator, and camera that are discussed in the original conceptual study report[1] remain unchanged. The underside of the bridge beam for the overhead manipulator should now be located 34 ft above the cell floor so that it will clear the top of the machine column by 6 in. A wall-mounted electromechanical manipulator is recommended to serve the shortened positioning machine because it can be used to assist in the installation and removal of machine modules and components, perform maintenance operations anywhere along the length of the machine column, and to perform operational functions that are beyond the capacity of the master-slave manipulators. The wall-mounted manipulator would therefore free the overhead manipulator for service elsewhere in the cell bank.

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*Central Research Laboratories, Inc., Red Wing, Minn.

5. OPERATING PRINCIPLES

The threefold operating philosophy originally selected as the basis for the conceptual design of the disassembly-reassembly equipment is not affected by shortening of the lengths of the core components and test assemblies to be handled. The three aspects of this philosophy include

1. maneuvering the core component or test assembly up or down so that any critical area may be placed directly in front of the operator to increase efficiency,
2. grouping intricate operations within convenient reach and using master-slave manipulators as much as possible to minimize the need for special devices, and
3. using portable and easily replaceable tooling to achieve maximum versatility in current and future operations.

5.1 Motion Studies

Motion studies were performed during the early phase of the original conceptual design work on the disassembly-reassembly equipment to define the motions involved and the vertical distance through which the core components and test assemblies had to be moved during disassembly operations. The operating criteria developed during the evolution of these motion studies were discussed in Subsection 5.1.1 of the original conceptual study report,[1] and the results of the motion studies were summarized in Subsection 5.1.2 of that report. While this work was done for assemblies up to 36 ft long, only disassembly operations on the lower end of these long assemblies were considered in the final motion studies because the lower end contained the pin bundle and instruments of primary interest. Since the shortened core components and test assemblies have essentially the same configuration as the lower ends of their respective longer assemblies originally studied, the principles presented in Section 5.1 of the original conceptual study report[1] are in general still applicable for this extended conceptual study.

The motion envelope for the positioning machine defines the vertical distance range through which the shortened core components and test assemblies must be moved during disassembly operations. This motion envelope was derived from the requirements for dismantling the 12-ft-long reference driver fuel assembly and from machine loading considerations. The driver fuel assembly was used as a basis for this derivation because specific overall lengths, length increments, and configuration data were not available for the shortened versions of other core components and test assemblies. Representative inner reflector, control safety rod poison tip, open test, and closed-loop test assemblies, as illustrated in Fig. 3.1, were then used to determine whether they could be disassembled within the available space.

The operating criteria and motion study principles used to determine the motion envelope were the same as those used at the completion of the original conceptual study. The location of the cut and camera line is retained at 2 ft 6 in. below the center line of the operating window, which is now the upper window in the cell as shown on conceptual drawing M-11325-EM-080-F in Appendix C. The camera field of view is assumed to be 12 in. high at the plane of the assembly. A portable cooling manifold at the top of the driver fuel assembly provides upward suction cooling during all disassembly operations. After the girth cut is made, the assembly is moved upward so that the cut in the flow duct is at the center line of the operating window. In this position, the top of the cooling manifold determines the upper end of the motion envelope, as illustrated in Fig. 5.1. The distance from the top of the motion envelope to the ceiling of the hot cell was kept the same as in the original conceptual study to allow adequate room for the overhead crane and overhead manipulator and to provide the necessary space for the upper slide at the top of the machine column.

Theoretically, the bottom of the motion envelope should be determined by the effective length of the reference driver fuel assembly since it was used as a basis for derivation of the motion envelope. This would place the lower end of the motion envelope about 14 ft below the center line of the operating window. However, it appeared desirable to provide a lower window in the hot cell so that both the top and bottom of an

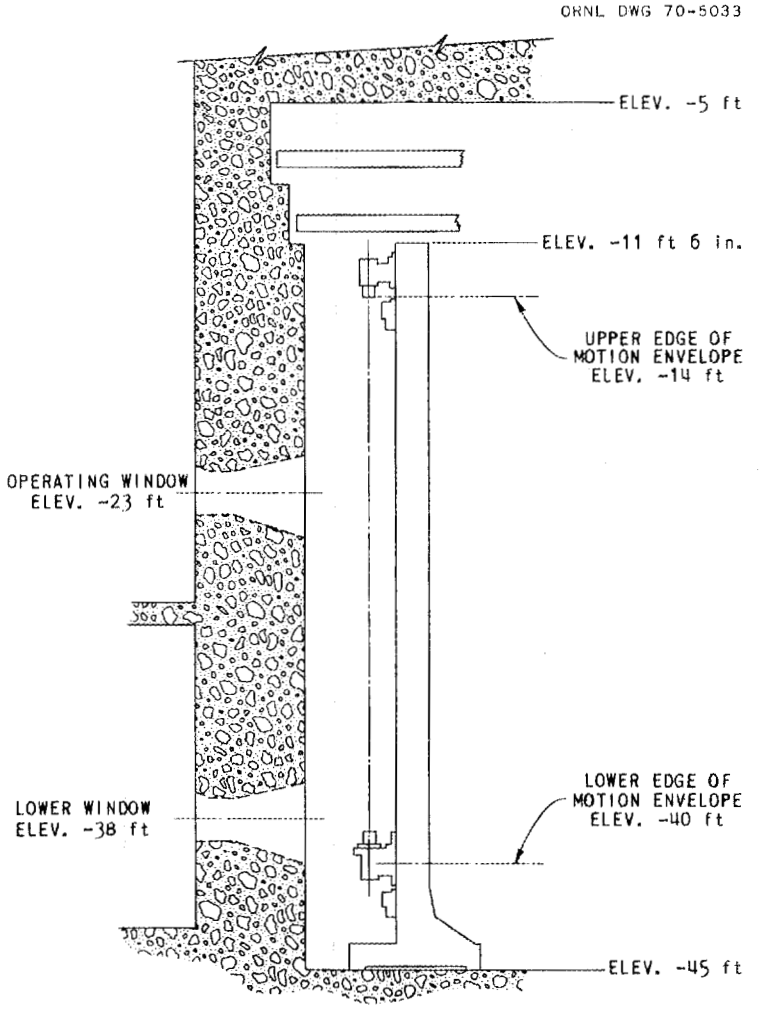

Fig. 5.1. Positioning Machine Envelope Developed to Dismantle 12-ft-Long Core Components and Test Assemblies.

assembly would be accessible simultaneously during loading operations. This lower window would also provide access to the lower slide subassemblies for maintenance, and it would improve viewing capabilities during installation of the positioning machine base and column. The lower end of the motion envelope was therefore lowered an additional 3 ft, as is illustrated in Fig. 5.1.

The distance from the center line of the lower window to the floor of the cell was set at 7 ft in accordance with the design criteria so that space would be available for work on individual pins 8 ft long. With the motion envelope and floor level of the cell determined, it

became possible to invert the position of the subassemblies on the lower slide so that the motor drive is positioned beneath the lower-grip subassembly. This arrangement results in better shielding of the motor drive and an improved ability to handle short assemblies.

Upon checking the capability of the positioning machine to accommodate the representative reflector and poison tip assemblies, as required by design criteria, it became necessary to slightly modify the disassembly procedure. Since both the inner reflector assembly and the poison tip assembly have bottom-supported pin bundles, their disassembly procedure is similar to that for driver fuel assemblies except that cooling of reflector and poison tip pin bundles is not required. The top of the motion envelope was determined by the top of the cooling manifold on the driver fuel assembly when the girth cut in the flow duct of that assembly was positioned at the center line of the operating window. For the representative reflector and poison tip assemblies being checked, it was necessary to accept an upward movement of the girth cut to a point somewhat below the center line of the window because they could be moved no higher without increasing the height of the motion envelope. This limitation is acceptable because there is still at least 18 in. of space between the fixed flow duct and the top of the worktable in which the pin bundle can be viewed and worked on as it is being withdrawn downward from the fixed flow duct.

The disassembly procedure used for the representative open test and closed-loop test assemblies was similar to that used in the previous conceptual design work, and the positioning machine motion envelope derived with the reference shortened driver fuel assembly was adequate for these test assemblies. A further discussion of the features of the disassembly of representative reflector, poison tip, open test, and closed-loop test assemblies is given in Section 5.4 of this report.

5.2 Machine Characteristics and Capabilities

The shortened version of the disassembly-reassembly equipment described in Chapter 4 of this report provides the means for handling and examining core components and test assemblies that are up to 12 ft long and have the specific configuration details and length increments discussed in this section. The specific reference drawings and criteria for the assemblies used to conceive this version of the disassembly-reassembly equipment are given in Paragraphs 3.2.1(b) and 3.2.1(c) of this report. In certain cases, assemblies that are slightly longer than 12 ft may be accommodated. Test assemblies with top-supported internals may require the use of an adaptor at the top of each assembly to extend its length and thereby permit proper placement of the transverse cooling shrouds.

The general capabilities of the equipment and the disassembly criteria that will affect the design of core components and test assemblies are essentially the same as those presented in Section 5.2 of the original conceptual study report.[1] They are repeated here with the necessary modifications resulting from the criteria revisions of this extended study.

1. The equipment will be capable of circumferentially severing and axially slitting the flow duct of core components and test assemblies to permit axial withdrawal of the internals.

2. The internals may be either top or bottom supported; however, consideration should be given to possible damage to instrument leads during disassembly.

3. The active fuel section may be cooled during all phases of loading, cutting, examining, and disassembly. The planned cooling capability is up to 20 kw for axial cooling and up to 10 kw for transverse cooling of the fuel bundle.

4. Access to top-supported internals is made by circumferentially cutting the flow duct near the top of the internals and below the support. The internals are then withdrawn upward.

5. Access to bottom-supported internals is made by circumferentially cutting the flow duct near the bottom of the internals and above the

support. The cut is then moved upward as near as possible to the center line of the operating window for better viewing and clamping of the bundle, and the internals are withdrawn downward.

6. After withdrawal of the internals from the fixed flow duct, the entire length of the internals may be repositioned in front of the operating window for optimum access.

7. The instrument package is considered part of the internals if axial withdrawal to expose instruments is required.

8. Removal of an upper end fitting and all operations on pin bundles and instruments are performed at the operating window.

9. The entire exterior of an assembly will be accessible.

The specific capabilities of the shortened disassembly-reassembly equipment may be defined in terms of the limitations that must be placed upon the design of shortened core components and test assemblies to ensure that they may be cut, examined, and dismantled. These limitations are similar to those found to be necessary for the longer assemblies originally studied, and they are based on the physical characteristics of the equipment and the cell structure shown on conceptual drawing M-11325-EM-081-F in Appendix C. The resulting design criteria for shortened core components and test assemblies with either bottom- or top-supported internals are summarized in Appendix A.

As in the original conceptual study, the nominal high and low points of travel for the upper and lower slides, respectively, determine a motion envelope for the core component or test assembly to be worked. The top end of the motion envelope defines the preferred uppermost point of travel for the top end of an assembly, while the bottom end of the motion envelope defines the preferred lowermost point of travel for the bottom end of an assembly. As in the previous work, overtravel has been provided at the top and bottom of the frame of the positioning machine to allow the upper and lower slides to exceed their nominal travel by 6 in. This provision allows for length tolerances on parts and the necessary clearance required to swing flow ducts aside. It also provides a stopping distance for the slides before they hit mechanical stops. However, it is not considered good practice to include this overtravel as a part of the nominal motion envelope for an assembly.

The maximum length of an assembly that can be loaded onto the positioning machine at the operating window is limited by the maximum height that the assembly can be lifted by the crane and the need for the operator to view insertion of the bottom end of the assembly into the lower adaptor. This maximum length appears to be about 15 ft when an allowance is made for the transfer grapple and the portable cooling manifold. If an assembly is to be loaded at the lower window, this assembly must be raised above the upper worktable and then passed downward through the hole in the upper table. A slightly longer assembly may be loaded in this manner.

The entire outer surface of an assembly, exclusive of areas required for attachment in the positioning machine, may be made accessible for viewing and manipulation, as shown in Fig. 5.2. The entire surface of

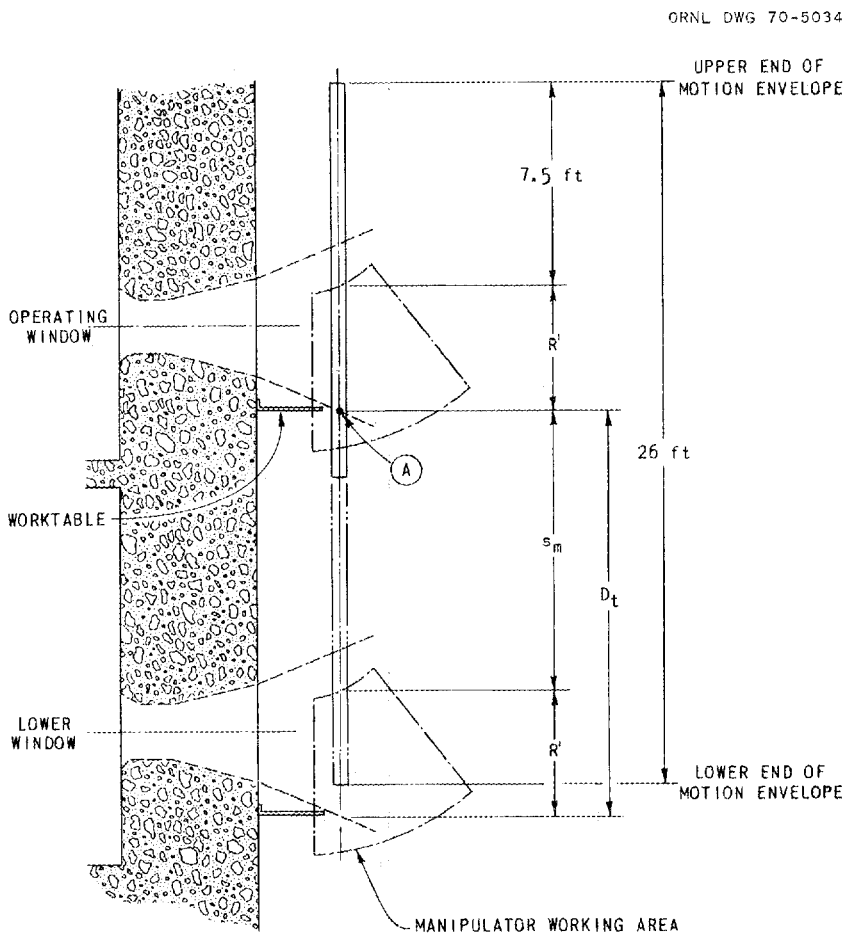

Fig. 5.2. Relationships for Maneuvering Shortened Core Components and Test Assemblies for Access to Exterior Surfaces.

that portion of the assembly above the upper worktable may be viewed and manipulated by moving the assembly downward past the operating window. About 7.5 ft of movement will be required to place the top of the assembly at the top of the manipulative range. That portion of the assembly below the upper worktable must be moved downward so that point A on the assembly shown in Fig. 5.2 is at the top of the manipulative range at the lower window.

The required maneuvering space, s_m, is related to the distance between the worktables, D_t, and the manipulative range above the worktables, R', as illustrated in Fig. 5.2. The required maneuvering space

$$s_m = D_t - R' \ . \tag{5.1}$$

Since $D_t = 15$ ft and $R' = 4.5$ ft,

$$s_m = 15 - 4.5 = 10.5 \text{ ft} \ .$$

The maximum length of an assembly, L'_{max}, that can be maneuvered in this manner is related to the height of the motion envelope and the maneuvering space. Therefore,

$$L'_{max} = 26 \text{ ft} - s_m = 15.5 \text{ ft} \ . \tag{5.2}$$

This length must include the portable cooling manifold when it is required during disassembly operations. Without using the lower window, access to the exterior of assemblies with a maximum length of 13.5 ft can be provided at the operating window. This length also must include the portable cooling manifold when it is needed for subsequent disassembly operations.

If photography of the outside surface of an assembly is required under these conditions of maximum length, a portable camera that can be placed at either of two positions at each window will be required. The camera positions can be selected to produce in effect a photographic range similar to the viewing and manipulative range.

Other characteristics and capabilities of the shortened disassembly-reassembly equipment relative to the shortened core components and test assemblies are shown on conceptual drawing M-11325-EM-081-F in Appendix C of this report. With reference to this drawing, the minimum length of an assembly that can be handled is determined by

1. the distance between the upper grapple and the lower adaptor when the three slides are closely spaced;
2. the distance from the bottom end of the assembly to the bottom of the active fuel section (core), and this may dictate a need to space the lower and middle slides farther apart;
3. the distance from the top of the upper end fitting to the top of the active fuel section (core), and this may dictate a need to space the upper and middle slides farther apart; and
4. the use of special adaptors to circumvent the physical limitations just mentioned.

It should be noted that in this version of the disassembly-reassembly equipment, the middle slide body is shorter and the subassemblies on the lower slide body have been interchanged to improve the capability of the positioning machine to handle shorter assemblies. In spite of this, however, it has been found necessary to use an adaptor at the upper end of short test assemblies with top-supported internals to permit placement of the transverse cooling shrouds adjacent to the active fuel section of these assemblies. The critical length that must be checked is the distance from the top of the active fuel section to the top of the assembly. This length increment must be 6 ft 3 in. or more, as shown on conceptual drawing M-11325-EM-081-F.

For assemblies with bottom-supported internals, the critical length that must be checked is the distance from the bottom of the active fuel section to the bottom of the assembly. This length increment must be 1 ft 11 in. or more, or in the case of closed-loop test assemblies, it must be 11 in. or more, as shown on conceptual drawing M-11325-EM-081-F. Fortunately, this length condition required of assemblies with bottom-supported internals is met by all of the proposed designs that have been considered to date. If this condition is not met by any future assembly, the length of the lower adaptor can easily be increased.

Adherence to these length conditions is necessary only when the active fuel section must be cooled with the transverse cooling shrouds during disassembly operations. These conditions may be disregarded when transverse cooling is not required.

As illustrated on conceptual drawing M-11325-EM-081-F, the cut-range capability of the disassembly-reassembly equipment may be expressed in terms of minimum and maximum cut distances. The cut distance, D, is defined as the distance from the bottom end of an assembly to the girth cut. Equations have been derived to mathematically define the cut distances in terms of the various length increments of the assemblies. Since these equations also depend upon the motion envelope and its relationship to the cut and camera line, some are significantly different from those presented in the original conceptual study report.[1] The specific equations to be used for each of the core components and test assemblies depend on whether the internals of that assembly are top supported or bottom supported. In certain cases, the equations apply directly only to assemblies with a relatively long nose piece. A correction factor must be applied to the calculated maximum cut distance if the end of the assembly cannot be fully inserted into the plenum of the lower-grip subassembly. For closed-loop test assemblies and assemblies with short nose pieces, it is necessary to restrict insertion of the assembly into the plenum so that the lock pin will remain accessible and so a girth cut can be made if the assembly has bottom-supported internals. The maximum cut distance for these types of assemblies is 1 ft less than that calculated by using the applicable equation.

The maximum cut distance for assemblies with bottom-supported internals is 15 ft minus the length of the internals, ℓ, measured from the girth cut to the top of the upper grid. Thus,

$$\text{Bottom-supported } D_{max} = (15 \text{ ft}) - \ell \ . \tag{5.3}$$

This allows for withdrawal of the internals and permits photography of the upper end of the internals.

The minimum cut distance for assemblies with bottom-supported internals is a function of the overall length of the assembly, L, and also the length of the portable cooling manifold, P, when cooling is required during disassembly operations. Thus,

$$\text{Bottom-supported } D_{min} = L + P - (10 \text{ ft } 6 \text{ in.}) \ . \tag{5.4}$$

This permits the assembly to be raised so that the girth cut will be

within 18 in. of the center line of the operating window prior to downward withdrawal of the internals from the flow duct.

The maximum cut distance for assemblies with top-supported internals is 14 ft. This allows room to lower the flow duct below the worktable after the internals have been withdrawn so that it may be swung aside.

The minimum cut distance for assemblies with top-supported internals is a function of the overall length of the assembly, L, and the length of the internals, ℓ, measured from the girth cut to the bottom of the bundle or to the bottom of any instruments that are below the bundle. Thus,

$$\text{Top-supported } D_{min} = L + \ell - (12 \text{ ft}) \ . \tag{5.5}$$

This allows for withdrawal of the internals and permits photography of the lower end of the internals.

A physical characteristic of the assemblies that relates directly to machine capability was reported in the original conceptual study.[1] This characteristic was termed the "effective length" of an assembly. The effective length of assemblies with bottom-supported internals is the distance from the bottom of the assembly to the top of the internals to be exposed, including the upper grid. As shown on conceptual drawing M-11325-EM-081-F, the maximum permissible effective length of assemblies with bottom-supported internals is 15 ft, except for closed-loop test assemblies and those assemblies with short nose pieces. For these assemblies, the maximum permissible effective length is 1 ft shorter or 14 ft. The effective length of assemblies with top-supported internals is the distance from the top of the assembly to the bottom of the internals to be exposed, including any instruments that are below the bundle. The maximum permissible effective length of assemblies with top-supported internals is 12 ft. This includes closed-loop and similar assemblies.

In this extended conceptual study, a second characteristic of the assemblies that also relates directly to machine capability was recognized. This second characteristic has been termed the "specific duct length" of the assembly, and it applies to that portion of the flow duct that surrounds the internals and to certain extensions of that portion of the duct. This specific duct length is related primarily to the limits of the motion envelope, the cut line, and an assumed view line, as shown

on conceptual drawing M-11325-EM-081-F. For assemblies with bottom supported internals, the specific duct length is measured from the girth cut to the top of the assembly. The maximum permissible specific duct length for these assemblies is 10 ft 6 in. minus the length of the portable cooling manifold when cooling is required. For assemblies with top-supported internals, the specific duct length is measured from the girth cut to the bottom of the assembly. The maximum permissible specific duct length for these assemblies is the same as the maximum cut distance, being 14 ft for assemblies with long nose pieces and 13 ft for closed-loop assemblies and assemblies with short nose pieces.

The effective length of an assembly and the specific duct length are useful parameters that may be used in determining whether a specific core component or test assembly can be accommodated by the disassembly-reassembly equipment. These parameters may also be used in determining the maximum length of an assembly that can be handled by the equipment, as is discussed in Section 5.3. As a point of interest, these parameters are also directly related to the minimum and maximum cut distances and may be used in lieu of calculations of these cut distances in determining the capability of the equipment. These relationships are as follows.

1. The maximum permissible effective length of an assembly with bottom-supported internals is directly related to the maximum cut distance.

2. The maximum permissible specific duct length of an assembly with bottom-supported internals is directly related to the minimum cut distance.

3. The maximum permissible effective length of an assembly with top-supported internals is directly related to the minimum cut distance.

4. The maximum permissible specific duct length of an assembly with top-supported internals is directly related to the maximum cut distance.

From the results of the studies presented in this section, it is evident that certain dimensions and configuration details must be known to determine whether a specific core component or test assembly can be handled with the disassembly-reassembly equipment. The basic data required for initial assessment include the

1. overall length of the assembly;
2. position of the fixed support (grid) for the internals (whether it is at the top or bottom of the internals);
3. details of the fixed support (grid) so that the cut point in the flow duct may be determined;
4. overall length of the internals, including instruments if they are to be exposed by axial withdrawal;
5. location of the internals with respect to one end of the assembly;
6. location of the active core section of the internals if that core section requires cooling; and
7. configuration of the lower and upper ends of the assembly for machine attachment considerations.

5.3 Maximum Length of Test Assemblies

Three parameters must be considered in determining the maximum length of assemblies that can be handled by the shortened disassembly-reassembly equipment. They are (1) the maximum permissible specific duct length, (2) the maximum permissible effective length, and (3) the position of the active fuel section with respect to the end of the assembly. In addition, it is necessary to know the end configurations and length increments beyond the pin bundles in assemblies being evaluated. The location of the active fuel section and the assumed end conditions for open test and closed-loop test assemblies that are used in the calculations in this section are illustrated in Fig. 5.3.

The maximum length of an assembly with bottom-supported internals that can be handled by the shortened disassembly-reassembly equipment is the lesser of

1. the sum of the maximum permissible specific duct length and the distance from the girth cut to the bottom of the assembly or
2. the sum of the maximum permissible effective length and the distance from the top of the pin bundle to the top of the assembly.

After determination of the maximum length, the position of the active fuel

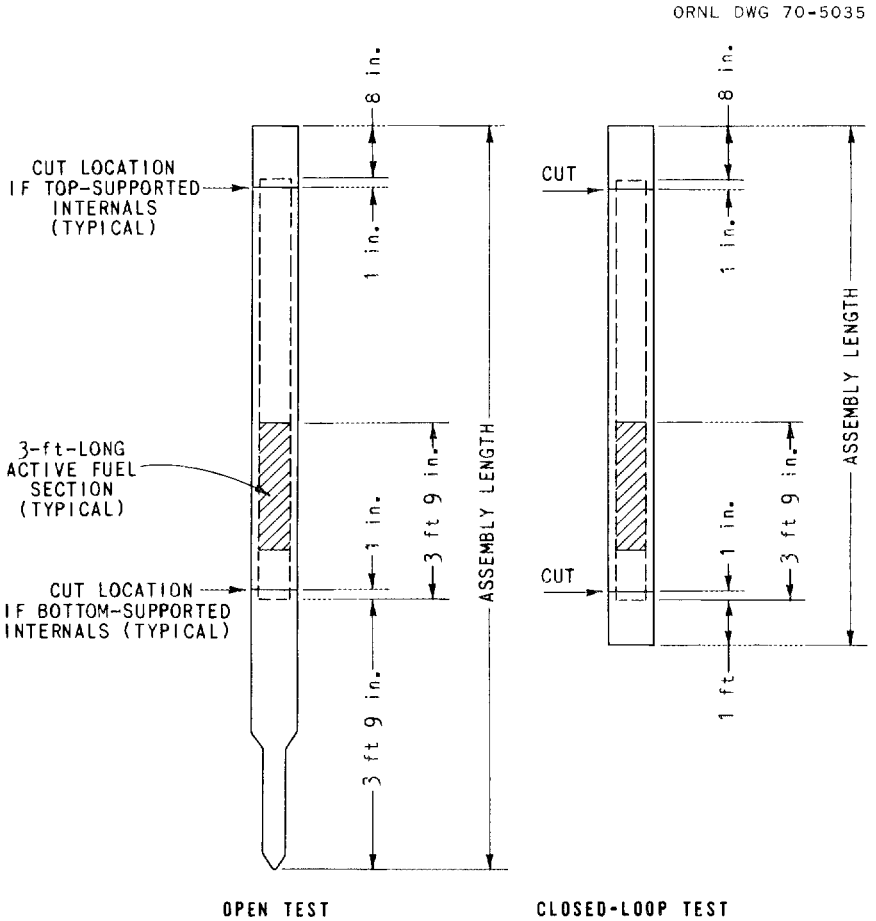

Fig. 5.3. Assumed End Conditions for Determining the Maximum Length of Test Assemblies.

section with respect to the bottom of the assembly should be checked to ensure that proper transverse cooling can be applied.

The maximum length of an assembly with top-supported internals that can be handled is the lesser of

1. the sum of the maximum permissible specific duct length and the distance from the girth cut to the top of the assembly or
2. the sum of the maximum permissible effective length and the distance from the bottom of the pin bundle to the bottom of the assembly.

After determination of the maximum length, the position of the active fuel section with respect to the top of the assembly should be checked to ensure that proper transverse cooling can be applied.

Applying these rules and using the maximum permissible specific duct lengths and effective lengths of assemblies given in Section 5.2, the assumed end conditions shown in Fig. 5.3, and an assumed length of 10 in. for the portable cooling manifold; the following calculations can be made.

The maximum length of an open test assembly with bottom-supported internals that can be handled is the lesser of

$$L_{1(max)} = (9 \text{ ft } 8 \text{ in.}) + (3 \text{ ft } 10 \text{ in.}) = 13 \text{ ft } 6 \text{ in.} \tag{5.6}$$

or

$$L_{2(max)} = (15 \text{ ft}) + (8 \text{ in.}) = 15 \text{ ft } 8 \text{ in.,} \tag{5.7}$$

where the overall length of the assembly $L_{1(max)}$ is based on the specific duct length and $L_{2(max)}$ is based on the effective length of the assembly. Thus, the open test assembly with bottom-supported internals can be 13 ft 6 in. long. For this assembly, the bottom of the active fuel section must be 1 ft 11 in. or more from the bottom of the assembly for proper positioning of the transverse cooling shrouds. This requirement is fulfilled by the assumed end conditions shown in Fig. 5.3.

The maximum length of an open test assembly with top-supported internals that can be handled is the lesser of

$$L_{1(max)} = (14 \text{ ft}) + (9 \text{ in.}) = 14 \text{ ft } 9 \text{ in.} \tag{5.8}$$

or

$$L_{2(max)} = (12 \text{ ft}) + (3 \text{ ft } 9 \text{ in.}) = 15 \text{ ft } 9 \text{ in.} \tag{5.9}$$

Thus, the open test assembly with top-supported internals can be 14 ft 9 in. long. For this assembly, the top of the active fuel section must be 6 ft 3 in. or more from the top of the assembly for proper positioning of the transverse cooling shrouds. This requirement is fulfilled since the overall length of the assembly minus 7 ft 6 in. (3 ft 9 in. + 3 ft 9 in. shown in Fig. 5.3) is 7 ft 3 in.

The maximum length of a closed-loop test assembly with bottom-supported internals that can be handled is the lesser of

$$L_{1(max)} = (9 \text{ ft } 8 \text{ in.}) + (1 \text{ ft } 1 \text{ in.}) \tag{5.10}$$
$$= 10 \text{ ft } 9 \text{ in.}$$

or

$$L_{2(max)} = (14 \text{ ft}) + (8 \text{ in.}) \tag{5.11}$$
$$= 14 \text{ ft } 8 \text{ in.},$$

where the overall length of the assembly $L_{1(max)}$ is based on the specific duct length and $L_{2(max)}$ is based on the effective length of the assembly. Thus, the closed-loop test assembly with bottom-supported internals can be 10 ft 9 in. long. For this assembly, the bottom of the active fuel section must be 11 in. or more from the bottom of the assembly for proper positioning of the transverse cooling shrouds. This requirement is fulfilled by the assumed end conditions shown in Fig. 5.3.

The maximum length of a closed-loop test assembly with top-supported internals that can be handled is the lesser of

$$L_{1(max)} = (13 \text{ ft}) + (9 \text{ in.}) \tag{5.12}$$
$$= 13 \text{ ft } 9 \text{ in.}$$

or

$$L_{2(max)} = (12 \text{ ft}) + (1 \text{ ft}) \tag{5.13}$$
$$= 13 \text{ ft.}$$

Thus, the closed-loop test assembly with top-supported internals can be 13 ft long. For this assembly, the top of the active fuel section must be 6 ft 3 in. or more from the top of the assembly for proper positioning of the transverse cooling shrouds. This requirement is fulfilled since the overall length of the assembly minus 4 ft 9 in. (1 ft + 3 ft 9 in. shown in Fig. 5.3) is 8 ft 3 in.

If the pin bundle does not fill the duct to the extent shown in Fig. 5.3, it is possible to calculate extremely long "acceptable" lengths by using the previously given rules. It is therefore necessary to limit the overall length of an assembly to 15 ft, which is the maximum length that can be loaded onto the positioning machine.

5.4 Disassembly Operations

The disassembly sequences for the reference 12-ft-long driver fuel assembly and for the representative inner reflector, control safety rod poison tip, open test, and closed-loop test assemblies are depicted on conceptual drawings M-11325-EM-082-F, EM-083-F, and EM-084-F in Appendix C of this report. These drawings illustrate the principles defined in Sections 5.1 and 5.2 as applied to specific assemblies and confirm the accessibility required to perform the necessary operations. A possible sequence of operations for complete disassembly of the reference driver fuel assembly from the time the assembly is loaded onto the positioning machine until the fuel bundle is exposed and repositioned for photography and disassembly is illustrated on conceptual drawing M-11325-EM-082-F. The disassembly sequences for the representative assemblies shown on the other two drawings depict only the "loading" mode and the "withdrawal completed" mode because these modes illustrate the significant features of the disassembly operation affected by shortening of the positioning machine. The notes on these drawings generally describe the steps in the disassembly operations. However, the observations in the following subsections may also be made.

5.4.1 Disassembly of Shortened Driver Fuel Assemblies

As previously noted, a possible sequence of disassembly operations for the reference shortened driver fuel assembly is shown on conceptual drawing M-11325-EM-082-F. Both the operating and the lower viewing windows are used in the loading operation so that the assembly may be stabilized in the positioning machine by the lower adaptor and the middle guide before the crane grapple is removed. Note that the loading operations must be performed at the extremes of the manipulative ranges. An alternate method of loading performed only at the operating window is discussed in Subsection 5.5.1 of this report.

The portable cooling manifold at the top of the assembly induces axial coolant flow upward through the bundle, and the manifold must be

in place during withdrawal of the bundle to provide effective cooling. It is also desirable that this manifold be in place during the girth cutting operation to minimize handling. This will require that the manifold be constructed in a manner that will permit free rotation of the flow duct.

With the girth cut in the flow duct located at the center line of the operating window, the fuel pin bundle is withdrawn downward from the fixed duct. The bundle can be observed and clamped while it is being withdrawn. Note that the bundle must be partially withdrawn from the duct before downward movement of the middle slide is initiated. This is necessary to align the active fuel section of the bundle with the transverse cooling shrouds.

5.4.2 Disassembly of Inner Reflector and Poison Tip Assemblies

The general sequence of disassembly operations for the representative inner reflector and control safety rod poison tip assemblies is shown on conceptual drawing M-11325-EM-084-F. Both of these types of assemblies contain bottom-supported pin bundles and are therefore dismantled in a manner similar to that used for driver fuel assemblies. However, cooling of the pin bundle is not required for either of these two types of assemblies, and a portable cooling manifold is not used. Since design data and drawings for the shortened versions of these two types of assemblies were not available for this study, assemblies intended for use in a reactor core with 14-ft-long driver fuel assemblies were modified for use as representative assemblies. The modifications were only those necessary for these assemblies to be dismantled with the shortened disassembly-reassembly equipment.

The inner reflector assembly was assumed to be constructed with the lower shield section as a separate component similar to a 14-ft-long driver fuel assembly. This modification reduced the specific duct length of the assembly to 9 ft 8 in. and permits the girth cut in the flow duct to be placed 8 in. below the center line of the operating window before downward withdrawal of the pin bundle.

The control safety rod poison tip assembly was modified by reducing the length of its integral hanger rod. The intent was not to redesign the assembly but to indicate the restriction that must be placed on its design to ensure that it can be dismantled with the shortened positioning machine and equipment. The specific duct length of the assembly was thus made the maximum permissible length, which is 10 ft 6 in. This change will permit the girth cut in the duct to be placed 18 in. below the center line of the operating window, and there will be adequate space between the bottom of the fixed duct and the top of the worktable for viewing and clamping of the bundle as it is withdrawn downward.

The short nose piece on the control safety rod poison tip assembly and the need for a low girth cut prevent the nose piece from being inserted deeply into the lower adaptor. The middle guide is used to stabilize the assembly during loading operations, but it must be placed relatively low on the assembly to remain accessible. This positioning is probably adequate, but the guide could be placed farther above the lower adaptor to provide greater stability if the assembly were loaded at the operating window rather than at the lower window. This method of loading is discussed in Subsection 5.5.1 of this report.

5.4.3 Disassembly of Fuel Test Assemblies With Top-Supported Internals

The general sequence of disassembly operations for representative open fuel test and closed-loop fuel test assemblies is shown on conceptual drawing M-11325-EM-083-F. Both of these types of assemblies have top-supported pin bundles, and cooling of these bundles is assumed to be required during disassembly operations. Except for a slight difference in the methods used to provide stability during loading operations, both types of assemblies are dismantled in a similar manner.

Each type of assembly is shown on drawing M-11325-EM-083-F being loaded into the lower adaptor of the positioning machine at the lower viewing window. The open test assembly is long enough to permit use of both the operating window and the lower viewing window during loading, and the middle guide may be attached high on the assembly. The closed

loop test assembly does not reach the operating window, and the lower adaptor has been extended to increase the stability of the assembly without using a middle guide. A better method of loading that would provide increased stability for the closed-loop test assembly during loading operations and that could be used for all assemblies is discussed in Section 5.5.1.

Both of these types of test assemblies require an upper adaptor to extend their length. As noted in Section 5.2, this adaptor is necessary to permit proper placement of the transverse cooling shrouds adjacent to the active fuel section of the bundle as it is being withdrawn. However, the adaptor is not needed if the pin bundle does not require cooling. With the girth cut in the flow duct positioned 6 in. above the top of the worktable, the bundle is withdrawn upward from the fixed duct. This positioning of the girth cut permits viewing and clamping of the bundle during withdrawal. The axial cooling plenum induces downward coolant flow through the bundle to provide effective cooling as the bundle is being withdrawn upward, and the portable cooling manifold may therefore be removed as soon as the plenum suction flow is started.

5.5 Improvements in Operating Methods

Loading of the positioning machine can be performed more easily and perhaps more reliably if slight changes are made in the previously discussed operating procedures. These changes involve loading of an assembly onto the positioning machine at the upper or operating window of the cell with the resulting obviation of the need to use the lower window for this operation. There are also indications that the capability of the machine for handling varied assemblies can be improved by changing the relationship between the operating window and the motion envelope of the positioning machine. The exact details of this change must be verified when size and configuration data become available for all of the shortened core components and test assemblies to be handled. The recommended changes and their effects are discussed in the following portions of this section.

5.5.1 Machine Loading at Operating Window

The loading of an assembly onto the positioning machine must be performed in such a way that the assembly will remain stable during all loading operations and not be damaged by an accidental bump or incidental maneuvering. The primary operations involved are the placement of the assembly into a lower adaptor and stabilization of the assembly with a middle guide while the crane grapple and grapple on the upper slide are interchanged. These operations can be performed without maneuvering the assembly if both the operating window and the lower viewing window are used and if the assembly is long enough to permit simultaneous access to both of its ends. This is the basis for the loading procedure illustrated on the conceptual drawings M-11325-EM-082-F, EM-083-F, and EM-084-F in Appendix C of this report and discussed in Section 5.4. This method of loading is just adequate for driver fuel, reflector, and open test assemblies; but problems arise in the loading of control safety rod poison tip and closed-loop test assemblies because of their shorter lengths.

Subsequent to the preparation of the disassembly sequence drawings, it was determined that the loading operations could be performed at the upper or operating window by accepting a shorter distance of about 4 ft between the middle guide and the lower adaptor. This shorter distance or span should provide reasonable stability of the assemblies and is actually an improvement over what could be achieved for poison tip and closed-loop test assemblies by using the initial loading method. The disassembly sequence drawings were not changed so that the problems involved in the loading of these shorter assemblies at the lower window would be apparent.

The loading of an assembly onto the positioning machine at the operating window is illustrated in Fig. 5.4. Insertion of the nose piece of the assembly into the lower adaptor can be seen much better when this loading method is used. This method appears to be applicable for all core components and test assemblies that can be handled with the shortened disassembly-reassembly equipment. However, one disadvantage is that the crane grapple cannot be seen to visually confirm release of the assembly. To lower the grapple so that it can be seen through the operating

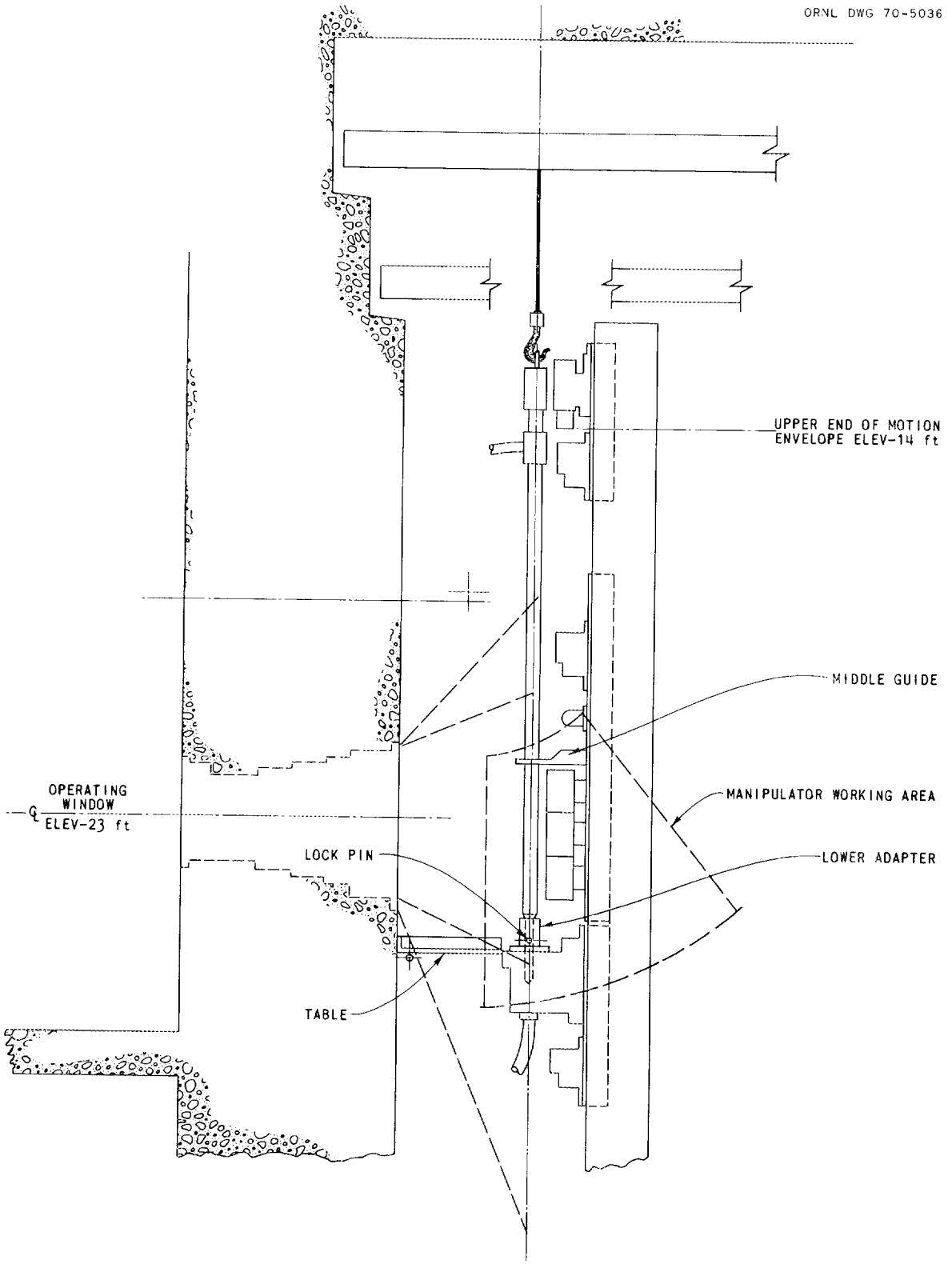

Fig. 5.4. Loading of an Assembly at the Operating Window.

window would require synchronization of the crane hoist and the lower slide, or some overload device would be necessary to protect the assembly from the downward pull of the lower slide. Considering all factors, loading at the operating window appears to be the most desirable method and is therefore recommended in lieu of the initial method depicted on the conceptual disassembly sequence drawings.

If complete loading of the positioning machine can be performed at the operating window, it is logical to reconsider the need for the lower viewing window. The remaining reasons for providing a lower window that are related to the installation, operation, and maintenance of the disassembly-reassembly equipment are to provide improved viewing during installation of the machine base and column, easier maintenance of the lower slide assembly, and to provide the option for loading at the lower window. The lower slide assembly may be maintained at the operating window, but work on the motor drive for this slide may require the use of in-cell television because of the limited viewing range and the inability to raise the slide to a position directly in front of the window. Installation of the positioning machine base to the floor of the cell and bolting of the column-to-base joint will also require the use of television in lieu of direct viewing through the lower window. Therefore, from the standpoint of installation, operation, and maintenance of the disassembly-reassembly equipment, it can be concluded that a lower window in the cell is not an absolute necessity but is considered optional. If windows are installed at the lower level of the cell for other reasons, such as for work on individual pins, these windows can provide convenient viewing for certain installation, operation, and maintenance procedures.

5.5.2 Optimization of Machine Capabilities

The disassembly-reassembly equipment described in this extended conceptual study report was sized in accordance with the design criteria to permit handling and examination of 12-ft-long driver fuel assemblies. Since specific design and configuration data were not available for the other shortened core components and test assemblies to be handled,

representative versions of these assemblies were used to check the capabilities of the equipment. The results of this work are documented in this report, and the characteristics and capabilities of the equipment are defined.

There is a definite indication from the results of the studies presented herein that machine motion above the center line of the operating window should be increased. The same effect could be attained by lowering the center line of the operating window 2 ft to elevation -25 ft. This would allow the lower slide to be placed directly in front of the window for easier maintenance, provide the capability of examining the exterior of assemblies that are up to 15.5 ft long, and provide improved viewing and access to pin bundles of reflector and poison tip assemblies as they are being withdrawn. The motion of the positioning machine below the center line of the operating window would be reduced if the total vertical range of machine motion were unchanged, but this would have no detrimental effect on the handling of those assemblies that have been studied.

The general result of lowering the center line of the operating window appears to be an optimization of machine capability for handling varied types of assemblies. The maximum length of test assemblies that could be accommodated if the window were relocated as suggested would generally approach more practical values of about 12 to 13 ft. Since the described change is really an optimization of the positioning machine, it does not appear desirable to consider the details until the relative importance of the various parameters are better known. It is therefore recommended that this change be implemented at the beginning of the preliminary design work when specific information on the shortened assemblies will be available.

6. SCHEDULE AND COSTS

A revised critical path schedule, an updated cost estimate, and several cost analyses for the design, development, fabrication, and testing of the FFTF disassembly-reassembly equipment are discussed in this chapter. The critical path time-cost schedule is appreciably different from the schedule presented in the original conceptual study report[1] because of the changes in the program and equipment that were requested by the FFTF project management. The most significant changes were the deletion of the second positioning machine with its accessory tooling and controls, the addition of computer-directed welding equipment as part of the accessory tooling for the remaining machine, and the deletion of performance testing of the equipment at ORNL. Performance testing will now be conducted in the Fuel Examination Cell Mockup at Richland, Washington, with ORNL engineers providing increased liaison.

Recent developments in the overall FFTF program have resulted in a delay in funding for the disassembly-reassembly equipment, and a starting date for the proposed program is uncertain at this time. The cost estimate for ORNL participation in the design, development, fabrication, and testing of the revised FFTF disassembly-reassembly equipment presented herein was corrected to include changes in the scheduled activities and then was updated on the basis of an assumed project start date of July 1971. The cost analyses in this chapter include a summary of the effects of the program and equipment changes on cost, a breakdown of costs for the welding equipment, a cost analysis by fiscal year, and a cost analysis by category of work or activity. The cost and scheduling data are also combined in a bar chart for graphical representation of the cost and time involved in the design, development, fabrication, and testing of the revised disassembly-reassembly equipment.

6.1 Critical Path Time-Cost Schedule

The critical path time-cost schedule illustrated on drawing M-11325-EM-085-F in Appendix C is the culmination of communication between personnel of the FFTF project and ORNL. In addition to providing a logical plan for accomplishing the work, this schedule defines for estimating purposes the separate steps involved and provides a convenient method for identifying each activity by I-J numbers. The new schedule is based on the schedule presented in the original conceptual study report,[1] and there are some similarities between the networks of activities in the two schedules. However, the two schedules are appreciably different in overall content because of significant revisions that have been made in the program under the criteria for this extended conceptual study.

Preliminary design and development of the positioning machine, accessory tooling, and controls are scheduled to proceed jointly; followed by final design, procurement, fabrication, and shipment to ORNL in a manner essentially the same as shown on the original critical path schedule. Allowance has been made for engineering liaison during both preliminary and final phases of machine and tooling design. It is still assumed that fabrication will be by outside contractors; that the Purchasing Division of Union Carbide Corporation, Nuclear Division, will negotiate fabrication contracts; and that engineering liaison will be provided by the General Engineering Division of ORNL during procurement negotiations, fabrication, and shop testing. The positioning machine, accessory tooling, and controls will be shipped to ORNL for integrated functional testing to ensure mating of components fabricated in different shops and to check the adequacy of the design for remote operation and maintenance.

At the direction of FFTF project management, performance testing of the disassembly-reassembly equipment will now be done by FFTF representatives in the Fuel Examination Cell Mockup at Richland, Washington, with increased engineering liaison being provided by ORNL. As a consequence of elimination of performance testing at ORNL, functional testing of tooling was added to the schedule. This new activity is necessary to permit mating and check-out of tooling with the positioning machine while the equipment is at ORNL. Any corrections necessary can then be made

before the equipment is shipped to Richland. Representatives of the FFTF project will be present at appropriate times to witness the final functional tests, thereby permitting these tests to also serve as preliminary acceptance tests. Some form of acceptance activity such as this is necessary to signify formal FFTF project satisfaction with the equipment before it is shipped to Richland for performance testing.

Except for subsequent engineering liaison work, this will complete ORNL participation in the project. The performance testing, developmental work to optimize welding parameters, and the final acceptance testing will be performed by FFTF representatives at Richland; and the schedule has been revised to reflect this change of responsibility. It is logical to assume that the final acceptance tests will be performed during or near the end of the performance testing period, and an activity for ORNL liaison during performance and acceptance testing has been added in lieu of the activity for operational testing liaison shown on the original schedule. The final phase of the schedule provides for remote installation and pre-start-up tests of the equipment in the Interim Examination and Disassembly Cell.

One of the more important revisions that was made in the schedule is the deletion of all procurement, fabrication, testing, and liaison activities for the second positioning machine and its accessory tooling and controls. There are no provisions in the new schedule for future acquisition of a second machine with its accessory tooling and controls or for providing any services or support equipment required for a second machine.

Several new activities were added to the time-cost schedule, and values of labor and/or cost figures were increased for other activities to provide the equipment needed to remotely weld girth joints in the flow ducts of reassembled test assemblies. The specific activities that were added or changed are given in the breakdown of costs for the welding equipment in Subsection 6.3.2. In determining these changes in the schedule, it was assumed that appropriate information will be furnished by the FFTF project from their flow duct welding program* being conducted at PNL to assist in the design of the welding fixture and specification of welding equipment.

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*Cladding and Duct Development Task 189a-121 CD.

The required welding fixture will be designed at the same time the other accessory tooling is being designed so that it will be compatible with the positioning machine and other tooling. Procurement and fabrication of the fixture are included in the schedule as part of that work for all the accessory tooling. Fabrication of the welding equipment and controls is shown as a separate activity on the schedule because of its significance and the probability that this equipment will be procured separately rather than as a part of the other accessory tooling. Specifications will be written for the welding equipment, including the computer, servo controls, and other devices necessary to control the welding process; and these items will be procured as a package from a commercial vendor of this type of equipment. The welding fixture and the welding equipment and controls will be shop tested before shipment to ORNL, and then the fixture and equipment will be reassembled and functionally tested at ORNL to ensure compatibility with the positioning machine and suitability for remote operation and maintenance. No welding will be performed as part of the functional testing. Final determination of the welding parameters and the test welding will be done during the performance testing by representatives of the FFTF project.

In the time-cost schedule presented in the original conceptual study report,[1] the functional and performance tests were to be conducted in the same large test facility at ORNL. Since the performance testing will no longer be conducted at ORNL, the activities pertaining to this large test facility have been deleted from the schedule and activities have been added for the design and construction of a small functional test facility at ORNL.

Several other changes were made in the schedule. The costs for activities related to the fabrication, testing, and shipment of the positioning machine were reduced because of the reduction in the height of the machine. However, the costs for these activities shown on the schedule reflect a net increase because of cost escalation effects produced by delaying the starting time for the project. The total scheduled time for activities related to the design, fabrication, and shipment of the machine to Richland was reduced 4 months to meet a specified completion date, but subsequent delay in funding and the resultant uncertainty of the starting

date for the project void the specified completion date. Assuming a starting date of July 1, 1971, the project is scheduled for completion on May 31, 1975. Work on the design, development, fabrication and testing of the revised disassembly-reassembly equipment is scheduled to continue for 47 months, and the significant milestones of this period are tabulated below.

Event	Months After Start Time
Completion of machine design and development with FFTF approval	18
Completion of tooling design and development with FFTF approval	22
Completion of machine fabrication and shipment to ORNL	30
Completion of tooling fabrication and shipment to ORNL	34
Completion of functional testing and shipment to Richland	36
Completion of performance testing, remote installation, and pre-start-up testing by FFTF representatives	47

Because of the shorter overall project period, the labor figures for project administration and documentation shown on the schedule reflect a net decrease. The increased need for documentation for the welding equipment partially offsets the benefits of the shorter period. This shorter period results in a reduction in the required number of monthly activity and cost reports, updating of critical path schedules and cost study charts, and time for which project direction is needed. It should be noted at this point that no attempt has been made to schedule the reports that will be required at various times throughout the course of the project. The critical path schedule is based on the assumption that approval of documentation will not delay the scheduling of activities. For example, final design may proceed after FFTF project approval of preliminary design drawings and possibly before approval of the formal preliminary report. In reviewing the revised schedule, the need for a schedule with as short a time period as is practicable appears more urgent than ever when the cost effects of delaying the project are considered.

6.2 Cost Estimate

The cost estimate for ORNL participation in the design, development, fabrication, and testing of the revised disassembly-reassembly equipment is given on the following five pages. This estimate does not include FFTF liaison activities or the cost of performance testing, final acceptance testing, remote installation, and pre-start-up testing of the equipment. The cost estimate was completely recalculated to include the changes in the program and equipment that were requested by FFTF project management and to update the costs on the basis of the assumed project start date of July 1971. The cost estimate for each activity was first based on a start date of July 1969 to permit the use of existing cost data, and these costs were then increased 14% to account for the delay in the project start date. A contingency factor of 20% was applied to selected activities with uncertain estimates. However, the estimate for the remote welding equipment includes a contingency factor of only 10% because this cost was derived from a vendor's proposal for similar equipment for the FFTF flow-duct welding program at PNL.

Assuming a project start date of July 1971, the total estimated cost for ORNL participation in the design, development, fabrication, and testing of the FFTF disassembly-reassembly equipment is $1,444,000. This total includes $109,000 for cost escalation over the 4-year period of the project. The estimated cost of FFTF participation must be added to the cost for ORNL participation to obtain the total cost of the disassembly-reassembly equipment.

COST ESTIMATE

General Engineering Division

DATE OF THIS ESTIMATE	ENG. JOB NO.	SHEET
2-19-70	11325	1 of 5
REQUESTING DIVISION: Gen. Engr.	ENGINEER: Beckers	WORK REQUEST: L-14320-01

PROJECT TITLE AND BUILDING

FFTF DISASSEMBLY-REASSEMBLY EQUIPMENT

X-10

SUMMARY	Gen. Eng. Div.	Material	Labor	TOTAL
10-20 Project Review	4,100	-	-	4,100
10-210 Project Administration & Documentation	151,500	-	-	151,500
20-24 Preliminary Machine Design	28,600	-	-	28,600
20-25 Preliminary Control Design - Machine	7,300	-	-	7,300
25-27 FFTF Approval Preliminary Machine Design	-	-	-	-
27-29 Final Machine Design	38,200	-	-	38,200
27-70 Final Control Design - Machine	14,500	-	-	14,500
70-75 FFTF Approval Final Machine Design	-	-	-	-
20-75 Machine Design Liaison	10,000	-	-	10,000
25-31 Start Preliminary Tooling Design	15,100	-	-	15,100
31-33 Complete Preliminary Tooling Design	28,600	-	-	28,600
25-33 Preliminary Control Design - Tooling	3,600	-	-	3,600
33-35 FFTF Approval Preliminary Tooling Design	-	-	-	-

[X] P	[ ] EXP. [ ] EQPT.	ESTIMATED BY: Beckers/Goolsby	ORIGINALLY ESTIMATED	DATE: 2-25-69	W/R: A-88960-01	EST. NO. 5
[ ] F	[ ] GPP [ ] AEC	SUBMITTED BY: Corea	LAST REVISION	DATE: 5-15-69	W/R: A-88960-01	

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COST ESTIMATE (Continuation Sheet)

SHEET 2 of 5

SUMMARY	Gen. Eng. Div.	Material	Labor	TOTAL
35-150 Final Tooling Design	74,500	-	-	74,500
35-155 Final Control Design - Tooling	5,000	-	-	5,000
155-160 FFTF Approval Final Tooling Design	-	-	-	-
20-160 Tooling Design Liaison	11,900	-	-	11,900
20-21 Design Development Facilities	4,000	-	-	4,000
21-23 Construct Development Facilities (CPFF)	1,700	2,900	8,500	13,100
20-23 Start Machine Development - Prototype Design, Fabricate, and Test	19,100	4,100	16,600	39,800
23-70 Complete Machine Development - Prototype Design, Fabricate and Test	24,800	8,200	35,000	68,000
20-34 Start Tooling Development - Prototype Design, Fabricate and Test	33,400	4,300	39,700	77,400
34-35 Complete Tooling Development - Prototype Design, Fabricate and Test	33,400	4,300	39,700	77,400
21-35 Development Area Services and Maintenance - Machine, Tooling and Controls	-	7,800	-	7,800
75-77 Machine Contract Liaison	6,100	-	-	6,100
75-80 Award Fabrication Contract - Machine and Controls	-	-	-	-

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COST ESTIMATE (Continuation Sheet)

SHEET 3 of 5

SUMMARY	Gen. Eng. Div.	Material	Labor	TOTAL
80-90 Fabricate Machine	-	24,000	60,500	84,500
80-100 Fabricate Machine Controls	-	8,600	17,100	25,700
90-110 Assemble and Shop Test Machine	-	700	11,300	12,000
110-170 Dismantle and Ship Machine and Controls to ORNL	-	4,400	4,400	8,800
80-110 Machine and Controls Fabrication Liaison	7,800	-	-	7,800
80-170 Upgrade Machine Drawings	3,400	-	-	3,400
160-161 Tooling Contract Liaison	9,600	-	-	9,600
160-163 Award Fabrication Contract - Tooling and Controls	-	-	-	-
163-165 Fabricate Tooling	-	28,200	124,800	153,000
163-166 Fabricate Tooling Controls	-	3,400	6,800	10,200
165-167 Assemble and Shop Test Tooling	-	200	4,300	4,500
163-164 Fabricate Welding Equipment and Controls	-	156,000	-	156,000
164-167 Shop Test Welding Equipment and Controls	-	800	6,200	7,000
167-174 Ship Tooling, Welding Equipment, and Controls to ORNL	-	1,700	3,400	5,100

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COST ESTIMATE (Continuation Sheet)

SHEET 4 of 5

SUMMARY	Gen. Eng. Div.	Material	Labor	TOTAL
163-167 Tooling, Welding Equipment, and Controls Fabrication Liaison	15,600	-	-	15,600
163-174 Upgrade Tooling Drawings	3,400	-	-	3,400
80-83 Design Test Facility	2,400	-	-	2,400
83-170 Fabricate and Erect Test Facility (CPFF)	800	2,500	8,000	11,300
83-84 Test Area Services and Maintenance - Facility	-	2,000	-	2,000
170-173 Machine and Tooling Modifications	-	1,700	20,500	22,200
170-174 Start Functional Test and Preliminary Acceptance - Machine and Controls	29,700	900	15,000	45,600
174-175 Complete Functional Test and Preliminary Acceptance - Machine, Tooling and Controls	8,900	-	3,600	12,500
175-180 Dismantle and Ship Machine, Tooling and Controls to FFTF	-	5,100	7,900	13,000
170-175 Testing Liaison - Machine, Tooling and Controls	4,100	-	-	4,100
170-178 Upgrade All Drawings	2,800	-	-	2,800
170-180 Test Area Services and Maintenance, Machine, Tooling and Controls	-	6,000	-	6,000
180-190 Performance Test and Final Acceptance of Machine, Tooling and Controls by FFTF	-	-	-	-

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COST ESTIMATE (Continuation Sheet)

SHEET 5 of 5

SUMMARY	Gen. Eng. Div.	Material	Labor	TOTAL
190-200 Remote Installation in IGCEF by FFTF	-	-	-	-
200-210 Pre-Startup Tests in IGCEF by FFTF	-	-	-	-
180-210 Performance Testing and Acceptance Liaison	20,000	-	-	20,000
Subtotal	623,900	277,800	433,300	1,335,000
Escalator (4-year period)				109,000
TOTAL				1,444,000

6.3 Cost Analyses

Several cost analyses were prepared to permit evaluation of various aspects of the program for the FFTF disassembly-reassembly equipment. These included an analysis of the effects of program and equipment changes on costs, an analysis of the welding equipment costs to better define the source of these costs for this important addition to the accessory tooling, a cost analysis by fiscal year to assist in the preparation of fiscal year budgets, and a cost analysis by category to show how the costs are divided among common categories of work or activities. A bar chart was also prepared to show cost and scheduling data for various categories of work by fiscal year.

6.3.1 Effects of Program and Equipment Changes on Costs

The effects of program and equipment changes on the cost of ORNL participation in the FFTF disassembly-reassembly equipment project are given in Table 6.1. Except as noted, the costs given in Table 6.1 are

based on July 1969 values. Note that costs for performance testing, welding development, and equipment installation in the hot cell are not included.

Table 6.1. Effect of Program and Equipment Changes on Cost of Disassembly-Reassembly Equipment

Item	Cost ($)
Original cost of 5-year program given in Ref. 1 (no escalation)	1,474,000
Net costs deleted by changes in program and equipment (no welding capability)	− 529,000
Cost of 4-year program for one shortened machine with no welding capability and performance testing by FFTF	945,000
Cost for addition of girth welding capability	+ 226,000
Cost of 4-year program	1,171,000
14% cost increase for delay of project start date to July 1971	+ 164,000
Cost of 4-year program starting July 1971 (no escalation)	1,335,000
8% cost escalation over 4-year period	+ 109,000
Total cost of ORNL participation in 4-year program	$1,444,000

6.3.2 Analysis of Welding Equipment Costs

The remote welding equipment, which is a part of the disassembly-reassembly equipment accessory tooling, consists of a welding fixture, welding components, a power supply and auxiliaries, sequence controls, servo and slope controls, and a small digital computer system. The acquisition cost of this equipment is a significant part of the total cost of the disassembly-reassembly equipment, and it is appropriate that the composition of this cost be analyzed briefly.

The specific activities in the critical path time-cost schedule that were added or modified because of the addition of the welding equipment are given in Table 6.2. The I-J numbers in Table 6.2 correspond

Table 6.2 Breakdown of Estimated Costs for Remote Welding Equipment

Activity Number I	Activity Number J	Activity Title	July 1969 Cost[a] ($)	July 1971 Cost[a] ($)	Fiscal Year Activity Scheduled	Average Escalator (%)	Escalated Cost[a] ($)
10	210	Project Administration and Documentation	8,000	9,100	1972, 73, 74	7	9,700
25	31	Start Preliminary Tooling Design	2,950	3,400	1972	0	3,400
31	33	Complete Preliminary Tooling Design	2,950	3,400	1972, 1973	3.5	3,500
35	150	Final Tooling Design	13,300	15,200	1973	7	16,300
20	160	Tooling Design Liaison	5,300	6,000	1972, 1973	3.5	6,200
160	161	Tooling Contract Liaison	3,100	3,500	1973	7	3,700
163	165	Fabricate Tooling[b]	28,600	32,600	1974	14	37,200
165	167	Assemble and Shop Test Tooling	800	900	1974	14	1,000
163	164	Fabricate Welding Equipment and Controls	137,000	156,200	1974	14	178,100
164	167	Shop Test Welding Equipment and Controls	6,100	7,000	1974	14	8,000
163	167	Tooling, Welding Equipment, and Controls Fabrication Liaison	6,900	7,900	1974	14	9,000
167	174	Ship Tooling, Welding Equipment, and Controls to ORNL	2,300	2,600	1974	14	3,000
174	175	Complete Functional Test and Preliminary Acceptance - Machine, Tooling, and Controls	3,100	3,500	1974	14	4,000
170	173	Machine and Tooling Modifications	3,300	3,800	1974	14	4,300
175	180	Dismantle and Ship Machine, Tooling, and Controls to FFTF	2,300	2,600	1974	14	3,000
		Subtotals	226,000	257,700	Escalated Cost of Welding Equipment		290,400
					Total Escalator (3-year period)		32,700

[a]Costs shown are only those attributed to welding equipment.

[b]Includes welding fixture and fixture adapters for positioning machine and worktable.

with the activity identification numbers shown on the new critical path schedule illustrated on drawing M-11325-EM-085-F in Appendix C. The portion of the total cost of each activity that is directly attributable to the addition of welding equipment is given in the first cost column in which the costs are based on July 1969 values to permit use of available cost data. The values given in the second cost column are based on the assumed project start date of July 1971 and have been increased 14% to obtain this updated cost basis. The fiscal years in which the specific activities are scheduled to occur and the average percentage of cost escalation that may be applied to each activity based on the scheduling of that activity are given. This is an approximate method of calculating costs but an acceptable one in this case because few activities occur in more than one fiscal year. The escalation factor used was 7% per year. Based on a project start date of July 1971, the total cost, which includes the escalation factor, for each activity is given in the last column of Table 6.2.

The total estimated cost of the welding equipment and controls is $290,400. This cost includes an escalation value of $32,700 that is 12.7% of the total updated cost. This escalation percentage is higher than the average escalation of 8.2% for the entire project because most of the activities related to the welding equipment occur in the third year of the program.

6.3.3 Cost Analysis by Fiscal Year

Non-critical activities in the critical path time-cost schedule require less time to complete than one or more parallel activities and they are said to have "float" time. They can be allowed to slip the extent of the float time without delaying completion of the project. If the fiscal years change during the life of an activity that has float time, the division of costs between the fiscal years is controlled by whether and when slippage occurs.

The revised disassembly-reassembly equipment cost analysis by fiscal year is given in Table 6.3. In compiling these values, the costs

Table 6.3. Cost Analysis by Fiscal Year for Revised FFTF Disassembly-Reassembly Equipment

Fiscal Year	Activity Number[a] I	Activity Number[a] J	Updated Cost of Activity[b] ($)	Percentage of Activity Scheduled for this Fiscal Year[c]	Prorated Cost of Activity for Fiscal Year ($)	Escalated Cost for Fiscal Year ($)
1972	10	20	4,100	100	4,100	
	10	210	151,500	33[d]	50,000	
	20	24	28,600	100	28,600	
	20	25	7,300	100	7,300	
	25	27	0	100	0	
	27	29	38,200	33	12,600	
	27	70	14,500	40	5,800	
	20	75	10,000	67	6,700	
	25	31	15,100	100	15,100	
	31	33	28,600	50	14,300	
	25	33	3,600	100	3,600	
	20	160	11,900	55	6,500	
	20	21	4,000	100	4,000	
	21	23	13,100	100	13,100	
	20	23	39,800	100	39,800	
	23	70	68,000	100	68,000	
	20	34	77,400	100	77,400	
	34	35	77,400	57	44,100	
	21	35	7,800	77	6,000	
1972 Totals					407,000	407,000
1973	10	210	151,500	33[d]	50,000	53,500
	27	29	38,200	67	25,600	27,400
	27	70	14,500	60	8,700	9,300
	70	75	0	100	0	0
	20	75	10,000	33	3,300	3,500
	31	33	28,600	50	14,300	15,300
	33	35	0	100	0	0
	35	150	74,500	100	74,500	79,700
	35	155	5,000	100	5,000	5,400
	155	160	0	100	0	0
	20	160	11,900	45	5,400	5,800
	34	35	77,400	43	33,300	35,600
	21	35	7,800	23	1,800	1,900
	75	77	6,100	100	6,100	6,500
	75	80	0	100	0	0
	80	90	84,500	50	42,200	45,200
	80	100	25,700	67	17,200	18,400
	80	110	7,800	44	3,400	3,600
	80	170	3,400	50	1,700	1,800
	160	161	9,600	100	9,600	10,300
	160	163	0	100	0	0
	80	83	2,400	100	2,400	2,600
	83	170	11,300	100	11,300	12,100
	83	84	2,000	100	2,000	2,100
1973 Totals					317,800	340,000

Table 6.3 (continued)

Fiscal Year	Activity Number[a] I	Activity Number[a] J	Updated Cost of Activity[b] ($)	Percentage of Activity Scheduled for this Fiscal Year[c]	Prorated Cost of Activity for Fiscal Year ($)	Escalated Cost for Fiscal Year ($)
1974	10	210	151,500	33[d]	50,000	57,000
	80	90	84,500	50	42,300	48,200
	80	100	25,700	33	8,500	9,700
	90	110	12,000	100	12,000	13,700
	110	170	8,800	100	8,800	10,000
	80	110	7,800	56	4,400	5,000
	80	170	3,400	50	1,700	1,900
	163	165	153,000	100	153,000	174,400
	163	166	10,200	100	10,200	11,600
	165	167	4,500	100	4,500	5,100
	163	164	156,000	100	156,000	177,800
	164	167	7,000	100	7,000	8,000
	167	174	5,100	100	5,100	5,800
	163	167	15,600	100	15,600	17,800
	163	174	3,400	100	3,400	3,900
	170	173	22,200	100	22,200	25,300
	170	174	45,600	100	45,600	52,000
	174	175	12,500	100	12,500	14,300
	175	180	13,000	100	13,000	14,800
	170	175	4,100	100	4,100	4,700
	170	178	2,800	100	2,800	3,200
	170	180	6,000	100	6,000	6,800
1974 Totals					588,700	671,000
1975	10	210	151,500	1[d]	1,500	1,800
	180	190	0	100	0	0
	190	200	0	100	0	0
	200	210	0	100	0	0
	180	210	20,000	100	20,000	24,200
1975 Totals					21,500	26,000
Total Cost for ORNL participation					1,335,000	1,444,000
Total Cost Escalation						109,000

[a]From critical path time-cost schedule shown on drawing M-11325-EM-085-F.

[b]From cost estimate given in Section 6.2.

[c]Percentage of activity performed in each fiscal year based on early start time.

[d]Based on work-load analysis of Project Administration and Documentation Activity.

were prorated on the basis that no slippage occurred. It was assumed that every activity was completed directly in the time estimated and that any float time involved transpired after completion of the activity. Some assumption of this nature must be made to complete such a cost analysis, and this assumption seemed to be the simplest. However, in actual practice, the normal slippage would tend to reduce expenditures in the earlier fiscal years and increase expenditures in the later fiscal years.

Because of the continuous rise in costs, an escalation factor of 7% per year was applied. This resulted in no escalation for fiscal year

1972, 7% escalation for fiscal year 1973, 14% escalation for fiscal year 1974, and 21% escalation for fiscal year 1975. When the cost of an activity was divided among fiscal years, the escalation factor for each year was applied to that portion of the cost assigned to each year. Because of the distribution pattern of work during the fiscal years, the average escalation factor is 8.2%.

6.3.4 Cost Analysis by Category

An analysis of escalated costs by category of work is given in Table 6.4. This analysis was developed by segregating costs of similar activities into common categories where the relative magnitude of these categories becomes readily apparent. This information should be of value to those concerned with industrial or research management. Again, the activity I-J numbers given in Table 6.4 correspond with the numbered activities shown in the critical path time-cost schedule on drawing M-11325-EM-085-F of Appendix C. The escalated costs for each activity were obtained from the cost analysis by fiscal year given in Table 6.3. Note that the cost analysis given in Table 6.4 includes only the costs for ORNL participation in the project and does not include costs for performance testing or remote installation of the disassembly-reassembly equipment.

Table 6.4. Escalated Cost Analysis by Category for Revised FFTF Disassembly-Reassembly Equipment

Cost Category	Included Activities by I-J Number	Fiscal Year	Escalated Activity Cost ($)	Escalated Category Cost ($)
Project Administration and Documentation	10-210	1972	50,000	
	10-210	1973	53,500	
	10-210	1974	57,000	
	10-210	1975	1,800	
				162,300
Liaison for Design, Procurement, Fabrication, and Testing, including travel	10-20	1972	4,100	
	20-75	1972	6,700	
	20-75	1973	3,500	
	20-160	1972	6,500	
	20-160	1973	5,800	
	75-77	1973	6,500	
	80-110	1973	3,600	
	80-110	1974	5,000	
	160-161	1973	10,300	
	163-167	1974	17,800	
	170-175	1974	4,700	
	180-210	1975	24,200	
				98,700
Machine and Controls Design	20-24	1972	28,600	
	20-25	1972	7,300	
	27-29	1972	12,600	
	27-29	1973	27,400	
	27-70	1972	5,800	
	27-70	1973	9,300	
	80-170	1973	1,800	
	80-170	1974	1,900	
	170-178	1974	3,200	
				97,900
Tooling and Controls Design	25-31	1972	15,100	
	25-33	1972	3,600	
	31-33	1972	14,300	
	31-33	1973	15,300	
	35-150	1973	79,700	
	35-155	1973	5,400	
	163-174	1974	3,900	
				137,300
Developmental Facilities	20-21	1972	4,000	
	21-23	1972	13,100	
				17,100
Development, Machine and Controls	20-23	1972	39,800	
	23-70	1972	68,000	
				107,800

Table 6.4 (continued)

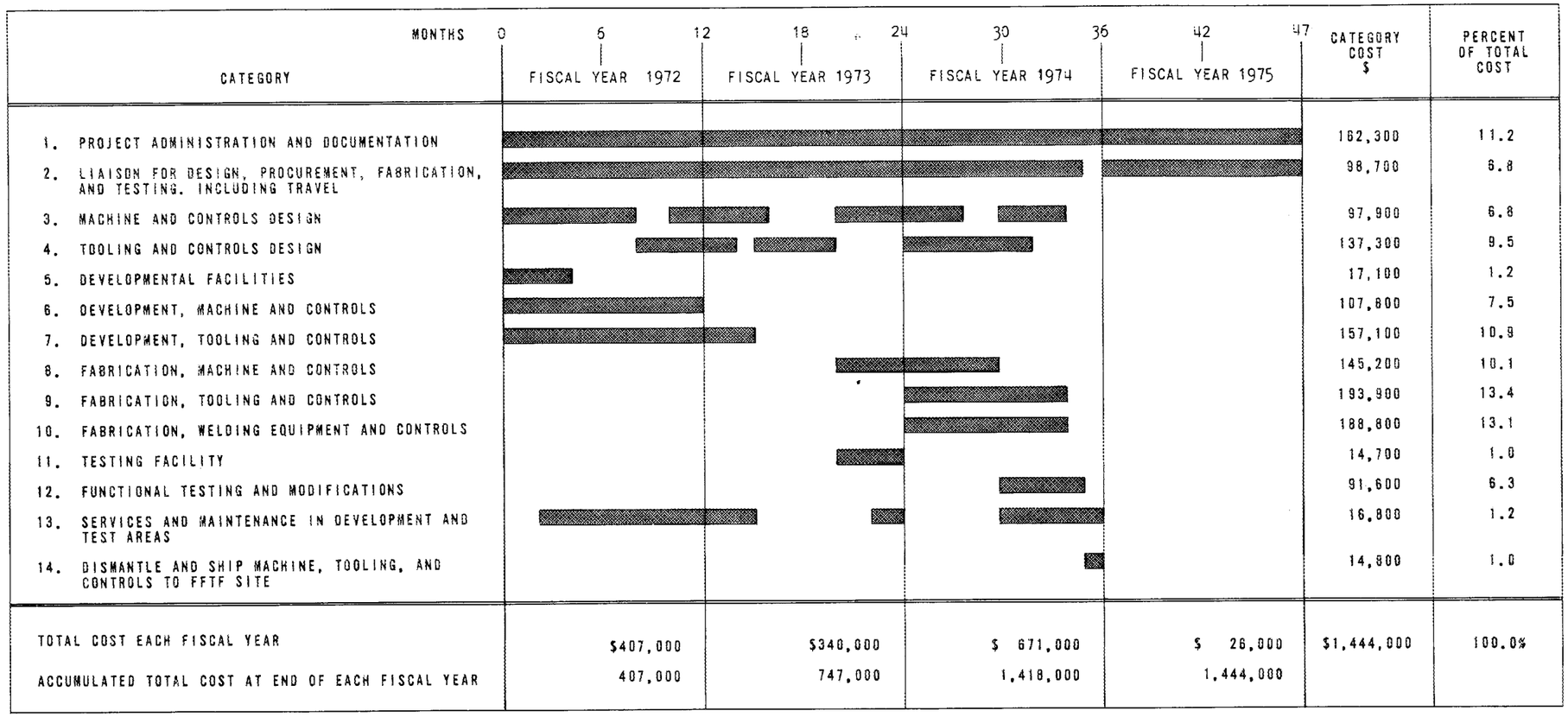
Cost Category	Included Activities by I-J Number	Fiscal Year	Escalated Activity Cost ($)	Escalated Category Cost ($)
Development, Tooling and Controls	20-34	1972	77,400	
	34-35	1972	44,100	
	34-35	1973	35,600	
				157,100
Fabrication, Machine and Controls	80-90	1973	45,200	
	80-90	1974	48,200	
	80-100	1973	18,400	
	80-100	1974	9,700	
	90-110	1974	13,700	
	110-170	1974	10,000	
				145,200
Fabrication, Tooling and Controls	163-165	1974	174,400	
	163-166	1974	11,600	
	165-167	1974	5,100	
	167-174	1974	2,800	
				193,900
Fabrication, Welding Equipment and Controls	163-164	1974	177,800	
	164-167	1974	8,000	
	167-174	1974	3,000	
				188,800
Testing Facility	80-83	1973	2,600	
	83-170	1973	12,100	
				14,700
Functional Testing and Modifications	170-174	1974	52,000	
	174-175	1974	14,300	
	170-173	1974	25,300	
				91,600
Services and Maintenance in Development and Test Areas	21-35	1972	6,000	
	21-35	1973	1,900	
	83-84	1973	2,100	
	170-180	1974	6,800	
				16,800
Dismantle and Ship Machine, Tooling, and Controls to FFTF Site	175-180	1974	14,800	14,800
Total Escalated Cost of All Categories				1,444,000

6.3.5 Bar Chart

The combined durations of various activities that were grouped together in each of the 14 categories given in Table 6.4 are depicted graphically in Fig. 6.1 to illustrate the general pattern of ORNL participation in the project. The costs for each fiscal year, the cost of each category, and the percentage of the total cost of ORNL participation that each category cost represents are included in this bar chart. However, the bars in the chart indicate only the duration of each activity and give no indication of cost. A high-cost category will appear no different than a lower-cost category with the same duration, as may be seen from the category cost figures at the end of the chart.

Project administration, documentation, and liaison activities continue throughout the duration of the entire project. Design and development activities prevail during fiscal year 1972 and early fiscal year 1973. Fabrication starts in late fiscal year 1973 and continues into fiscal year 1974. Functional testing is completed by the end of fiscal year 1974. The activities to be performed by ORNL during fiscal year 1975 consist primarily of engineering liaison during the performance testing and installation phases of the work at Richland, Washington.

ORNL DWG 70-6070



CATEGORY	CATEGORY COST $	PERCENT OF TOTAL COST
1. PROJECT ADMINISTRATION AND DOCUMENTATION	162,300	11.2
2. LIAISON FOR DESIGN, PROCUREMENT, FABRICATION, AND TESTING, INCLUDING TRAVEL	98,700	6.8
3. MACHINE AND CONTROLS DESIGN	97,900	6.8
4. TOOLING AND CONTROLS DESIGN	137,300	9.5
5. DEVELOPMENTAL FACILITIES	17,100	1.2
6. DEVELOPMENT, MACHINE AND CONTROLS	107,800	7.5
7. DEVELOPMENT, TOOLING AND CONTROLS	157,100	10.9
8. FABRICATION, MACHINE AND CONTROLS	145,200	10.1
9. FABRICATION, TOOLING AND CONTROLS	193,900	13.4
10. FABRICATION, WELDING EQUIPMENT AND CONTROLS	188,800	13.1
11. TESTING FACILITY	14,700	1.0
12. FUNCTIONAL TESTING AND MODIFICATIONS	91,600	6.3
13. SERVICES AND MAINTENANCE IN DEVELOPMENT AND TEST AREAS	16,800	1.2
14. DISMANTLE AND SHIP MACHINE, TOOLING, AND CONTROLS TO FFTF SITE	14,800	1.0

TOTAL COST EACH FISCAL YEAR	$407,000	$340,000	$ 671,000	$ 26,000	$1,444,000	100.0%
ACCUMULATED TOTAL COST AT END OF EACH FISCAL YEAR	407,000	747,000	1,418,000	1,444,000		

Fig. 6.1. Graphic Representation of ORNL Participation in Revised FFTF Disassembly-Reassembly Equipment Program by Category.

REFERENCES

1. J. N. Baird, R. M. Beckers, et al., "Conceptual Study of Disassembly-Reassembly Equipment for Examination of FFTF Core Components and Test Assemblies," USAEC Report ORNL-TM-2759, Oak Ridge National Laboratory, January 1970.
2. Fast Flux Test Facility Project Technical Direction Memorandum from C. L. Boyd of Pacific Northwest Laboratory to R. M. Beckers of Oak Ridge National Laboratory; Subject: Extended Conceptual Design, Disassembly-Reassembly Equipment; November 13, 1969.
3. Fast Flux Test Facility Project Telephone Conversation Record from W. S. Chenault of Pacific Northwest Laboratory to R. M. Beckers of Oak Ridge National Laboratory, August 29, 1969.
4. T. B. Correy and R. E. Mahan, "Feasibility Study, Data Processing Equipment and Services," BNW-70-7, Pacific Northwest Laboratory, October 22, 1969 (internal document).
5. R. M. Beckers, "Survey and Analysis of Remote Technology Applicable to Disassembly and Reassembly of FFTF Core Components," USAEC Report ORNL-TM-2610, Oak Ridge National Laboratory, July 1969.
6. M. A. Slawecki, G. J. Bernstein, and L. F. Coleman, "Tests of Commutating Brushes for Use in D.C. Motors Operating in a Dry Argon Atmosphere," USAEC Report ANL-7262, Argonne National Laboratory, December 1966.

APPENDICES

Appendix A

DESIGN CRITERIA FOR SHORTENED CORE COMPONENTS AND TEST ASSEMBLIES

The following limitations must be placed on the design for the core components and test assemblies to assure that they can be cut, examined, and dismantled with the FFTF disassembly-reassembly equipment as conceived in this extended conceptual study. These limitations are discussed in Section 5.2, and those applicable to a specific assembly must be complied with concurrently. It should be noted that the criteria given here will change if the operating window is lowered as recommended in Subsection 5.5.2.

1.	Maximum length of an assembly for loading at the operating window	15 ft
2.	Maximum length of an assembly for access to its exterior, excluding that portion of the assembly within the lower adaptor (grip), at the operating window	12 ft*
3.	Maximum permissible effective length for assemblies with	
	a. bottom-supported internals and long nose piece	15 ft
	b. bottom-supported internals and short nose piece or no nose piece	14 ft
	c. top-supported internals	12 ft
4.	Maximum permissible specific duct length for assemblies with	
	a. bottom-supported internals	10 ft 6 in.*
	b. top-supported internals and long nose piece	14 ft
	c. top-supported internals and short nose piece or no nose piece	13 ft
5.	Minimum length increment from the bottom of an assembly with bottom-supported internals to the bottom of the active fuel section for	
	a. driver fuel assemblies	1 ft 11 in.
	b. open test assemblies	1 ft 11 in.
	c. closed-loop test assemblies	11 in.

*Length includes portable cooling manifold on assemblies with bottom-supported internals that require cooling.

6. Minimum length increment from the top of an assembly with top-supported internals to the top of the active fuel section for

a. driver fuel assemblies	6 ft 3 in.
b. open test assemblies	6 ft 3 in.
c. closed-loop test assemblies	6 ft 3 in.

If the criteria in items 5 or 6 cannot be met, an adaptor may be used to extend the length of the assembly. This adaptor must be included as part of the overall length of the assembly when considering the criteria in items 1, 2, 3, and 4.

Appendix B

ALTERNATE WELDING METHODS

Two alternate methods are suggested for joining the flow ducts of reassembled test assemblies by welding. They are fusion spot welding and intermittent fillet welding. Their use will depend upon the acceptance of a slip joint in flow ducts of reassembled test assemblies and the performance requirements for the finished weld. The primary advantages in the use of these alternate methods are the elimination of the need for a computer as part of the welding equipment and a potential reduction in the number of required in-cell welding components. Both advantages result in capital cost reductions. These alternate welding methods are discussed in the following paragraphs for future consideration when the welding requirements have been better defined.

Fusion spot welding is used at the Fuel Cycle Facility to join the hexagonal sheath and nose piece of driver subassemblies for the Experimental Breeder Reactor II (EBR-II). The operation has been highly successful, and it is therefore logical to consider this method for joining the flow ducts of FFTF test assemblies. The fusion spot welding method is used to join two overlapping pieces of metal where only one side of the joint is accessible. A TIG welding torch is held stationary and the arc is operated for a sufficient time to melt through the outer piece and partially or completely through the inner piece of metal. The mating surfaces must be in intimate contact to assure the best and most reliable transfer of heat to the inner piece, and the welding time, arc voltage, and welding current must be adequately controlled.

The fusion spot welding method is best adapted for welding sheet-metal parts with thicknesses from about 0.030 to 0.090 in., but somewhat thinner or thicker parts may be welded successfully if the operation is engineered and controlled adequately. Operation with direct current provides greater penetration and is preferred for material with thicknesses over 0.060 in. The orientation of the joint must also be considered when spot welding thicker pieces because the longer welding time required to obtain sufficient penetration will also increase the size of

the molten pool. When the outer surface of the joint is oriented vertically for welding, as will be the case for reassembled test assemblies, the molten material will tend to sag as the welding time is increased. This suggests that the 0.140-in. thickness of the flow duct should be reduced at the weld joint if this welding method is used.

The fusion spot-weld is conical in shape, and the size of the weld at the mating surface is appreciably less than the apparent size of the weld at the outer surface. A number of adjacent spot-welds can be made on each face of the hexagonal flow duct to increase the strength of the joint. Quality fusion spot-welds can also be made at the edge of a lap joint. This technique reduces the heat input requirements and has the potential for reducing sag of the molten metal.

Use of the spot welding method at the edge of a lap joint suggests the use of fillet fusion welds on each face of the hexagonal flow duct, as illustrated in Fig. B.1. The end of the upper duct piece could be specially shaped to form a slip joint, and a projection within the pocket could be melted to form the fillet weld. Assuming favorable composition of the base metal, there is a potential for making this fillet weld in a few passes without filler metal and still prevent cracking of the weld. Alignment of the joint is provided by the shape of the duct pieces and

ORNL DWG 70-5031

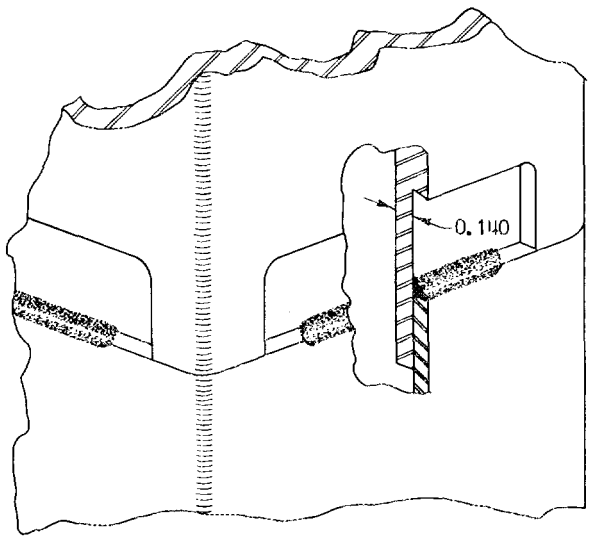


Fig. B.1. Proposed Weld Joint for Fillet Welding of Flow Ducts of Reassembled Test Assemblies.

by firm abutment of the joint edges, as illustrated in Fig. B.1. The flow duct could be indexed as required and then locked during welding. Sequencing controls would direct the welding operation and movement of the torch along the edge of the joint.

The welding equipment and fixture components required to make continuous butt welds, fusion spot-welds, and intermittent fillet welds in the flow ducts of reassembled test assemblies are given in Table B.1. Neither of the alternate welding methods require the use of a computer because the flow duct is stationary during the welding operation. The torch-travel mode is used to index the torch for successive spot-welds or to control torch travel during fillet welding. Indexing of the

Table B.1. Welding Equipment and Fixture Components Required to Make Continuous Butt Welds, Fusion Spot-Welds, and Intermittent Fillet Welds in Flow Ducts of Reassembled Test Assemblies

	Continuous Butt Weld	Fusion Spot-Weld	Intermittent Fillet Weld
Welding Equipment			
Welding torch	X	X	X
Wire feeder	X	a	a
Power supply	X	X	X
Shield gas system	X	X	X
Arc starting system	X	X	X
Water-cooling system	X	X	X
Arc voltage controls	X	X	X
Current controls	X	X	X
Wire feed controls	X		
Duct rotation controls	X		
Torch tilt controls	X		
Torch travel controls		X	X
Sequencing controls	X	X	X
Computer system	X		
Welding Fixture Components			
Duct rotating mechanism	X		
Torch tilt mechanism	X		
Torch arc voltage mechanism	X	X	X
Torch travel mechanism		X	X
Torch elevating mechanism	X	X	X
Fixture lock-to-duct device	b	X	X

[a]Wire feed system may be provided if required.

[b]This feature is provided by the duct rotating mechanism.

hexagonal flow duct to present a new duct face for welding can be done manually or with the motor drive of the lower grip subassembly on the positioning machine. The duct rotating and torch tilting systems will not be needed for either spot or fillet welding and it is also assumed that the wire feed apparatus will not be required.

An order-of-magnitude cost comparison of the welding method considered in this extended conceptual study and the two alternate methods discussed here that accounts for the aforementioned differences is given in Table B.2. Almost all of the general activities in Table B.2 associated with spot and fillet welding reflect the simplification of equipment and tooling in their reduced estimated costs. As might be expected, a major reduction occurs in the cost of the welding equipment because of the deletion of the computer system, wire feed system, and the duct rotation controls.

Table B.2. Order-of-Magnitude Comparison of Costs Associated With Welding Equipment, Fixture and Tooling for Butt, Fusion Spot, and Intermittent Fillet Welding of Reassembled Test Assemblies[a]

	Cost for	
General Activity	Butt Welding ($)	Spot or Fillet Welding ($)
Documentation	9,000	7,000
Design of fixture and tooling	22,000	20,000
Fabricate fixture and tooling	33,500	25,000
Fabricate welding equipment	163,000	70,000
Functional test and modification	7,500	7,500
Liaison and quality assurance	17,500	17,500
Shipping to ORNL and FFTF	5,000	4,000
	257,500	151,000
Escalator	32,500	19,000
Total cost	$290,000	$170,000

[a]All costs based on project start date of July 1971.

Development programs must also be considered when comparing the welding methods. The development of techniques for butt welding flow ducts is being done in a separate FFTF developmental program at Pacific Northwest Laboratory, as noted in Subsection 4.3.1. From one to two

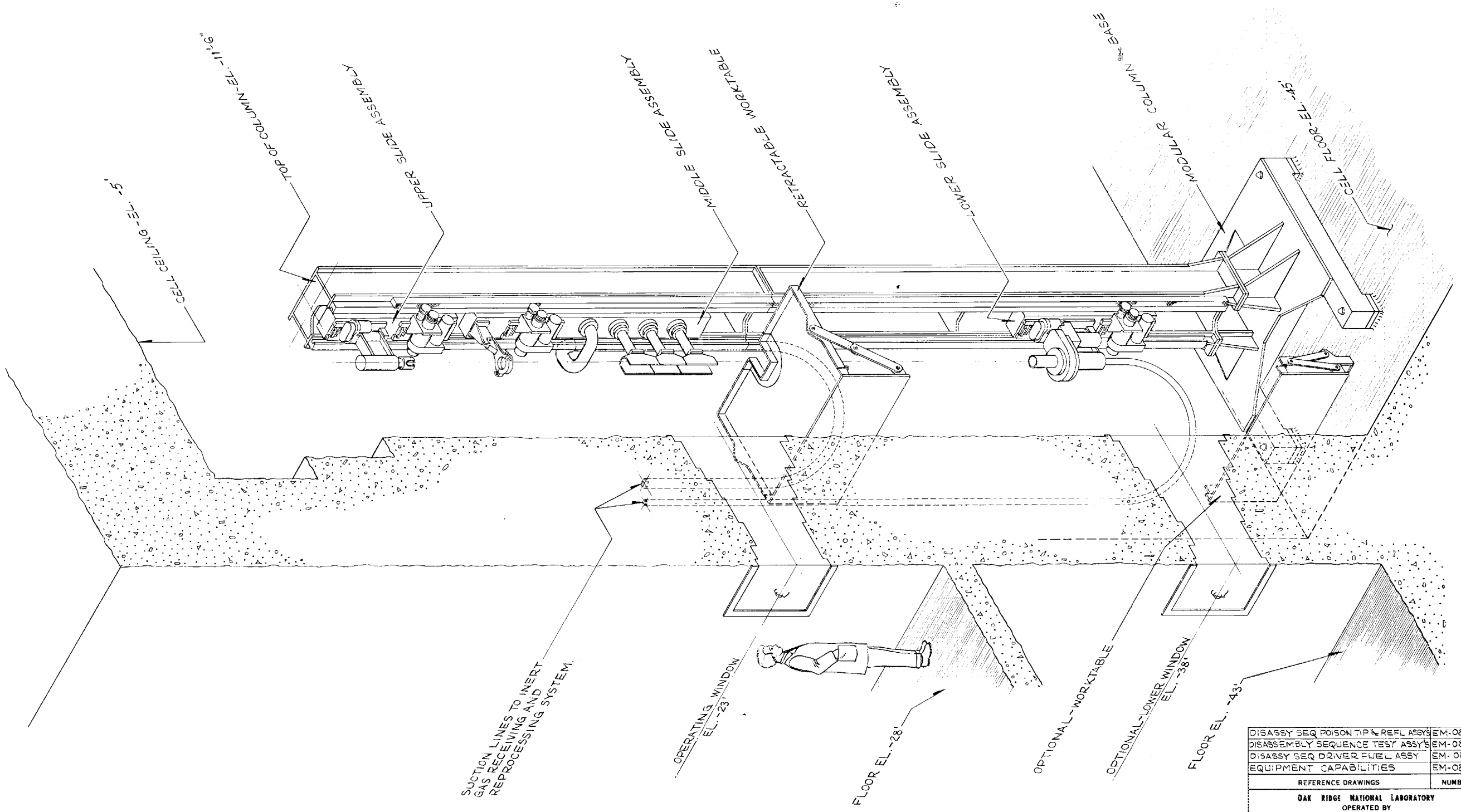
months of additional developmental work will be required to optimize the welding parameters for butt welding vertically oriented flow ducts. An extensive program will also be required for development of techniques to be used with either the spot welding or fillet welding method. Based upon the time required for optimization of spot welding techniques for EBR-II subassemblies and the time expected to be devoted to the FFTF duct welding development program, it is estimated that a four- to five-month development program will be required to optimize either spot or fillet welding techniques for in-cell welding of reassembled FFTF test assemblies.

Appendix C

CONCEPTUAL DRAWINGS OF REVISED FFTF DISASSEMBLY-REASSEMBLY EQUIPMENT

Drawing M-11325-	Title
EM-080-F	Conceptual Design, Disassembly-Reassembly Equipment 33 ft 6 in. Tall
EM-081-F	Conceptual DRE (33 ft 6 in. Tall), Equipment Characteristics and Capabilities
EM-082-F	Conceptual DRE (33 ft 6 in. Tall), Disassembly Sequence for 12-ft Driver Fuel Assembly
EM-083-F	Conceptual DRE (33 ft 6 in. Tall), Disassembly Sequence for Test Assemblies
EM-084-F	Conceptual DRE (33 ft 6 in. Tall), Disassembly Sequence for Poison Tip and Inner Reflector Assemblies
EM-085-F	Disassembly-Reassembly Equipment, Critical Path Schedule - 2

PARTS LIST					
PART	DWG NO.	REQD	DESCRIPTION	STOCK SIZE	MATERIAL



DISASSY SEQ POISON TIP & REFL ASSY'S	EM-084-F
DISASSEMBLY SEQUENCE TEST ASSY'S	EM-083-F
DISASSY SEQ DRIVER FUEL ASSY	EM-082-F
EQUIPMENT CAPABILITIES	EM-081-F
REFERENCE DRAWINGS	NUMBER

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2. TYPE, GRADE, OR FINISH OF MATERIAL MAY BE CHOSEN BY FABRICATOR.
3. MACHINED SURFACE FINISH SHALL NOT EXCEED: ~√ (ASA B46.1-1962)

TOLERANCES UNLESS OTHERWISE SPECIFIED:
FRACTIONS ± ~
DECIMALS ± ~
ANGLES ± ~
SCALE: 3/4" = 1'-0"

NO.	REVISIONS	DATE	APPD	APPD
1	REMOVED PROVISION FOR 2ND MACHINE & MADE LOWER WINDOW & TABLE OPTIONAL	4-3-1970	RWB	WB

DRAWN	DATE	SUBMITTED	DATE	APPROVED	DATE	APPROVED	DATE
HENNON	12-69						
DESIGNED DECKERS & VINYARD	DATE	APPROVED	DATE	APPROVED	DATE	APPROVED	DATE
CHECKED L. VINYARD	DATE 12-69	APPROVED	DATE	APPROVED	DATE	APPROVED	DATE

OAK RIDGE NATIONAL LABORATORY
OPERATED BY
UNION CARBIDE CORPORATION
OAK RIDGE, TENNESSEE

FAST FLUX TEST FACILITY

CONCEPTUAL DESIGN
DISASSEMBLY REASSEMBLY EQUIPMENT 33'-6" TALL

SUBMITTED R.M. Beckers | ACCEPTED | APPROVED H. S. Duggan

M	11325	EM	080	F	REV 1

PARTS LIST					
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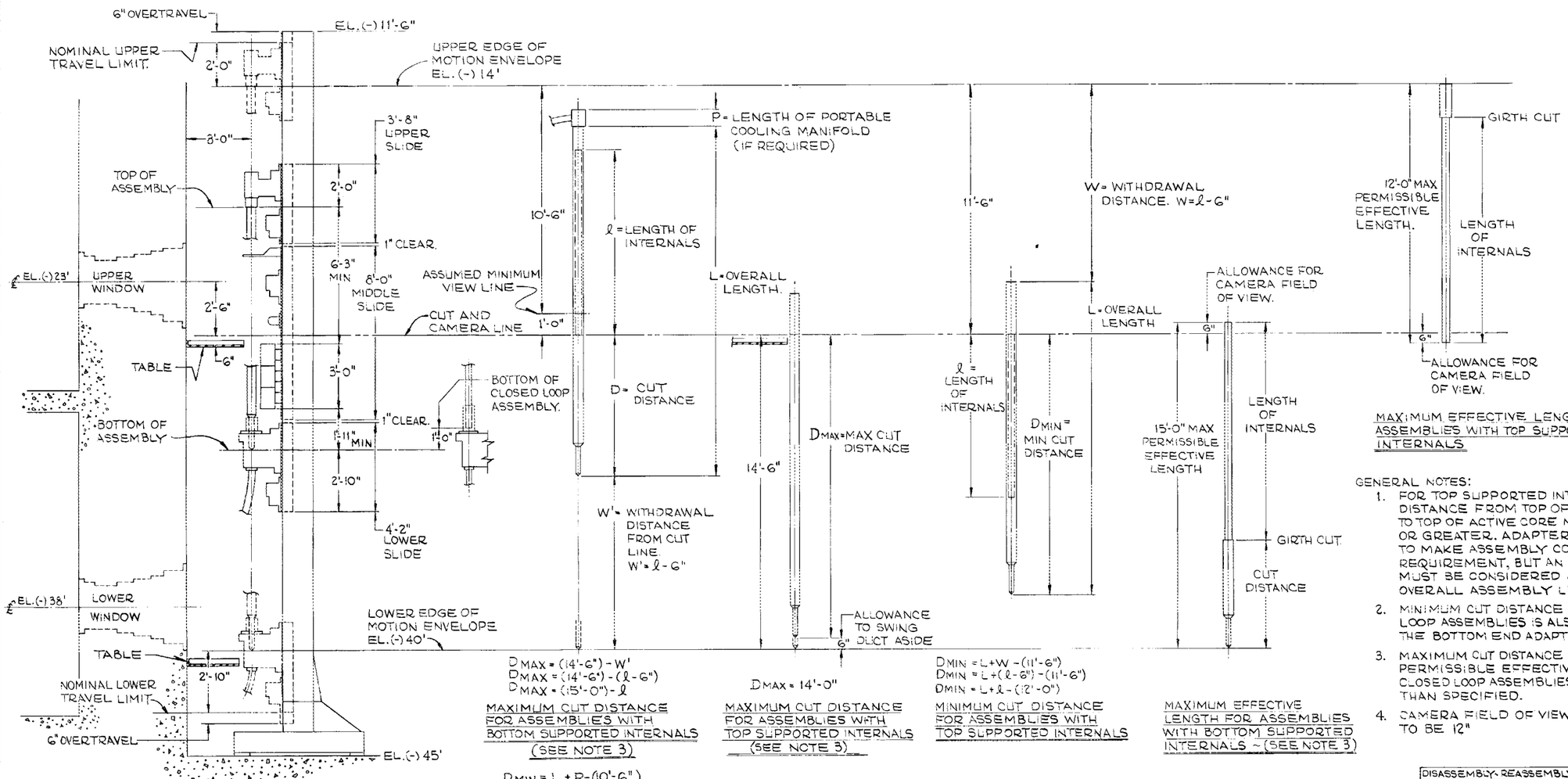

GENERAL NOTES:

1. FOR TOP SUPPORTED INTERNALS, DISTANCE FROM TOP OF ASSEMBLY TO TOP OF ACTIVE CORE MUST BE 6'-3" OR GREATER. ADAPTER MAY BE USED TO MAKE ASSEMBLY COMPLY TO THIS REQUIREMENT, BUT AN ADAPTER MUST BE CONSIDERED AS PART OF OVERALL ASSEMBLY LENGTH.
2. MINIMUM CUT DISTANCE FOR CLOSED LOOP ASSEMBLIES IS ALSO LIMITED BY THE BOTTOM END ADAPTER.
3. MAXIMUM CUT DISTANCE AND MAXIMUM PERMISSIBLE EFFECTIVE LENGTH FOR CLOSED LOOP ASSEMBLIES IS 1'-0" LESS THAN SPECIFIED.
4. CAMERA FIELD OF VIEW IS ASSUMED TO BE 12"

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3. MACHINED SURFACE FINISH SHALL NOT EXCEED 125 (ASA B46.1-1962)

TOLERANCES UNLESS OTHERWISE SPECIFIED:
FRACTIONS ± —
DECIMALS ± —
ANGLES ± —
SCALE ½" = 1'-0"

NO.	REVISIONS	DATE	APPD	APPD
1	REVISED GENERAL NOTE #3	4-3-70	RCB	WLB

DRAWN	DATE	SUBMITTED	DATE	APPROVED	DATE
HENNON	12-69				
DESIGNED (CHECKED)	DATE	APPROVED	DATE	APPROVED	DATE
CHECKED L. VINYARD	DATE 12-69	APPROVED	DATE	APPROVED	DATE

DISASSEMBLY-REASSEMBLY EQUIP. | EM-080-F
REFERENCE DRAWINGS | NUMBER

OAK RIDGE NATIONAL LABORATORY
OPERATED BY
UNION CARBIDE CORPORATION
OAK RIDGE, TENNESSEE

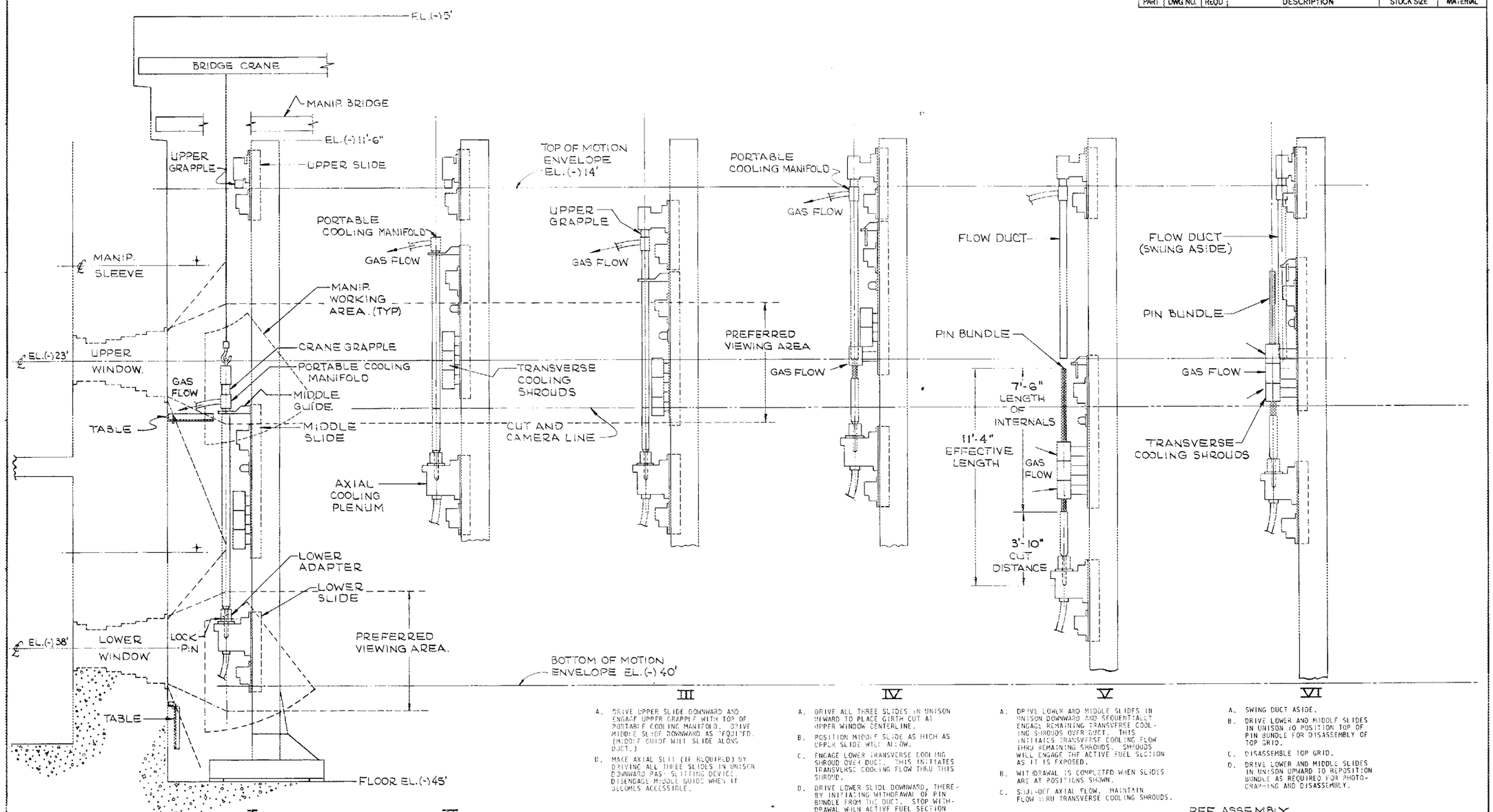
FAST FLUX TEST FACILITY

CONCEPTUAL DRE (33'-6" TALL) EQUIPMENT CHARACTERISTICS AND CAPABILITIES

SUBMITTED R. M. Beckers | ACCEPTED | APPROVED H. G. Duggan

M | 11325 | EM | 081 | F | REV. 1

PARTS LIST					
PART	DWG NO.	REQD	DESCRIPTION	STOCK SIZE	MATERIAL



I

A. POSITION SLIDES AS SHOWN WITH UPPER GRAPPLE SWUNG ASIDE.

B. LOAD ASSEMBLY INTO LOWER ADAPTER WITH CRANE. ENGAGE LOCK PIN AND MIDDLE GUIDE.

C. MAINTAIN AXIAL SUCTION FLOW UPWARD THRU PORTABLE COOLING MANIFOLD.

D. REMOVE CRANE GRAPPLE.

II

A. DRIVE MIDDLE AND LOWER SLIDES IN UNISON UPWARD TO PLACE ASSEMBLY AT CUTTING POSITION.

B. MAKE GIRTH CUT WITH CUTTING DEVICE ON TABLE.

III

A. DRIVE UPPER SLIDE DOWNWARD AND ENGAGE UPPER GRAPPLE WITH TOP OF PORTABLE COOLING MANIFOLD. DRIVE MIDDLE SLIDE DOWNWARD AS REQUIRED. (MIDDLE GUIDE WILL SLIDE ALONG DUCT.)

D. MAKE AXIAL SLIT (IF REQUIRED) BY DRIVING ALL THREE SLIDES IN UNISON DOWNWARD PAST SLITTING DEVICE. DISENGAGE MIDDLE GUIDE WHEN IT BECOMES ACCESSIBLE.

IV

A. DRIVE ALL THREE SLIDES IN UNISON UPWARD TO PLACE GIRTH CUT AT UPPER WINDOW CENTERLINE.

B. POSITION MIDDLE SLIDE AS HIGH AS UPPER SLIDE WILL ALLOW.

C. ENGAGE LOWER TRANSVERSE COOLING SHROUD OVER DUCT. THIS INITIATES TRANSVERSE COOLING FLOW THRU THIS SHROUD.

D. DRIVE LOWER SLIDE DOWNWARD, THEREBY INITIATING WITHDRAWAL OF PIN BUNDLE FROM THE DUCT. STOP WITHDRAWAL WHEN ACTIVE FUEL SECTION IS ADJACENT TO TRANSVERSE COOLING SHROUDS.

V

A. DRIVE LOWER AND MIDDLE SLIDES IN UNISON DOWNWARD AND SEQUENTIALLY ENGAGE REMAINING TRANSVERSE COOLING SHROUDS OVER DUCT. THIS INITIATES TRANSVERSE COOLING FLOW THRU REMAINING SHROUDS. SHROUDS WILL ENGAGE THE ACTIVE FUEL SECTION AS IT IS EXPOSED.

B. WITHDRAWAL IS COMPLETED WHEN SLIDES ARE AT POSITIONS SHOWN.

C. SHUT-OFF AXIAL FLOW. MAINTAIN FLOW THRU TRANSVERSE COOLING SHROUDS.

VI

A. SWING DUCT ASIDE.

B. DRIVE LOWER AND MIDDLE SLIDES IN UNISON TO POSITION TOP OF PIN BUNDLE FOR DISASSEMBLY OF TOP GRID.

C. DISASSEMBLE TOP GRID.

D. DRIVE LOWER AND MIDDLE SLIDES IN UNISON UPWARD TO REPOSITION BUNDLE AS REQUIRED FOR PHOTOGRAPHING AND DISASSEMBLY.

REF. ASSEMBLY,
12'-0" LONG DRIVER FUEL, PNL DWG
SK-3-147118, 1ST ISSUE 8/14/69.

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TOLERANCES UNLESS OTHERWISE SPECIFIED:
FRACTIONS ±
DECIMALS ±
ANGLES ±
SCALE 1/3" = 1'-0"

NO.	REVISIONS	DATE	APPD	APPD
I	REVISED SEQUENCE NOTES I & III	4-5-70	RMB	HJB

DRAWN	DATE	SUBMITTED	DATE	APPROVED	DATE	APPROVED	DATE
HENNON	12-69						
DESIGNED BELKENG L.VINYARD		APPROVED					
CHECKED L.VINYARD	DATE 12-69	APPROVED					

DISASSEMBLY REASSEMBLY EQUIPMENT	EM-080-F
REFERENCE DRAWINGS	NUMBER

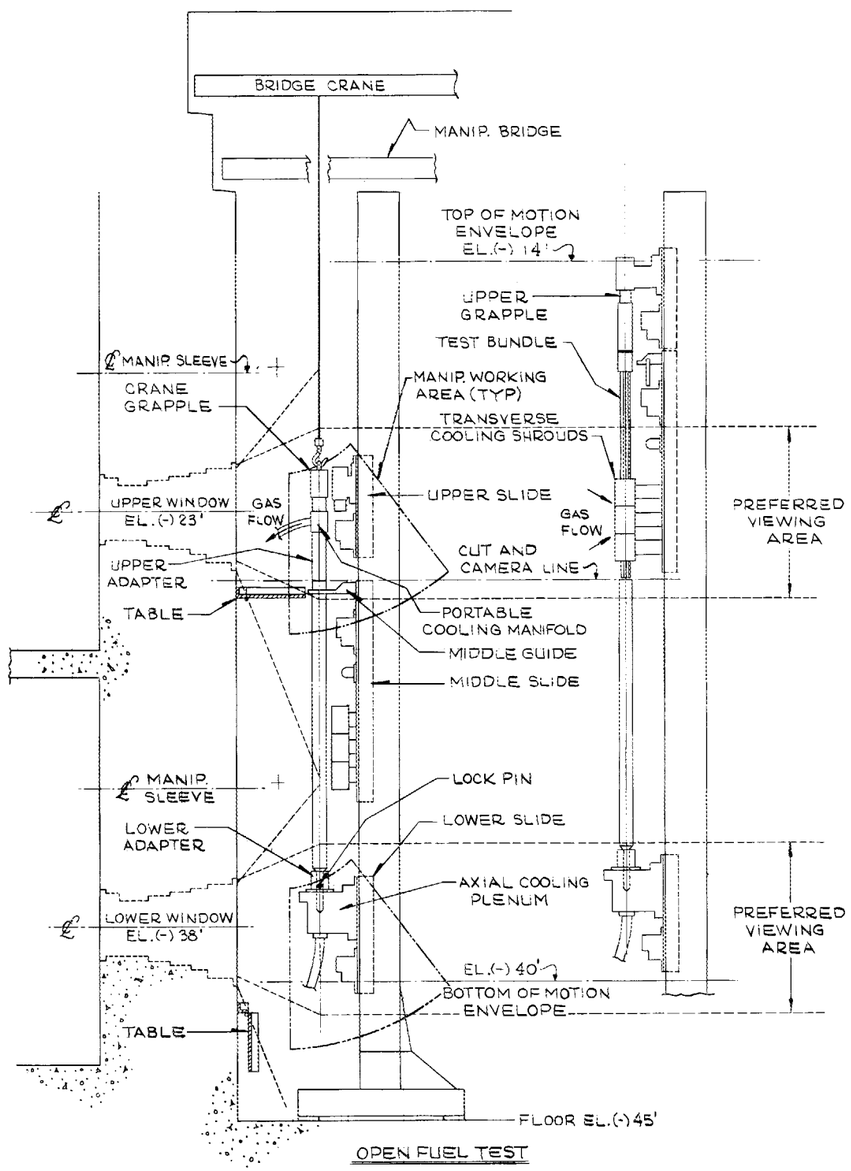
OAK RIDGE NATIONAL LABORATORY
OPERATED BY
UNION CARBIDE CORPORATION
OAK RIDGE, TENNESSEE

FAST FLUX TEST FACILITY

CONCEPTUAL DRE (33'-6" TALL)
DISASSEMBLY SEQUENCE FOR
12'-0" DRIVER FUEL ASSEMBLY

SUBMITTED R.M. Beckers | ACCEPTED | APPROVED H. J. Buggen

M 11325 EM 082 F 1 REV.



OPEN FUEL TEST

I

NOTE: 12 FT. LONG OPEN FUEL TEST ASSEMBLY REQUIRES 17'-9" LONG UPPER ADAPTER FOR PROPER TRANSVERSE COOLING.

A. LOAD ASSEMBLY INTO LOWER ADAPTER WITH CRANE. ENGAGE LOCK PIN AND MIDDLE GUIDE.

B. INITIATE AXIAL SUCTION FLOW DOWNWARD THRU AXIAL COOLING PLENUM.

C. REMOVE CRANE GRAPPLE AND PORTABLE COOLING MANIFOLD.

D. DRIVE UPPER SLIDE DOWNWARD AND ENGAGE UPPER GRAPPLE WITH TOP OF UPPER ADAPTER.

II

A. DRIVE ALL THREE SLIDES IN UNISON UPWARD TO PLACE ASSEMBLY AT CUTTING POSITION.

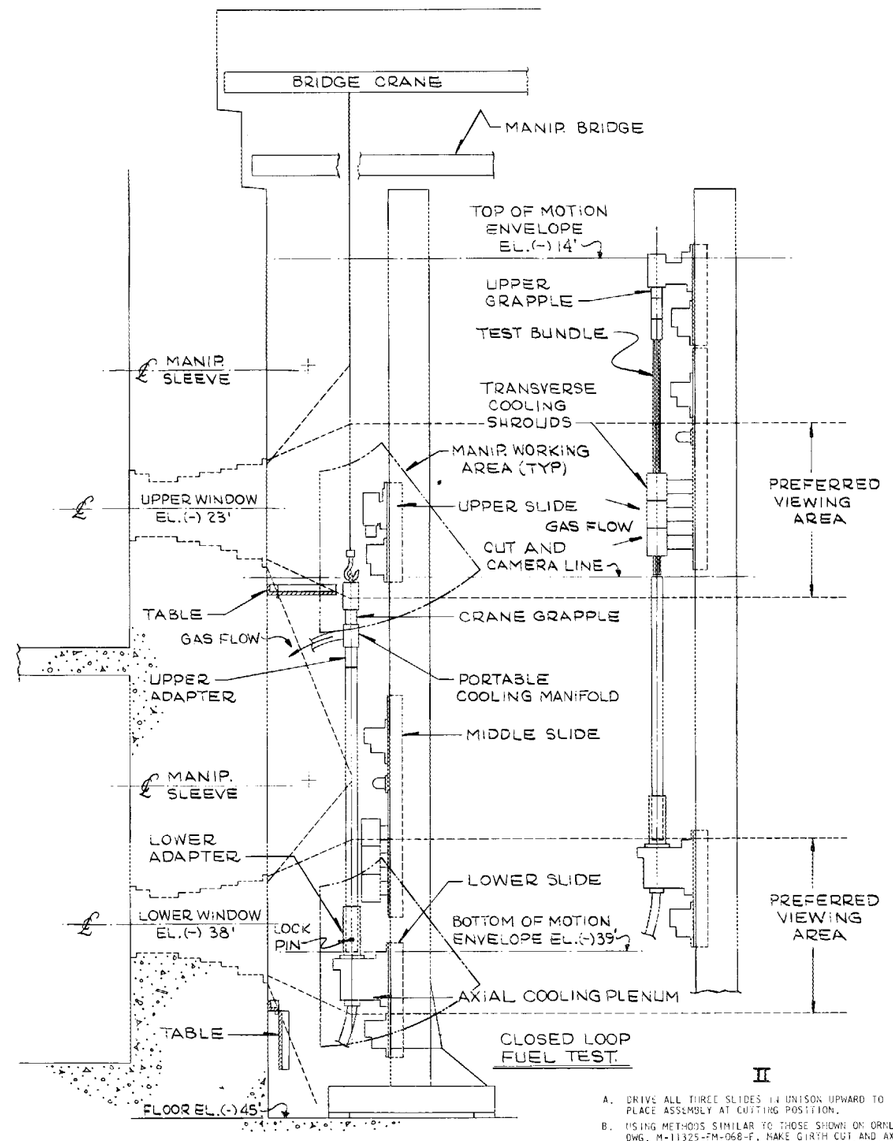
B. USING METHODS SIMILAR TO THOSE SHOWN ON ORNL DWG. M-11325-EM-067-F, MAKE GIRTH CUT AND AXIAL SLIT (IF REQUIRED), WITHDRAW TEST BUNDLE AND INITIATE TRANSVERSE COOLING FLOW.

C. WITHDRAWAL IS COMPLETED WHEN SLIDES ARE AT POSITIONS SHOWN.

D. SHUT-OFF AXIAL FLOW. MAINTAIN FLOW THRU TRANSVERSE COOLING SHROUDS.

E. DUCT MAY NOW BE LOWERED BELOW TABLE AND SWUNG ASIDE SO BUNDLE CAN BE REPOSITIONED AS REQUIRED FOR PHOTOGRAPHING AND DISASSEMBLY.

PARTS LIST					
PART	DWG NO.	REQD	DESCRIPTION	STOCK SIZE	MATERIAL



I

NOTE: 10'-3" LONG CLOSED LOOP FUEL TEST ASSEMBLY REQUIRES 9" UPPER ADAPTER FOR PROPER TRANSVERSE COOLING.

A. LOAD ASSEMBLY INTO LOWER ADAPTER WITH CRANE. ENGAGE LOCK PIN.

B. INITIATE AXIAL SUCTION FLOW DOWNWARD THRU AXIAL COOLING PLENUM.

C. REMOVE CRANE GRAPPLE AND PORTABLE COOLING MANIFOLD.

D. DRIVE LOWER AND MIDDLE SLIDES IN UNISON UPWARD AND ENGAGE UPPER GRAPPLE WITH TOP OF UPPER ADAPTER.

II

A. DRIVE ALL THREE SLIDES IN UNISON UPWARD TO PLACE ASSEMBLY AT CUTTING POSITION.

B. USING METHODS SIMILAR TO THOSE SHOWN ON ORNL DWG. M-11325-FM-068-F, MAKE GIRTH CUT AND AXIAL SLIT (IF REQUIRED), WITHDRAW TEST BUNDLE AND INITIATE TRANSVERSE COOLING FLOW.

C. WITHDRAWAL IS COMPLETED WHEN SLIDES ARE AT POSITIONS SHOWN.

D. SHUT-OFF AXIAL FLOW. MAINTAIN FLOW THRU TRANSVERSE COOLING SHROUDS.

F. DUCT MAY NOW BE LOWERED BELOW TABLE AND SWUNG ASIDE SO BUNDLE CAN BE REPOSITIONED AS REQUIRED FOR PHOTOGRAPHING AND DISASSEMBLY.

REF. ASSEMBLIES

1- 12'-0" LONG OPEN TEST WITH 7'-6" LENGTH OF TOP SUPPORTED INTERNALS TO BE EXPOSED.

2- 10'-3" LONG CLOSED LOOP TEST WITH 8'-6" LENGTH OF TOP SUPPORTED INTERNALS TO BE EXPOSED.

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GENERAL SPECIFICATIONS
UNLESS OTHERWISE SPECIFIED:
1. BREAK ALL SHARP EDGES
2. TYPE, GRADE, OR FINISH OF MATERIAL MAY BE CHOSEN BY FABRICATOR.
3. MACHINED SURFACE FINISH SHALL NOT EXCEED: 125 (ASA B46.1-1962)

TOLERANCES UNLESS OTHERWISE SPECIFIED: FRACTIONS ± — DECIMALS ± — ANGLES ± —
SCALE: 1/2" = 1'-0"

NO.	REVISIONS	DATE	APPD	APPD
1	REVISED ALL SEQUENCE NOTES	4-3-70	[illegible]	[illegible]

DRAWN	DATE	SUBMITTED	DATE	APPROVED	DATE
HENNON	12-69				
DESIGNED BECKERS-VINYARD	DATE	APPROVED	DATE	APPROVED	DATE
CHECKED L. VINYARD	DATE 12-69	APPROVED	DATE	APPROVED	DATE

DISASSEMBLY REASSEMBLY EQUIP — EM-080-F
REFERENCE DRAWINGS — NUMBER

OAK RIDGE NATIONAL LABORATORY
OPERATED BY
UNION CARBIDE CORPORATION
OAK RIDGE, TENNESSEE

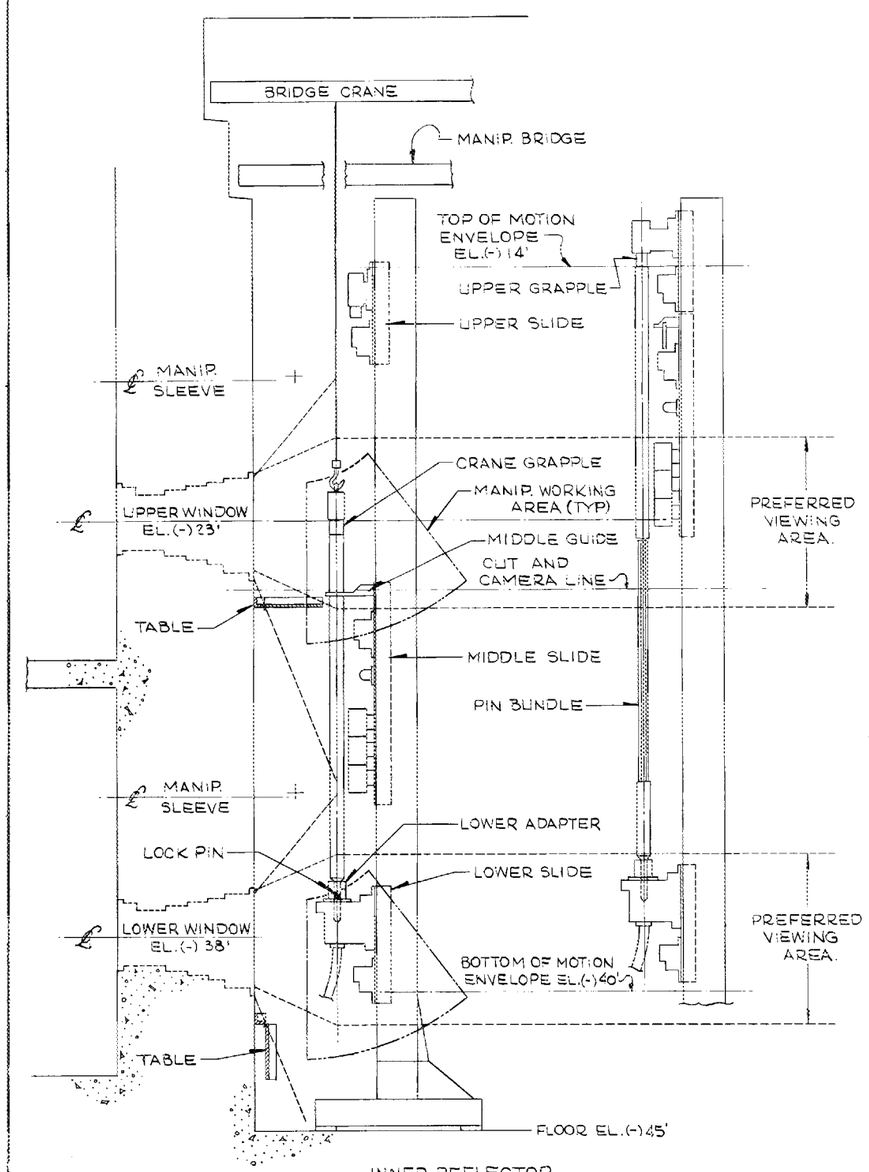
FAST FLUX TEST FACILITY

CONCEPTUAL DRE (33'-6" TALL) DISASSEMBLY SEQUENCE FOR TEST ASSEMBLIES

SUBMITTED Ron Beckers — ACCEPTED — APPROVED H. E. Duggan

M 11325 EM 083 F REV. 1

PARTS LIST					
PART	DWG NO.	REQD	DESCRIPTION	STOCK SIZE	MATERIAL



INNER REFLECTOR

I

NOTE: INNER REFLECTOR ASSEMBLY DOES NOT REQUIRE AXIAL OR TRANSVERSE COOLING.

A. LOAD ASSEMBLY INTO LOWER ADAPTER WITH CRANE. ENGAGE LOCK PIN AND MIDDLE GUIDE.

B. REMOVE CRANE GRAPPLE.

C. DRIVE UPPER SLIDE DOWNWARD AND ENGAGE UPPER GRAPPLE WITH TOP OF ASSEMBLY.

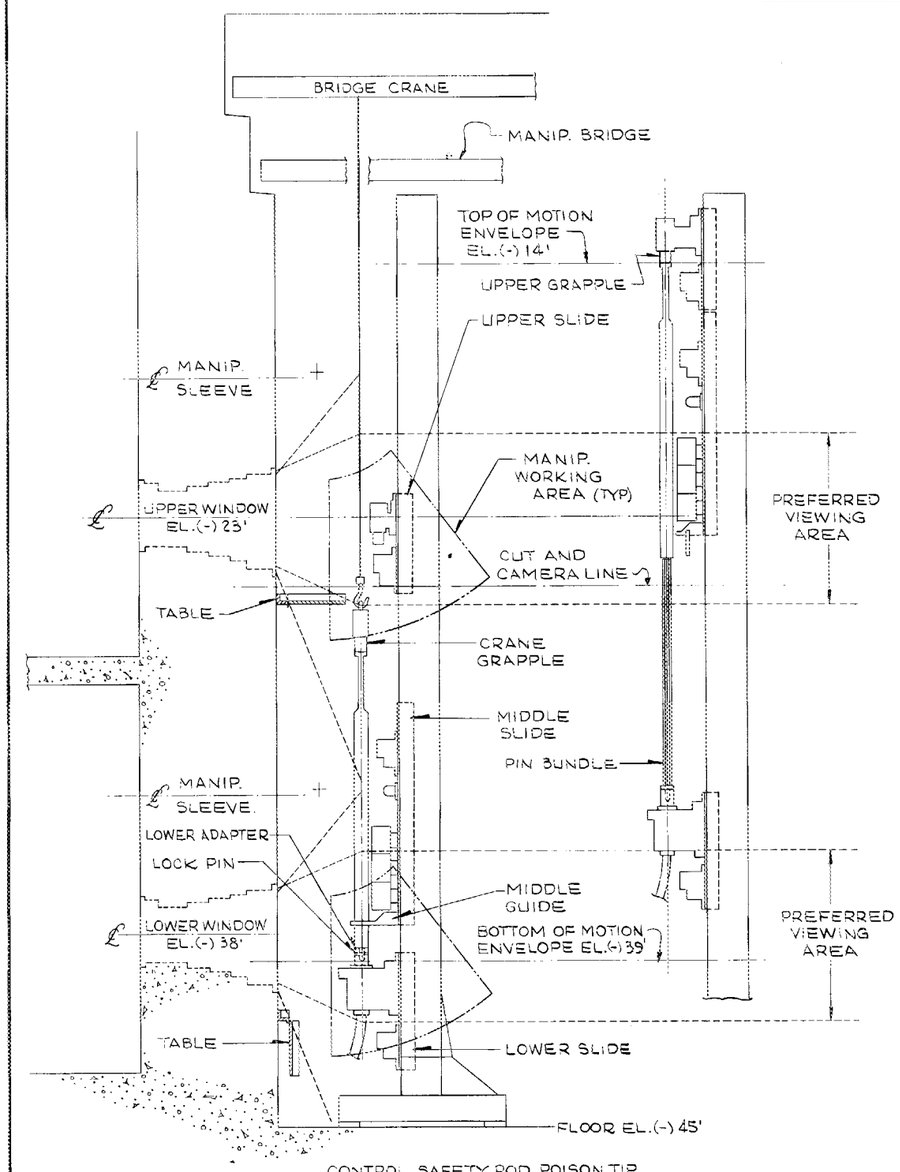
II

A. DRIVE ALL THREE SLIDES IN UNISON UPWARD TO PLACE ASSEMBLY AT CUTTING POSITION.

B. USING METHODS SIMILAR TO THOSE SHOWN ON ORNL DWG. M-11325-EM-082-F, MAKE GIRTH CUT AND AXIAL SLIT (IF REQUIRED) AND WITHDRAW PIN BUNDLE. AXIAL OR TRANSVERSE COOLING IS NOT REQUIRED.

C. WITHDRAWAL IS COMPLETED WHEN SLIDES ARE AT POSITIONS SHOWN.

D. DUCT MAY NOW BE SWUNG ASIDE SO BUNDLE CAN BE REPOSITIONED AS REQUIRED FOR PHOTOGRAPHING AND DISASSEMBLY.



CONTROL SAFETY ROD POISON TIP

REF. ASSEMBLIES

1 - INNER REFLECTOR, PNL DWG SK-3-14636, 1ST ISSUE 3/14/69 MODIFIED SO THE LOWER SHIELD SECTION IS A SEPARATE COMPONENT.

2 - CONTROL SAFETY ROD POISON TIP, PNL DWG SK-3-14732, 2ND ISSUE 8/26/69 MODIFIED SO THE INTEGRAL HANGER ROD AND DUCT ABOVE THE GIRTH CUT DOES NOT EXCEED 10'-6".

I

NOTE: CONTROL SAFETY ROD POISON TIP ASSEMBLY DOES NOT REQUIRE AXIAL OR TRANSVERSE COOLING.

A. LOAD ASSEMBLY INTO LOWER ADAPTER WITH CRANE. ENGAGE LOCK PIN AND MIDDLE GUIDE.

B. REMOVE CRANE GRAPPLE.

C. DRIVE LOWER AND MIDDLE SLIDES IN UNISON UPWARD AND ENGAGE UPPER GRAPPLE WITH TOP OF ASSEMBLY.

II

A. DRIVE ALL THREE SLIDES IN UNISON UPWARD TO PLACE ASSEMBLY AT CUTTING POSITION.

B. USING METHODS SIMILAR TO THOSE SHOWN ON ORNL DWG. M-11325-EM-082-F, MAKE GIRTH CUT AND AXIAL SLIT (IF REQUIRED) AND WITHDRAW PIN BUNDLE. AXIAL OR TRANSVERSE COOLING IS NOT REQUIRED.

C. WITHDRAWAL IS COMPLETED WHEN SLIDES ARE AT POSITIONS SHOWN.

D. DUCT MAY NOW BE SWUNG ASIDE SO BUNDLE CAN BE REPOSITIONED AS REQUIRED FOR PHOTOGRAPHING AND DISASSEMBLY.

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GENERAL SPECIFICATIONS
UNLESS OTHERWISE SPECIFIED:
1. BREAK ALL SHARP EDGES
2. TYP. GRADE, OR FINISH OF MATERIAL MAY BE CHOSEN BY FABRICATOR.
3. MACHINED SURFACE FINISH SHALL NOT EXCEED: — (ASA B46.1-1962)

TOLERANCES UNLESS OTHERWISE SPECIFIED:
FRACTIONS ± —
DECIMALS ± —
ANGLES ± —
SCALE: 3/8" = 1'-0"

NO.	REVISIONS	DATE	APPD	APPD
1	REVISED ALL SEQUENCE NOTES	4-3-70	[illegible]	[illegible]

DRAWN	DATE	SUBMITTED	DATE	APPROVED	DATE	APPROVED	DATE
HENNON	12-69						
DESIGNED BECKERS, KONRAD		DATE	APPROVED	DATE	APPROVED	DATE	APPROVED
CHECKED L. VINYARD	DATE 12-69	APPROVED	DATE	APPROVED	DATE	APPROVED	DATE

DISASSEMBLY REASSEMBLY EQUIP.	EM-080-F
REFERENCE DRAWINGS	NUMBER

OAK RIDGE NATIONAL LABORATORY
OPERATED BY
UNION CARBIDE CORPORATION
OAK RIDGE, TENNESSEE

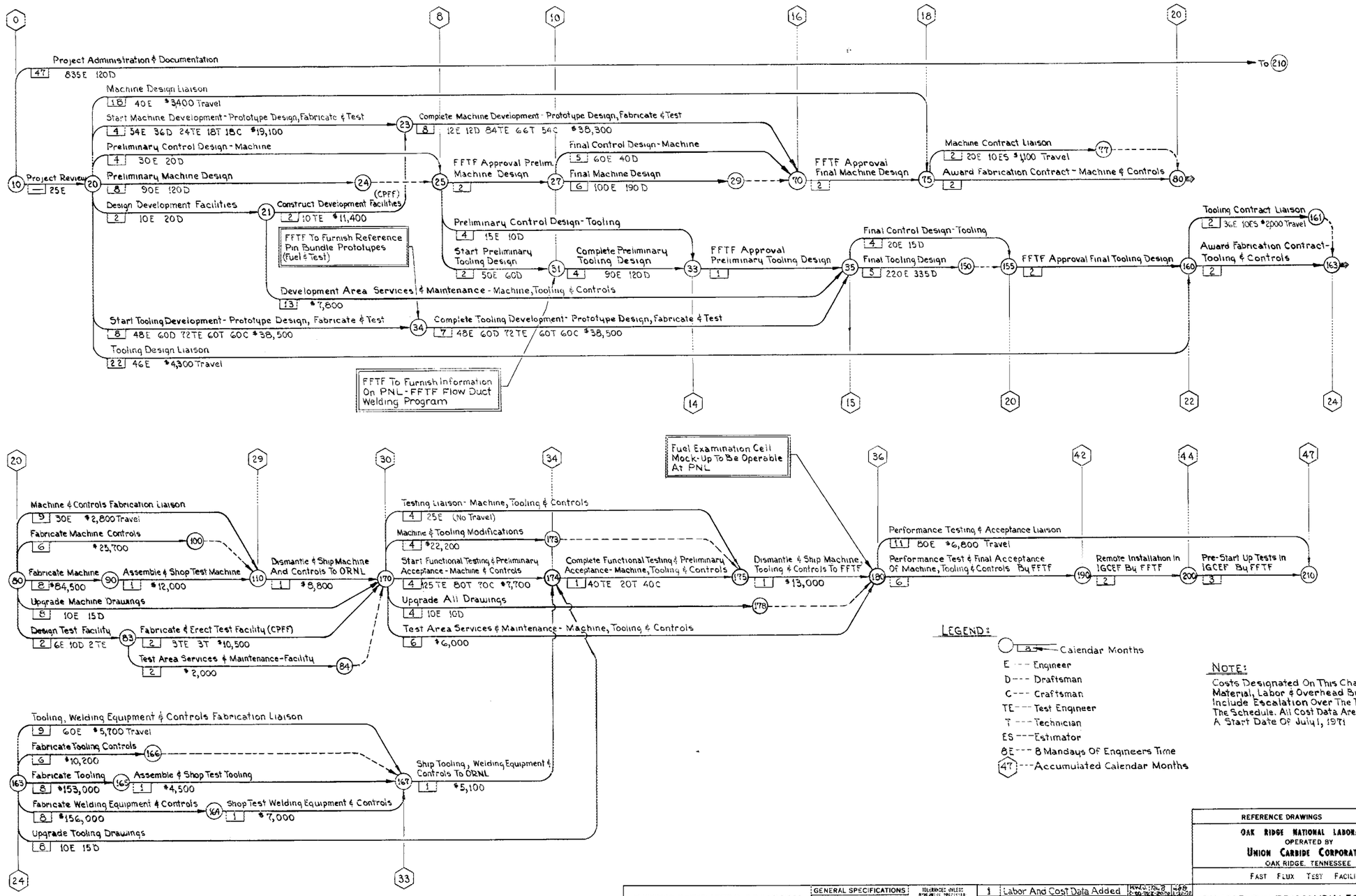
FAST FLUX TEST FACILITY

CONCEPTUAL DRE (33'-6" TALL)
DISASSEMBLY SEQUENCE FOR POISON TIP AND INNER REFLECTOR ASSEMBLIES

SUBMITTED: R. M. Beckers
ACCEPTED
APPROVED: H. J. Duggan

M	11325	EM	084	F	REV. L

PARTS LIST					
PART	DWG NO.	REQD	DESCRIPTION	STOCK SIZE	MATERIAL



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UNLESS OTHERWISE SPECIFIED:
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2. TYPE, GRADE, OR FINISH OF MATERIAL MAY BE CHOSEN BY FABRICATOR
3. MACHINED SURFACE FINISH SHALL NOT EXCEED: (ASA B46.1-1962)

TOLERANCES UNLESS OTHERWISE SPECIFIED
FRACTIONS ±
DECIMALS ±
ANGLES ±
SCALE:

NO.	REVISIONS	DATE	APPD	APPD
1	Labor And Cost Data Added			

DRAWN	DATE	SUBMITTED	DATE	APPROVED	DATE
H.W. Jinks	12-9-69				
DESIGNED	DATE	APPROVED	DATE	APPROVED	DATE
CHECKED	DATE	APPROVED	DATE	APPROVED	DATE
W.W. Worley	12-9-69				

REFERENCE DRAWINGS | NUMBER

OAK RIDGE NATIONAL LABORATORY
OPERATED BY
UNION CARBIDE CORPORATION
OAK RIDGE, TENNESSEE

FAST FLUX TEST FACILITY

DISASSEMBLY-REASSEMBLY EQUIPMENT
CRITICAL PATH SCHEDULE-2

SUBMITTED R. M. Peckar | ACCEPTED | APPROVED H. G. Duggan

M 11325 EM 085 F REV 1

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