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LASER DISASSEMBLY
SYSTEM ASSESSMENT
FOR THE
WASTE TECHNOLOGY SERVICE DIVISION

AUGUST, 1984

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LASER DISASSEMBLY SYSTEM ASSESSMENT - FINAL REPORT

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ABSTRACT

A system integration study of the Laser Disassembly Equipment for the Fuel Consolidation System was performed by the Westinghouse Advanced Energy Systems Division. The Laser Disassembly System consists of a Laser Generating Subsystem, a Laser Beam Transport Subsystem, and a Laser Focusing Subsystem. The objectives of this study were to:

- establish feasibility of a Laser Disassembly System for use in removing excess hardware of spent fuel assemblies.
- to perform canister cutting/welding operations.
- establish interfaces in conjunction with other proposed equipment.

The results of the study show that a laser cutting operation is feasible for this application. The Laser Disassembly System does interface with the Fuel Consolidation System meets the preliminary system design requirements.

1.0 INTRODUCTION AND SUMMARY

The Westinghouse Electric Corporation, Advanced Energy Systems Division, has performed a conceptual study of a Laser Disassembly System (LDS) for the Fuel Consolidation System (FCS).

The LDS was investigated to determine the feasibility of its application in the FCS. The function of this system is the removal of hardware from nuclear reactor fuel assemblies prior to further consolidation. The LDS is required to remove the PWR handling hardware and the inlet and handling hardware of BWR assemblies. In addition, the system is to provide the capability to cut/weld fuel canisters.

The LDS consists of three major subsystems: the Laser Generating Subsystem (LGS), which is the laser power source, alignment laser source, and the associated controls; the Laser Beam Transport Subsystem (LBTS), which directs the laser beam from the laser generator through the hot cell wall to the final focus mirrors; and the Laser Focusing Subsystem (LFS) consisting of two separate stations, which provides the required beam motion, laser beam focusing and focal point positioning of the laser beam to perform the required operations.

The scope of work for this study was limited to the LBTS, LFS and their Instrumentation and Control (I&C). The LGS was investigated only to the extent necessary for the required interfacing information.

1.1 Project Objectives

The feasibility and integration assessment of the LDS was performed by completing the following objectives:

- o Review of the Preliminary System Design Requirements (verbal).
- o Feasibility study of the LDS to determine compatibility with the FCS.

1.2 Summary

The LDS concept (Figure 1) studied consisted of three subsystems, the LGS, LBTS, and LFS. Each system was analyzed for materials, configuration, optical performance, interface relationships to other systems, and remote operation and maintenance.

The LGS must be capable of high power (several KW) and low power (several hundred watt) operation. This variation in power level is required to perform the various process operations identified.

The LBTS consists of water-cooled mirrors, hot cell window, beam protective enclosure, and the associated instrumentation that aligns and directs the laser beam from the LGS to the LFS. An approximate two-inch diameter laser beam from the LGS is transmitted through a four-inch diameter, water-cooled, zinc selenide (ZnSe) window in the hot cell wall. A manually indexable mirror also is provided to divert the beam to a target range in the plug gallery for diagnostic alignment testing. The two-inch diameter beam inside the hot cell is directed toward the LFS and is completely enclosed in a duct. Clean nitrogen gas is forced through the rectangular duct to exclude particulates on the mirrors and to prevent beam divergence from impurities in the beam transport environment. The LFS is connected to the duct in an open U-shaped section that covers the length of travel required by the LFS cutting sequences. The U-shaped duct is sealed by a retractable stainless steel ribbon attached to the LFS.

The LFS is a two-station concept. Station one's function is to remove excess hardware from spent assemblies. Station two's function is to cut/weld canisters.

The LFS (Figure 2) positions and focuses the laser beam. Ball screw drives position movable tables along the three major axes to provide the required locations and motions of the beam focal point. Four mirrors and two lens are mounted in the LFS to receive, turn, and focus the beam on the workpiece. The LFS proximity sensors controls and positions the LFS final focusing mirror to maintain the laser beam focal point-to-work surface relation. The LFS final

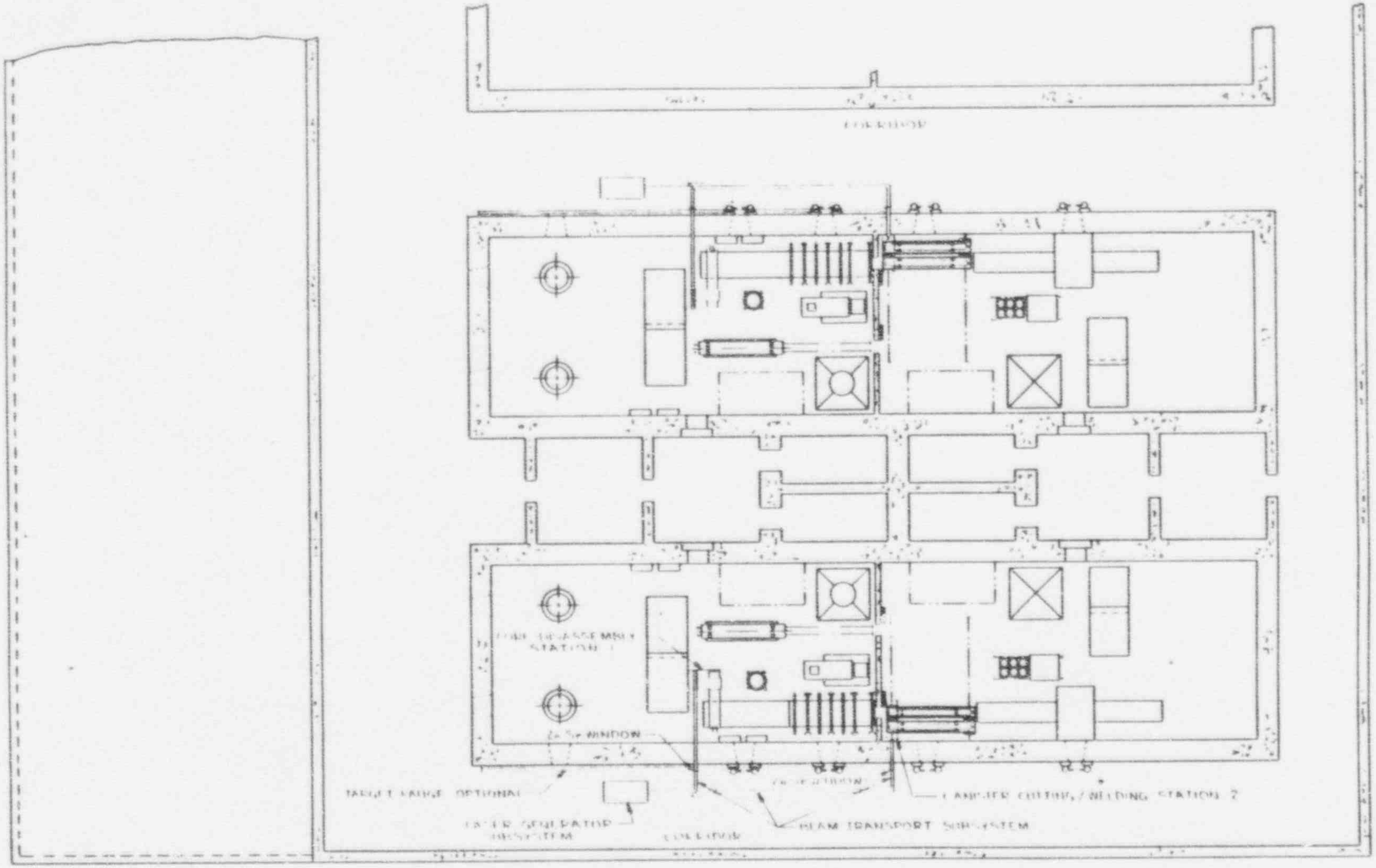


Figure 1. Laser Disassembly System Plan View in Fuel Consolidation System

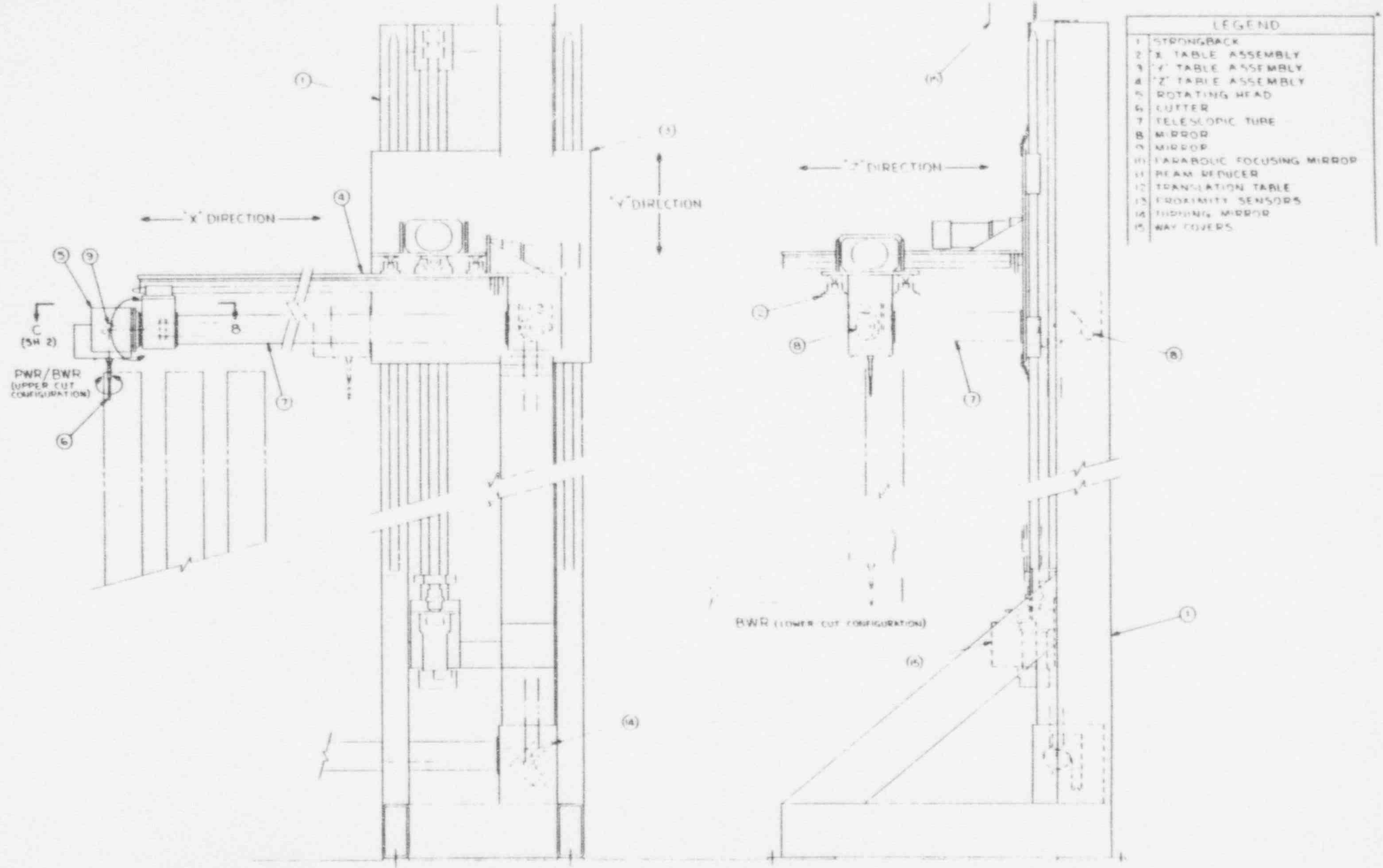


Figure 2. Laser Focusing Subsystem Layout

focusing mirror is rotated 360° to accomplish internal tube cutting. To perform external tube cutting, the LFS proximity sensors controls and positions via the X-Y-Z tables the focusing mirror. The canister cutting and welding station can be passively or actively controlled to perform the laser processing. Further review of this area is required to choose the optimum arrangement. A gas jet is provided to remove the molten kerf and to assist in cutting. A debris collection system concept still must be reviewed for applicability.

All mirrors in both systems are made of polished copper except for a tungsten final focus mirror. The fixed LBTS mirrors and lens are water-cooled to minimize thermal distortions. The LFS mirrors and lens are passively cooled due to the unreliability of flexible water-cooling lines and the increased maintenance.

The feasibility of the LFS for use in the disassembly operations was established. The results of the interface studies and beam accuracy analysis indicate that the LBTS and LFS will interface with the LCS and will provide the required beam focal point control.

2.0 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions resulted from the assessment of the LDS:

- The LDS concept meets the overall requirements and is overall compatible with the FCS with minor modifications.
- Further LDS/FCS system interface definition is required to finalize the concepts.

2.1 Recommended Areas for Future Development

The following developmental areas or confirmation tests are recommended in order of priority:

- Establishment or reconfirmation of engineering laser parameters at the workpiece for each process scenario
- Determine if a universal focusing mirror system is possible
- Experimentally verify stability of the final focusing mirror - divergence, transient thermal response, focal point movement, debris product degradation.
- Specify the laser generator system parameters including power levels, CW/pulsed operation.
- Determine adjacent fuel pin burn-through
- Establish system and subsystem interfaces
- Investigate and apply remote maintenance philosophy
- Conceptually design and configure the FCS/LDS Instrumentation and Control System

- Investigate the proximity sensors and their interface with the control system

- Investigate surveillance systems to monitor laser cutting operations

- Verify stability of ZnSe window concept

- Investigate remote laser alignment systems

3.0 TECHNICAL DISCUSSION

3.1 Scoping and Feasibility

The LDS scope and feasibility were assessed on the basis of criteria mutually agreed upon at program meetings.

An investigation into the reprocessing technology was conducted to determine the applicability of laser systems, arrangements, equipment, and methods of operation.

3.1.1 System Studies

System studies were accomplished in two discrete tasks; a detailed literature search and investigation of related fuel reprocessing and laser programs, and observation of existing laser facilities.

Information for the system studies was received previously from the following sources:

- Westinghouse Research and Development Center
- United Technologies Research Center
- AVCO Everett Metalworking Lasers
- SPAWR Optical Research, Inc.
- II-VI Incorporated

The study served as the basis for both recommending laser system equipment and evaluating system design requirements. In parallel AESD personnel visited Westinghouse Research and Development to observe and discuss laser facilities, laser auxiliary equipment, and laser operation. This background provided first hand knowledge of current laser operation and design technology.

3.2 System Description

3.2.1 General Features

The LDS concept is shown on Figure 1 and on Drawing H-3-54915, Sheet 7 and when integrated with the FCS, will provide the means for cutting and removing excess hardware. A complete drawing list of the LDS concept is provided in Appendix A. The LDS consists of three subsystems: the LGS, the LBTS, and the LFS. The LGS consists of two laser sources; a Bureau of Radiological Health (BRH) certified CO_2 laser source for cutting (and welding), and a HeNe laser source for system alignment. The LGS provides all the necessary power supplies, cooling, and beam controls necessary to direct the CO_2 and HeNe laser beams through the LDS and to produce a collinear CO_2/HeNe beam throughout the LDS. The LBTS performs the following functions: manipulates a CO_2 laser beam and a HeNe laser beam from the LGS in order to verify a collinear CO_2/HeNe beam for the intended travel limits of the LDS, transfers the beam through the hot cell containment boundary into the hot cell, and directs the beam once inside the hot cell to the LFS. The LFS provides the motions required to position the final focusing mirror to the assembly to be cut while maintaining the laser beam focal point-to-work surface relation.

A comparison of the LDS functional requirements and design features is presented in Table 1.

3.2.2 Materials

Materials used in the LBTS and LFS were recommended according to the component function and area of use in the LDS. For example, the LFS structure is fabricated of stainless steel; the mirror mounts and translation tables are commercial items made of aluminum; the hot cell and laser containment boundary is fabricated of ZnSe. Nuclear radiation levels in the cell require that the use of organic materials be considered on a case-by-case basis particularly with respect to electrical insulation, cables, lubricants, gaskets, seals, and commercially available components. Lubricants containing SF_6 or any fluorides should be reviewed on a case-by-case basis in the LDS area due to their adverse effect on the laser beam.

TABLE 1

LASER DISASSEMBLY SYSTEM FUNCTIONAL REQUIREMENTS AND DESIGN FEATURES

Functional Requirements	Design Features
o Provide Laser Power Source	o BRH Multi kW CO_2 Laser
o Provide Laser Alignment Source	o HeNe Laser
o Provide Hot Cell Containment	o ZnSe Window
o Limit Thermal Growth/Blooming	o Beam Transport Enclosure and Nitrogen Gas Flow
o Provide Beam Transport	o Mirror/Len System
o Maintain Laser Beam, Focus Point Manipulation and Location	o LFS - X,Y,Z, and θ Tables
o Provide Control and Monitoring of LDS	o Instrumentation and Control Proximity Sensors
o Remote Maintenance	o Modular Design, Lifting Bails, Guide Pins, and Remote Connectors
o Provide Gas Assist Jet for Laser Cutting	o Gas Assist Jet Through Final Focusing Mirror Nozzle
o Provide Laser Beam-On/Off Indication	o Wander Rings and Pyroelectric Sensors (as req'd)
o Interface with proposed FCS Equipment	o Preliminary Review With Proposed FCS Equipment
o Provide Laser Cutting System Beam Alignment Verification	o Target Range in Plug Gallery
o Collect Debris Generated During Cutting Operation	o Debris Collection Subsystem Req't To Be Determined

The recommendation of the mirror material was made after a comprehensive literature search and consultation with several laser optics manufacturers. The material recommendation was based on durability, reflectivity/absorbitivity, damage power threshold, thermal properties, and radiation degradation. Three materials (oxygen free copper, molybdenum, and tungsten) are currently used for industrial grade reflective optics. Their physical, mechanical, and optical properties are listed in Table 2. The reflected power produced by the CO_2 laser at the 10.6 µm wavelength is 99, 98, and 96% for copper, molybdenum, and tungsten mirrors, respectively. Neutron radiation degradation tests also were conducted on these three materials at Argonne National Laboratory. The results of these experiments show a decrease in reflectivity (increase in absorbitivity) for the copper material and no change in the molybdenum and tungsten mirrors at 632.8 nm visible wavelength. However, reflectivity measurements performed at the 10.6 µm wavelength showed no significant change.

In the LFS concept, water-cooling of the mirrors is undesirable because of the travel requirements of the LFS and complications caused by possible water leaks in the hot cell. The LFS mirrors must be cooled by the beam enclosure gas or other heat sink methods (heat pipes, thermoelectric devices, or finned base). The cooling requirements are, therefore, dependent on the mirror material. The literature search and consultations performed aided in the recommendation of copper for this mirror application. Copper was recommended because of its cost and availability. A thick copper mirror also was recommended to increase the mirror's heat capacity which reduces the mirror distortion during the cutting scenarios. However, copper has a low scratch resistance. Tungsten was recommended for the final focusing mirror due to its cleanability and maximum temperature limit.

Several alternatives were considered for the hot cell containment boundary which included an aerodynamic window, a ZnSe window, and alternate salt window concepts. The aerodynamic window provides its boundary protection by a positive gas flow through a mechanical opening through which the laser beam is transported. This concept configuration was not recommended because it does not provide a physical hot cell containment barrier. ZnSe, NaCl, and KCl window materials were also evaluated for this application since these

Table 2. Physical, Mechanical and Optical Properties of Industrial Grade Mirror Materials

Metals →	Oxygen Free Copper	Molybdenum	Tungsten
Physical Properties			
Density, lb/cu in.	0.323	0.37	0.70
Melting Temp °F	1981	4730	6170
Specific Heat (68°F) Btu/lb°F	0.092	0.065	0.034
Coef of Thermal Exp (68-572°F) in/in°F	9.8×10^{-6}	2.7×10^{-6}	2.5×10^{-6}
Thermal Conductivity (68°F), Btu/hr/sq ft/°F/ft	226	84.5	96.6
Electrical Resistivity (68°F) Annealed, microhm-cm	1.71	5.2	5.48
Mechanical Properties			
Modulus of Elasticity, psi	17×10^6	47×10^6	59×10^6
Tensile Stress 1000 psi	32-35	95	220
Yield Stress 1000 psi	10-11	82	220
Reduction of Area %	45-55	60	-
Hardness (annealed)	40-45 RF	250 VHN	450 VHN
Optical Properties			
Reflectivity 10.6 μm	99%	98%	96%
Cleanability	Poor	Good	Excellent

materials are widely used by many laser manufacturers for laser cavity containment. The NaCl and KCl salt materials cannot be exposed to water or humidity (corridor side) without degradation or without special coatings. Therefore, ZnSe was recommended for the window material for use in the LBTS.

3.2.3 Design Life

The recommendation of the components for the LDS is based on a plant life of 30 years at 60% availability. Remote servicing, removal, or replacement features have been recommended for those components and/or assemblies expected to require maintenance within the 30-year period. In specific instances, the LDS concept was based on the elimination of components to increase reliability, decrease servicing, and reduce the requirement for remote accessibility. Maintainability/reliability will be discussed in more detail in Section 3.2.5.

3.2.4 Laser Cutting System Operational Requirement

The LDS operational requirement for minimum throughput through all three cells is seven PWR fuel assemblies or ten BWR fuel assemblies per day (24 hour operation). The maximum throughput (based on 50% availability) is fourteen PWR fuel assemblies or twenty BWR fuel assemblies per 24 hour operation. The LDS Station 1 operational requirement for throughput per batch is three PWR fuel assemblies or seven BWR fuel assemblies. Each LDS subsystem was evaluated based on batch throughput. Details of each evaluation are provided in the respective sections of this report. The total batch laser cutting time for PWR assemblies is estimated in Table 3. The total batch laser cutting time for BWR assemblies is estimated in Table 4. No operational requirements were specified for Station 2 canister cutting/welding.

Sizing of components in each subsystem was based on the design life and operating rates required for maximum throughput. It was considered essential to apply both of these factors for the recommendation of the components in each subsystem.

TABLE 3

LASER CUTTING SEQUENCE FOR PWRs

Cutting Sequence	Velocity of Cutting Motion (IPM)	Power (kW) at Cutting Surface	Estimated Material Removal (0.030 width) (cubic inch)	Approximate Time (sec)
1. Stow Position				
2. Position for Upper Handling Attachment Cut (Locate First Tube and Insert Nozzle)	150 X, Z 60 Y	NA NA	NA NA	5 6
3. Rotate Cutter	150 (θ)	0.2	.001	1
4. Retract Cutter	60 (Y)	NA	NA	6
5. Repeat Steps 2, 3, 4 23 times	---	--	.022	414
6. Proceed to Second Assembly and Repeat				5 427
7. Proceed to Third Assembly and Repeat				5 427
Total Time				1296 sec 21.6 min

TABLE 4

LASER CUTTING SEQUENCE FOR BWRs

Cutting Sequence	Velocity of Cutting Motion (IPM)	Power (kW) at Cutting Surface	Estimated Material Removal (0.030 width) (cubic inch)	Approximate Time (sec)
1. Stow Position				
2. Position for Upper Lifting Attachment Cut (Locate First Tie Rod).	150 X, Z 60 Y	NA NA	NA NA	5 6
3. Oscillate Cutter	100 X	0.5	0.004	5
4. Retract Cutter	60 Y	NA	NA	6
5. Repeat Steps 2, 3, and 4 Seven Times.	--	--	0.028	154
6. Proceed to Second Assembly and Repeat.			0.030	176
7. Proceed to Third Through Seventh Assembly and Repeat (5 Additional Assemblies).			0.150	880
8. Retract to Stow Position, Horizontally Position BWR Assemblies.				300
9. Reposition LDS to Lower Elevation for Lower Attachment Cuts.				100

TABLE 4 (Continued)

Cutting Sequence	Velocity of Cutting Motion (IPM)	Power (kW) at Cutting Surface	Estimated Material Removal (0.030 width) (cubic inch)	Approximate Time (sec)
10. Cut Eight Tie Rods per Assembly, Total of Seven Assemblies.			0.21	1232
11. Position LDS to Stow Position.				100
TOTAL TIME				2864 sec 47.7 min

3.2.5 Maintainability/Reliability

Maintainability/reliability is achieved in a final product through a totally integrated effort starting at the system concept level and carried out through detailed component design. The level of success is dependent upon the designer's experience and knowledge of systems and hardware. The concept evaluated combines system requirements, arrangements, and features as the initial effort to attain the life, reliability, and maintainability design goals.

The approach taken regarding maintainability and reliability was to design all "in cell" equipment for remote maintenance (modularization), minimize the need for servicing, utilize existing "state of the art" technology, and provide single function type equipment to the extent practicable.

Specific examples of this approach are embodied in the review of each subsystem. For example, the LBTS and LFS are an assembly of modular groups of components. Thus, a malfunctioning item is replaced with its module. Each module can be remotely removed and replaced by removing bolts, nuts, and/or releasing clamps. All major components and modules will be provided with lifting bails, locating pins, and remote coupling devices.

The Remote Disassembly System, recently designed and installed by WAESD at the Oak Ridge National Laboratory, is a prime example of the above maintenance philosophy (see Figure 3).

3.2.6 Cabling

Various methods of reducing the amount of hot-cell cabling were considered, including optical and frequency modulated transmission of signals. The decision to recommend a wired system was based on the unreliability of the transmission equipment in a high radiation environment.

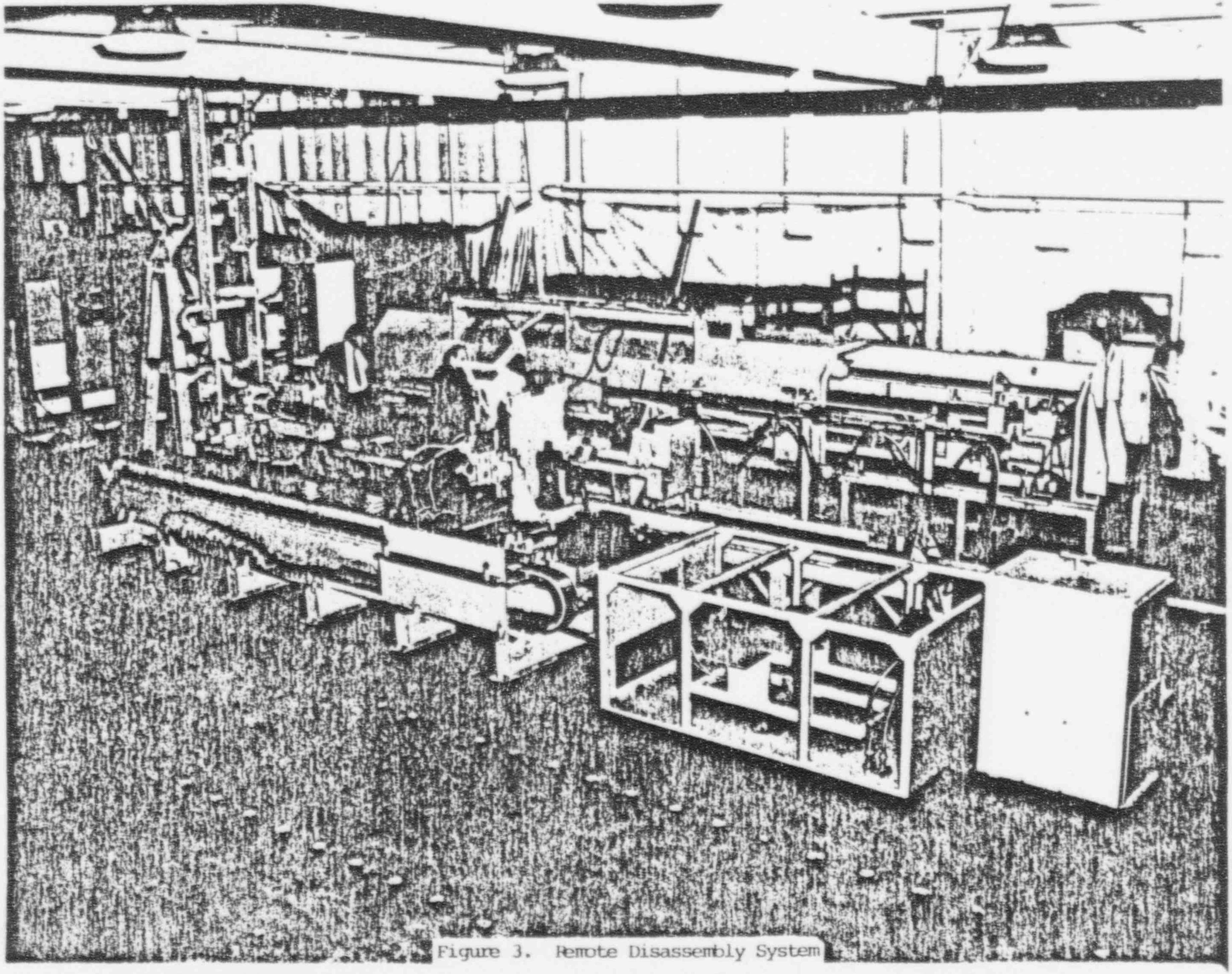


Figure 3. Remote Disassembly System

3.2.7 Laser Disassembly System Interfaces

The LDS functions within certain design and interface constraints. The following discussion assesses the key interface assumptions and their effect to the overall LDS concept.

The LDS as shown in Drawing H-3-54915, Sheet 7 must interface with the proposed FCS corridor, hot cell containment wall, and the hot cell with its associated equipment. The major interface constraint of the LDS is the length of beam travel. The LBTS beam travel and cell gas environment will influence the LFS mirrors size and final focusing mirror arrangement. The final focusing mirror arrangement will in turn affect the cutting or focal point qualities (e.g., waist, depth of focus, power density, etc.). The laser beam transport distance from LGS to either station's focal point is less than 75 feet. The natural divergence of the laser beam was estimated to increase the 2.0-inch diameter beam to 3.0-inch diameter at the focusing mirror using experimental CO_2 laser beam divergence data. Since the hot-cell environment may contain contaminant detrimental to the LDS operation, a recommendation was made to fully enclose the beam from the LGS to the LFS and to provide a continuous, clean nitrogen gas flow. This beam enclosure with nitrogen gas flow will reduce thermal blooming effects. In addition, the LDS equipment was located to minimize laser beam travel to limit the effects of thermal growth, blooming and divergence. The second major interface is the size and space constraint of Station 1 and Station 2 and how the LDS equipment interfaces with the FCS layout.

3.2.7.1 General Laser Cutting Processing Description

Two types of fuel, PWR and BWR, will be processed by the integrated laser and disassembly systems.

LASER CUTTING OF PWR ASSEMBLIES

The procedures for processing a PWR-type fuel assembly are shown in Table 3 and described in the following sequence:

- The LFS is positioned using proximity sensors for the upper handling attachment cut. The final focusing mirror is positioned interrally into a tie rod. The tie rod is cut internally. This is repeated for each tie rod (maximum number 24).

- The LFS is then repositioned for the other PWRs (total of three) and the above operation is repeated.

LASER CUTTING OF BWR ASSEMBLIES

The procedures for processing a BWR-type fuel assembly are described in the following sequence:

- The LFS is positioned for the upper lifting attachment cut. The eight tie rods are cut individually externally by positioning the LFH with X, Y, Z, θ table motions.

- The LFS is then positioned for the next BWR. The above step is then repeated.

- The above two steps are then repeated six times (total of seven assemblies).

- The BWRs are then placed in a horizontal position.

- All pins are extracted approximately two inches, except for the eight tie rods per assembly.

- The LFS is lowered and positioned to cut the eight tie rods per assembly for all seven assemblies.

3.2.7.2 Laser Generating Subsystem

The key interface constraints of the LGS are power, gas supply, and equipment floor area and height requirements in the corridor and the LGS beam quality, size, shape and power density.

3.2.7.3 Laser Beam Transport Subsystem

The LBTS interfaces with the LGS, hot cell containment, and the LFS. The key interface of the LBTS is the hot cell containment window. The window concept affects the LGS in energy backscatter to the LGS, the realignment and collinearity of the LGS laser beams (CO_2 and HeNe), and the LGS power level versus the allowable time of operation. The window concept directly affects the hot cell containment. The second key interface of the LBTS is the length of laser beam travel. The length of beam travel directly affects the beam quality transferred to the LFS. The LBTS also interfaces with the test range which verifies collinearity of the LGS laser beams.

3.2.7.4 Laser Focusing Subsystem

The LFS interfaces with the FCS, LBTS, LGS and core assemblies. The major interface constraints are with the FCS. These constraints are shown on Drawings H-3-54914 and H-3-54915. The FCS Downender and Canister Station limits the LFS height, length, and structural features.

The different core assembly shapes, sizes, and variety of materials are the second major interface constraint. The LFS will remove specified material from various spent fuel. As these assemblies have different sizes, heights, guide tubes, each assembly affects the universality of the laser cutter (see Table 5).

Last, in Station 2, the canisters shapes, sizes, location and support equipment affect directly the design of the Station 2 cutter/welder. Furthermore, equipment (both LCS/FCS) size and shape constraints must be evaluated to ensure total system interface.

The LFS interfaces with the LBTS through the LBTS beam enclosure concept and the laser beam location, shape, size and power distribution. The LGS interfaces with the LFS indirectly by supplying the CO_2 and HeNe laser beams.

Table 5

PWR Thimble and Guide Tube I.D. Variations

Manufacturing & Array	O.D. (inch)	Wall (inch)	I.D. (inch)	No. Tubes	Notes
Babcock & Wilcox					
15x15 (G)	.530	.016	.498	16	See Sample Cal
(I)	.493	.026	.441	1	
17x17 (G)	.465	.0175	.43	24	
(I)	.420	.015	.39	1	
Combustion Engineering					
15x15 (G)	1.115	.040	1.035	4	
(I)	.440	.026	.338	1	
14x14 (G)	1.135	.030	1.075	4	.....Largest
(I)	.440	.026	.338	1	
(G)	1.115	.030	1.055	4	
(I)	.440	.026	.338	1	
16x16 (G)	.97	.035	.90	4	
(I)	.382	.025	.332	1	
(G)	.98	.035	.91	4	
(I)	.382	.025	.332	1	.....Smallest
Westinghouse					
14x14 (G)	.539	.034	.471	16	
(I)	.539	.034	1		
(G)	.4805	.034	.4125	16	
(I)	.539	.034	.471	1	
15x15 (G)	.543	.012	.519	20	
(I)	.543	.012	.519	1	
(G)	.478	.012	.454	20	
(I)	.543	.012	.519	1	
(G)	.545	.015	.515	20	
(I)	.545	.015	.515	1	
(G)	.484	.015	.454	20	
(I)	.545	.015	.515	1	
17x17 (G)	.482	.016	.450	24	14' Core
(I)	.545	.015	.515	1	
(G)	.429	.016	.397	24	14' Core
(I)	.545	.015	.515	1	
17x17(L) (I)	.482	.016	.450	1	
Exxon Refills					
14x14 (G)	1.115	.036	1.043	4	
(I)	1.115	.036	1.043	1	
15x15 (G)	Information N/A				
(I)	.417	.027	.363	1	
15x15 (G)	.544	.017	.510	20	
(I)	.544	.017	.510	1	
17x17 (G)	.480	.016	.448	24	
(I)	.480	.016	.448	1	

SAMPLE CALCULATION: ID = OD-2X Wall Thickness
.530-2X .016 = 0.408

3.2.7.5 Laser Disassembly System Instrumentation and Control

The instrumentation and controls of the LDS are designed for integration and supervision from an overall plant Data Acquisition and Control System (DACS). The LDS Process Unit Controller (PUC) incorporates microcomputer control of the system that minimizes the usage of memory and computational requirements necessary within the DACS components.

A general block diagram showing the integration of the LDS into the DACS architecture is shown in Figure 4. The Local Instrumentation System (LIS) supplies the PUC with positioning and operational information. The PUC uses the information to initiate system operation and control system data. The information within the PUC is available to the DACS via the data bus highway. The information will be used by the DACS for archival/analysis functions necessary at the plant level. The PUC initiates and supervises all functions, controlling directly the slow and medium speed operations. Functions of a high speed nature and those which require precision positioning will be controlled by components within the LIS. These component functions are initiated and analyzed by the PUC. The LDS PUC must interface with other system PUC's to satisfy any data transfer requirements that are too fast for the DACS data highway. These interfaces represent both operational data and system statuses necessary to implement operational logic interlocks between systems. These interlocks ensure safe and proper operations of the FCS. In the event of an interlock malfunction, the LDS operation is halted while operations personnel are informed through the DACS to diagnose and correct the malfunction.

3.3 Laser Generating Subsystem

The function of the LGS is to provide a BRH certified CO_2 laser source for cutting and a HeNe laser source for LDS alignment. The LGS provides all the necessary power supplies, cooling and beam controls to direct the CO_2 and HeNe laser beams to the LBTS and produce a collinear CO_2/HeNe beam throughout the LDS. In the study, the LGS was reviewed with respect to beam size and quality requirements, equipment space, and FCS location requirements. A further discussion of the LGS is given in Appendix B.

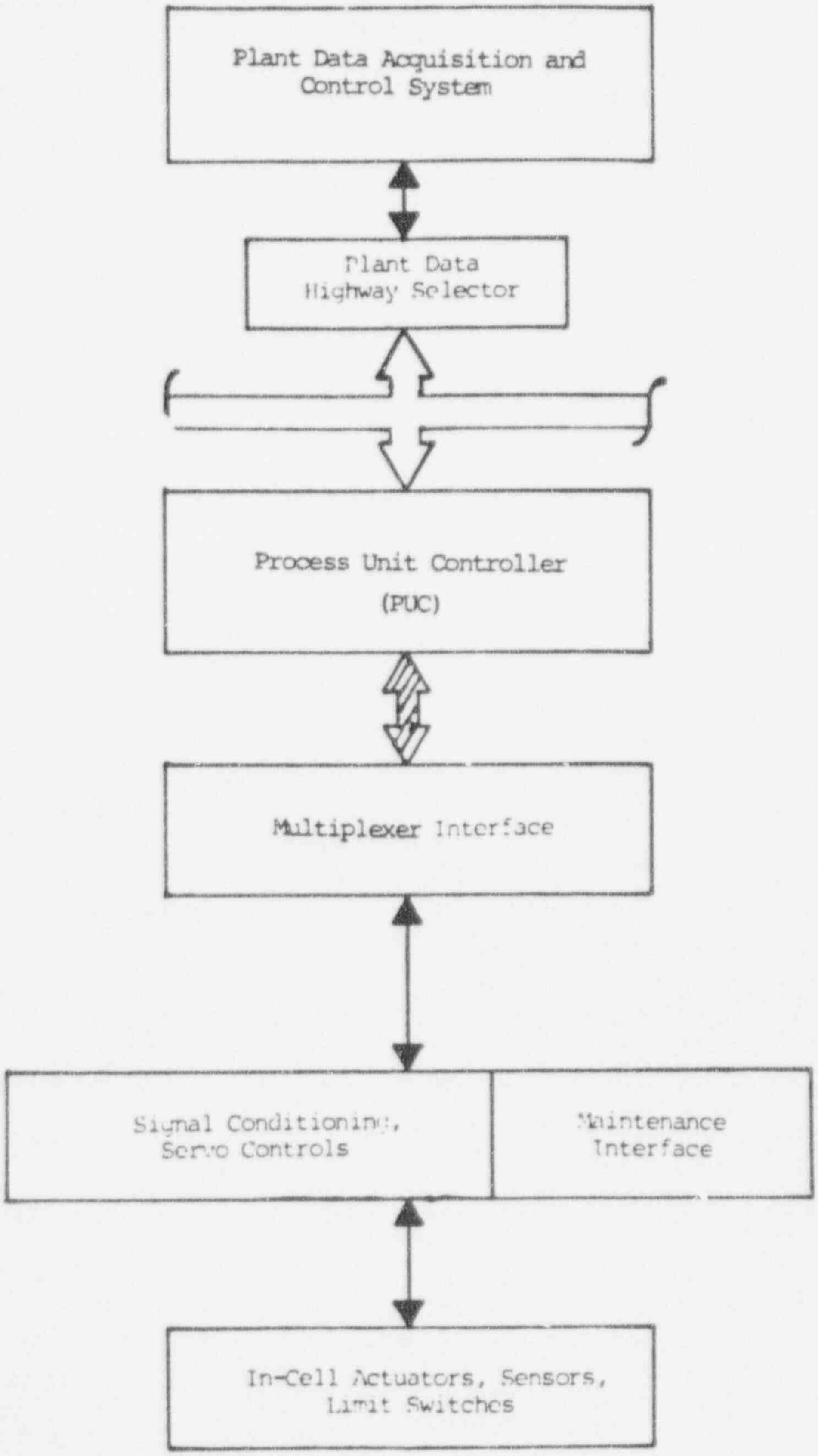


Figure 4. Laser Cutting System Instrumentation and Control Architecture

3.4 Laser Beam Transport Subsystem

The LBTS function is to transport a CO_2 and a HeNe laser beam from the LGS to the LFS. The LGS is located in the corridor (manned access area) and the LFS is located in the hot cell. The corridor and hot cell are separated by a concrete wall. The proposed corridor/hot cell equipment layout is shown in Drawing H-3-54915, Sheet 7. The CO_2 laser beam will be used for the laser cutting operations and the HeNe laser beam will be used for laser beam system alignment.

The LBTS shown in Drawing H-3-54915 includes three main areas: a ZnSe window concept, an in-cell turning mirrors (as required), and a beam enclosure concept.

3.4.1 ZnSe Window Concept

The function of the ZnSe window concept is to retain the hot-cell containment integrity and provide of a collinear CO_2/HeNe beam alignment verification. In the ZnSe window concept, the laser beam from the LGS is transported through the ZnSe window (hot-cell containment boundary) and then through the 6-foot concrete wall into the hot cell. For the collinear CO_2/HeNe beam alignment and verification a target range turning mirror is placed in the beam path. The CO_2 and HeNe laser beams are directed from the target range turning mirror down a target range for collinear beam alignment verification. Also included in the ZnSe window concept are: alignment target, wander rings as required, a moisture detector, and shutters covering all penetration to permit maintenance. The ZnSe window concept will be designed for hands-on maintenance through a glove box that was integrated into the concept. The glove box has the required ports and storage space for replacement components.

The laser beam/mirror alignment is performed using both HeNe and CO_2 laser beams and the mirror targets. Initial beam/mirror alignment will be accomplished using the HeNe laser beam while final verification will be done with a low power CO_2 laser beam. In order for the LDS alignment to be performed and verified, a collinear HeNe and CO_2 laser beam is required. However, if ZnSe window surface cannot be perfectly aligned perpendicular to the laser beams, the HeNe and CO_2 beams will be misaligned beyond the ZnSe window, since the transmissive optical properties (index of refraction) of the ZnSe window are different for both the HeNe and CO_2 laser beams. The index of refraction value for the HeNe (632.8 nm) and CO_2 (10.6 μm) laser beams are 2.59 and 2.405, respectively. Therefore, this CO_2/HeNe beam misalignment requires provisions to be made by the LGS to collimate the CO_2 and HeNe beams beyond the ZnSe window.

The collinear HeNe and CO_2 laser beam alignment can be verified using a target range located in the corridor, which has the same beam transport distance as the LCS. The two collinear laser beams are directed down the target range by an indexable (45° rotation) target range turning mirror. This target range turning mirror is a flat, water-cooled, copper mirror.

3.4.2 In-Cell Turning Mirror Concept

The function of the in-cell turning mirror concept is to transport the laser beam from the ZnSe window (corridor) to the LFS and to provide radiation shielding. An in-cell turning mirror concept, shown in Figure 5, contains an in-cell turning mirror (M1), hot-cell penetration shield plug, beam enclosure, and shielding as required to prevent streaming through the four-inch diameter hot-cell penetration during LDS and FCS operation.

3.4.3 Beam Enclosure Concept

The LBTS beam enclosure concept provides a containment barrier that permits the laser beam to be transported through a clean nitrogen gas environment. The clean nitrogen gas environment will limit the thermal growth/blooming of the laser beam over the transport distance. The nitrogen supply will be provided by TBD. The LBTS beam enclosure is a "U"-shaped channel supported in the LFS. The LFS moves within the LBTS enclosure throughout the LFS Drive travel. The LBTS beam enclosure provides an effective enclosure throughout the LFS travel by using a retractable stainless steel ribbon in conjunction with the U-shaped channel.

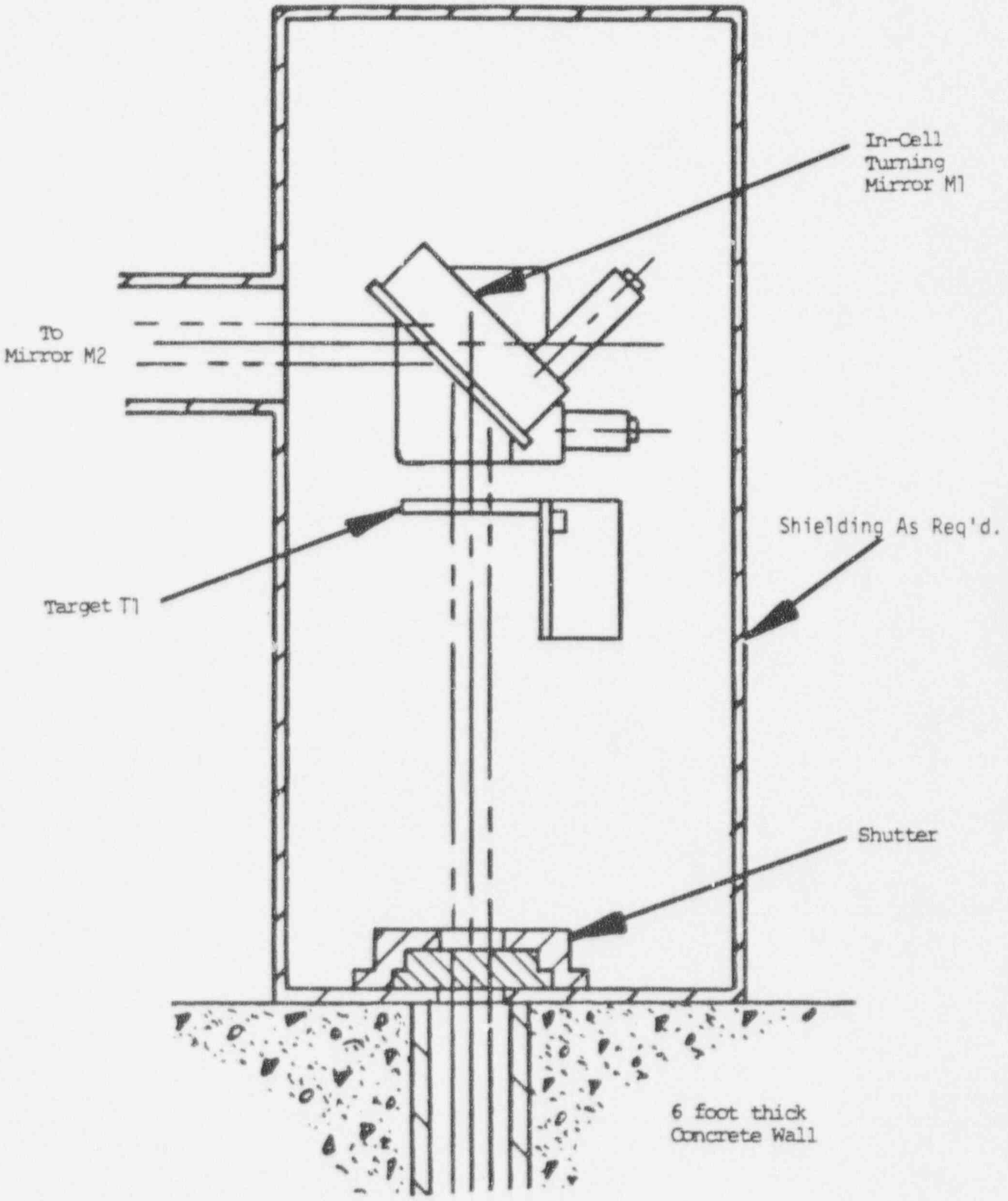


Figure 5. Laser Beam Transport Subsystem In-Cell Turning Mirror Concept

3.5 Laser Focusing Subsystem

The LFS directs a laser beam from the LBTS and focuses the beam on the spent fuel assembly surface to perform the required cutting operations prior to fuel consolidation (see Drawing H-3-54915). Throughout the cutting operation, the LFS controls the placement of the laser beam focal point-to-work surface relation for optimum cutting performance. This is accomplished by utilizing a fuel assembly surface proximity sensors.

The LFS concept consists of the following subcomponents: focal point positioning using a combination of X, Y, Z, and θ movable tables positioned by ball screw drives; an active head follower; and final focusing mirror module.

APPENDIX A

DRAWING LIST

H-3-54914	Sheets 1 through 2	Material Handling Fuel Consolidations System Equipment General Assembly
H-3-54915	Sheets 1 through 10	Material Handling Fuel Consolidations System Laser Disassembly Equipment

APPENDIX B

From R&D CENTER
WIN 236-1645
Date August 16, 1984
Subject LASER CUTTING SYSTEM ASSESSMENT

To WALTZ MILLS

Dan Racki

The purpose of this document is to summarize my comments regarding the feasibility of using laser cutting/welding techniques in the Fuel Consolidation System (FCS) that is under development. The types of laser operations involved in this application include: a) internal cutting of thin-walled metal tubes in PWR fuel assemblies; b) cutting of several small diameter metal rods (nominal 3/8 in. diameter) in BWR fuel assemblies; and c) cutting/welding the end caps on the metal canisters in which the fuel rod elements are enclosed. These operations are rather diverse, requiring significantly different laser power levels and optical systems and one must determine whether a single laser generator system (LGS) will perform all the functions.

In this application one is working with highly radioactive materials and the usual requirements for remote operation and maintenance must be followed. You are familiar with these procedures, having worked on the Remote Disassembly System for the Oak Ridge National Laboratory, and thus these matters need not be considered further at this time.

One of the most challenging laser operations in this application is the internal cutting of the thin-walled metal tubes in the PWR assemblies. In this operation a small diameter tube containing the appropriate focusing optics is inserted into each tube to be cut and caused to rotate. The laser beam is transported along this tube, strikes the focusing optics, probably an off-axis parabolic mirror, and is focused onto the inside wall of the tube being cut. Your drawings H-3-54915 Nos. 1, 2 and 3 show some of the details of the system proposed for this operation.

Discard Date

It is of interest to examine the laser beam focusing system used in this operation. After the laser beam is transported to the focus head via the X-Y-Z orthogonal motion assembly, see drawing H-3-54915 No. 1, it is first reduced in diameter by the lenses, 11, in drawing H-3-54915 No. 2, deflected through 90° by mirror 9, enters the beam tube 6 and is finally focused by the mirror 10. (The focus head is capable of two degrees of rotation about orthogonal axis to first orient the beam tube 6 and then rotate the mirror 10 to facilitate cutting the metal tubes in question.) All of the optical components used in this operation are themselves state-of-the-art, however their integration into a functioning system represents a challenge.

It is my understanding that the wall thicknesses of the PWR tubes to be cut are in the range 0.020 to 0.040 in. The CO_2 laser beam energy required to cut such tubes is in the range 100 to 200 watts with cutting speeds of 50-100 in/min. We shall assume that the inside diameter of the beam tube 6 is 0.25 in. and thus the laser power density on the focusing mirror 10 is of the order 350 to 700 watt/cm^2, which is within the normal limits for metal mirrors.

The off-axis parabolic focus mirror 10 must have a very short focal length since it is necessary to focus the laser energy transported through the beam tube 6 onto the inner surface of PWR tubes that are only slightly larger than the beam tube itself. Insofar as fabrication of mirror 10 is concerned, this does not represent any real problem. A major problem does occur however in the use of such a short focal length mirror due to the significant amount of debris that will be produced in the cutting operation. Some of this debris may settle on mirror 10, causing higher laser energy absorption by the mirror and possible damage to the surface. Some means of gas flow to flush away this debris must be provided.

It is highly recommended that this focusing mirror be fabricated of tungsten, since this material is more easily cleaned and can be operated at high temperatures. It may, in fact, be desirable to consider purposely operating the system with the focus mirror quite hot, several hundred degrees Fahrenheit. Under this condition, the debris will not tend to condense on the mirror surface, and satisfactory operation may be achieved with little, or no cooling gas flow. (This approach requires further study to determine its feasibility.)

I have been advised that in the process of cutting the tubes in the PWR assemblies, one does not want to "burn-through" adjacent tubes of the assembly. Since the mirror 10 has a very short focal length and subsequently a short depth of focus, the potential for damaging adjacent tubes should be small and "burn-through" should not occur.

A second challenging laser operation in this application is the cutting of the 8 solid metal rods in the BWR assemblies as shown in drawing H-3-54915 No. 4. For this operation one would like to use the laser beam focusing system described above. However several changes would be required in this system before it could be used in this operation. First it would be necessary to replace the focusing mirror with one having a longer focal length in order to have the depth of field to cut through the rods. Secondly it will be necessary to increase the laser beam power for this operation. This change, in turn, may require a large beam tube, 6, and a different beam reducer system, 11. By use of a modular system it should be possible to make these changes remotely with no difficulty.

In the cutting of the solid rods in the BWR assemblies it may be necessary to make several passes before the rods are cut through. In this operation I assume that the laser beam focus system will oscillate back and forth in a direction parallel to the axes of the rods to be cut. With each pass the focus head may advance toward the rod, thus keeping the laser beam focus spot at the bottom of the cut that is being made in the rod. The extent to which one must resort to this back and forth motion depends on the laser power used and is a parameter to be determined later.

The laser cutting/welding operations at the ends of the canisters as shown in drawings H-3-54915 Nos. 5, 6 and 10 are straightforward and do not present any major technical problems. The optical systems used in these operations are state-of-the-art and the off-axis parabolic focusing systems shown in the drawings should perform satisfactorily.

It is assumed that the wall thickness of the canisters is in the range 0.3 to 0.4 in. The corresponding laser power required to cut/weld the canisters is about 2 to 4 kW and the expected travel speed is 20 to 50 in/min. The optimum paramters for these operations will need to be determined at a later time.

In this application one would prefer to use only one laser generator system. From the discussion above it is clear that this laser must be capable of producing output powers of several kilowatts. Generally speaking, lasers of this type will not operate satisfactorily at the lower powers, 100 to 200 watts, required for the internal cutting of the PWR tubes. Furthermore, it may be desirable in these latter operations to use a pulsed, rather than cw, laser output. This mode of laser operation may not be possible with laser generators that can produce multi-kilowatt outputs. On the basis of this discussion it may be necessary to consider the use of two different laser generators to satisfy the required cutting/welding operations.

Before choosing the laser generators, one should conduct further studies to see if a single generator that will fulfill the requirements can be found. One should try to work at the lowest powers that can feasibly be used for the cutting/welding of the canisters. (It may be possible tc perform these operations at 1500 watts if a lower travel speed is used.) By working with the lowest power laser generator system, it may be feasible to obtain a unit whose output power can be reduced to the range required for the internal tube cutting. Furthermore, such laser generators may be able to operate in a pulsed mode. Candidate laser generator systems that immediately come to mind are the 1000-1500 watt lasers manufactured by Coherent and Photon Sources.

If it is necessary to use a multi-kilowatt laser generator having a "fixed" output power, it may be desirable to investigate the use of beam splitters and/or beam apertures to reduce the laser power delivered to the work station. Through the use of beam limiting apertures it may be possible to simplify the optical component change required to go from the internal tube cutting operation to the rod cutting operation on the BWR assemblies. In earlier discussion it was noted that the beam condensing lenses, 11, of drawing H-3-54915 No. 2, would have to be changed in going from one of these operations to the other. If apertures are used to control beam power, it may not be necessary to change these lenses.

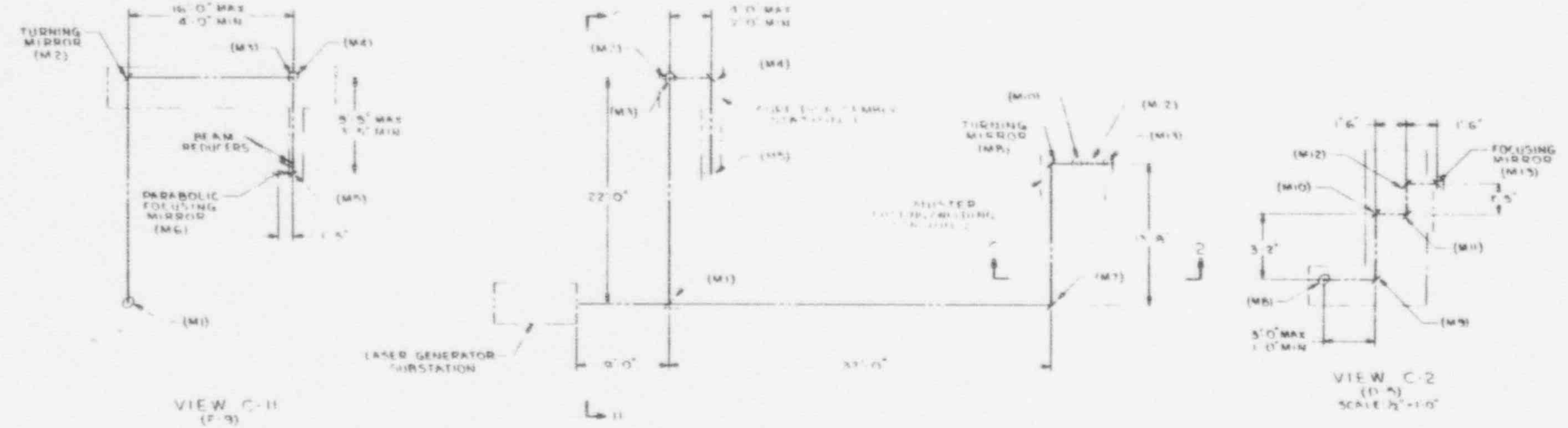
In summary, it is my opinion that all of the laser assisted operations presently envisioned in the FCS are feasible. In some cases it will be necessary to conduct additional studies to determine the appropriate operating parameters. Careful consideration must be given to the laser beam transport system and to the requirements for remote operation and maintenance. In the design of the FCS one must carefully consider the placement of all components, including the laser generator. The laser generator and its auxiliary hardware should not be relegated to an "isolated corner" of the facility. Its positioning impacts the required beam transport system and the overall successful functioning of the FCS.

W. H. Kasner

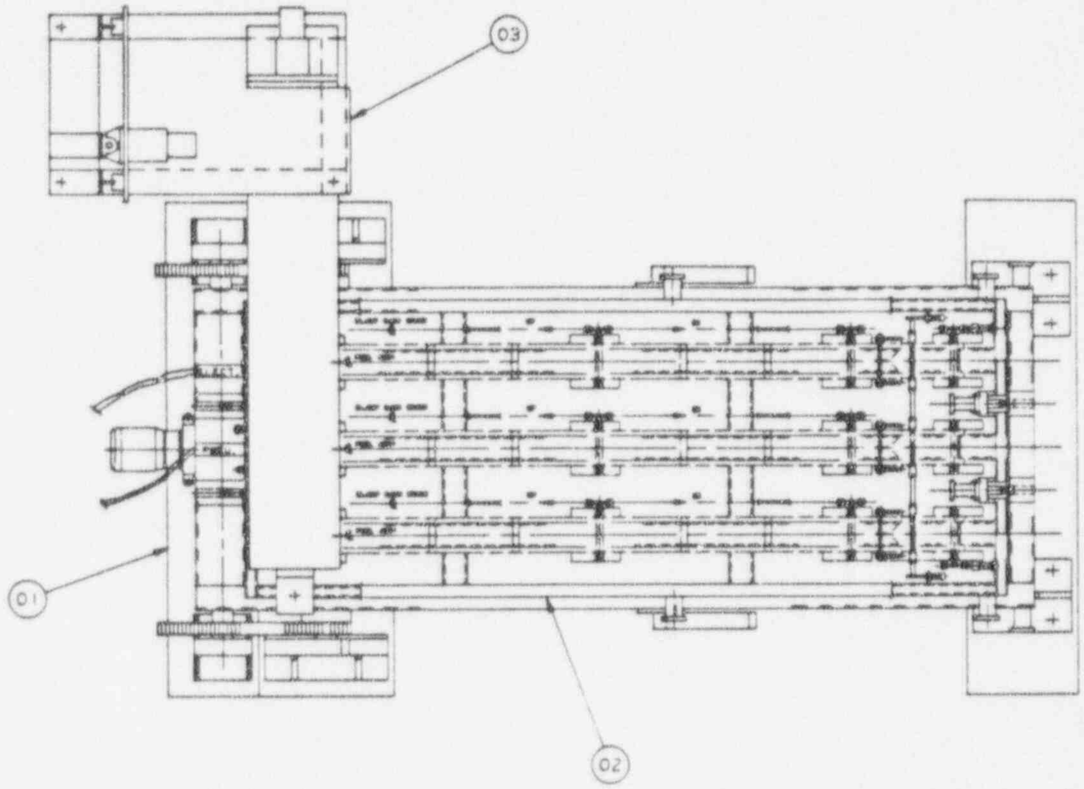
W. H. Kasner
Directed Energy Research

svb

APPENDIX C
ILLUSTRATIONS



LASER BEAM TRANSPORT SCHEMATIC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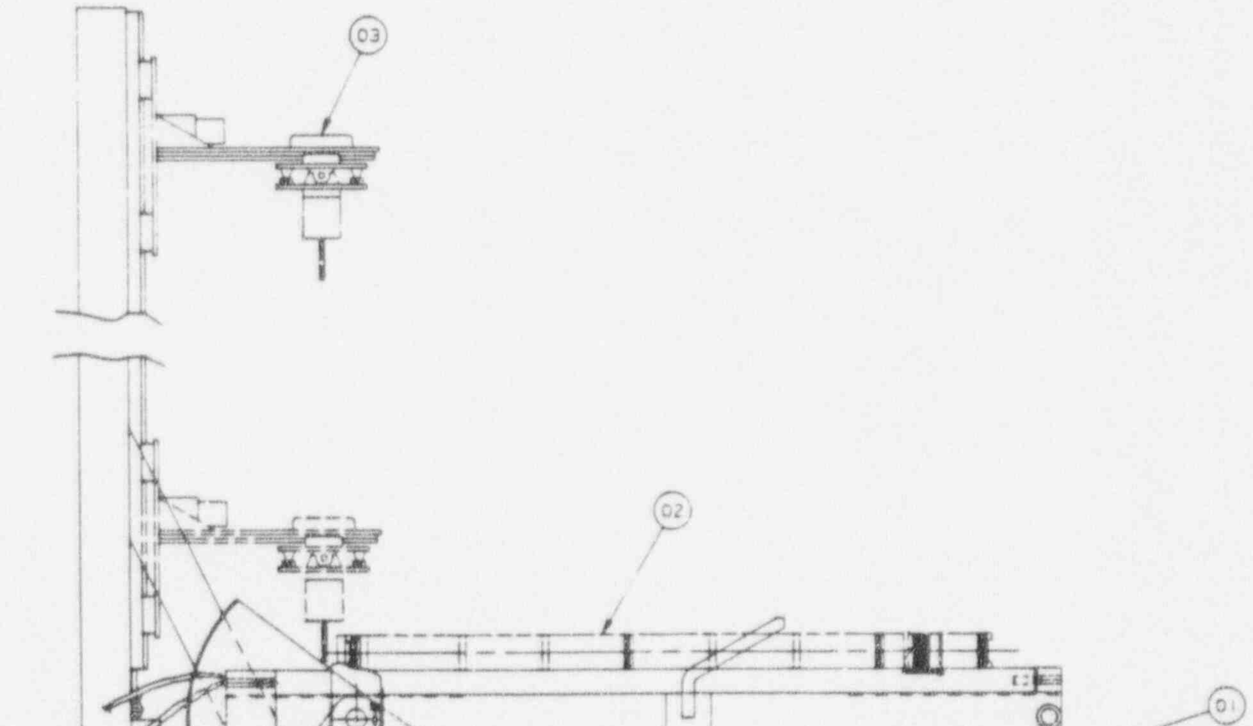
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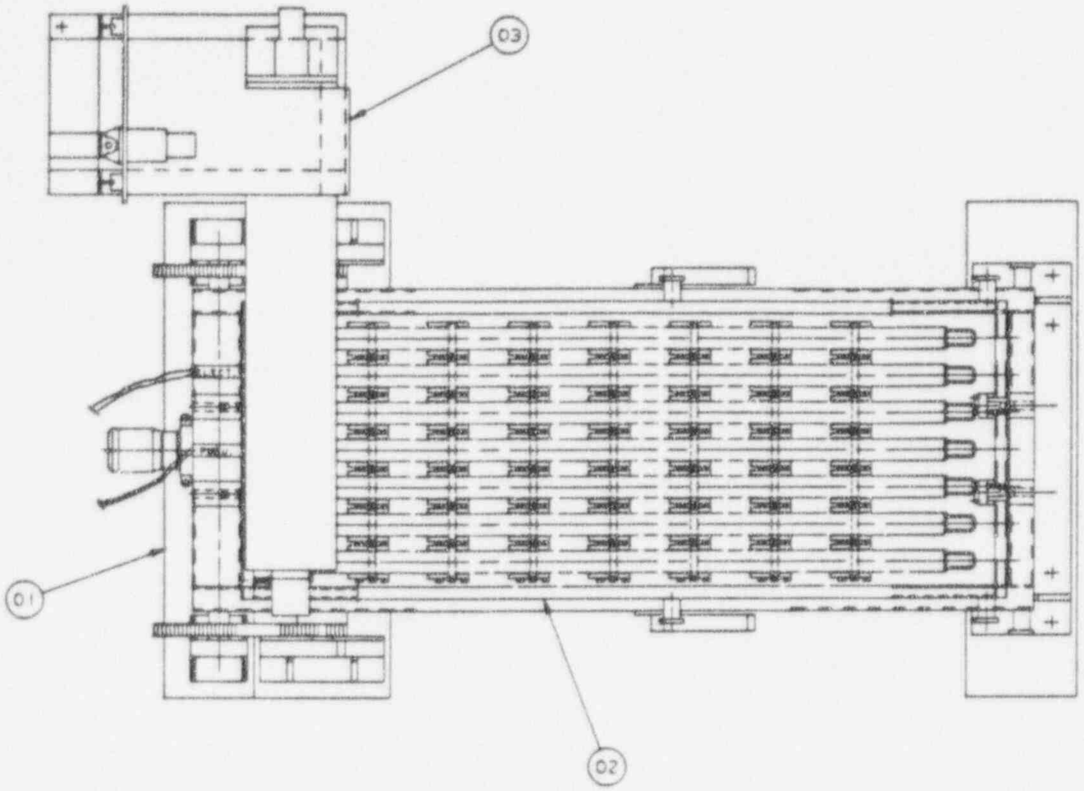
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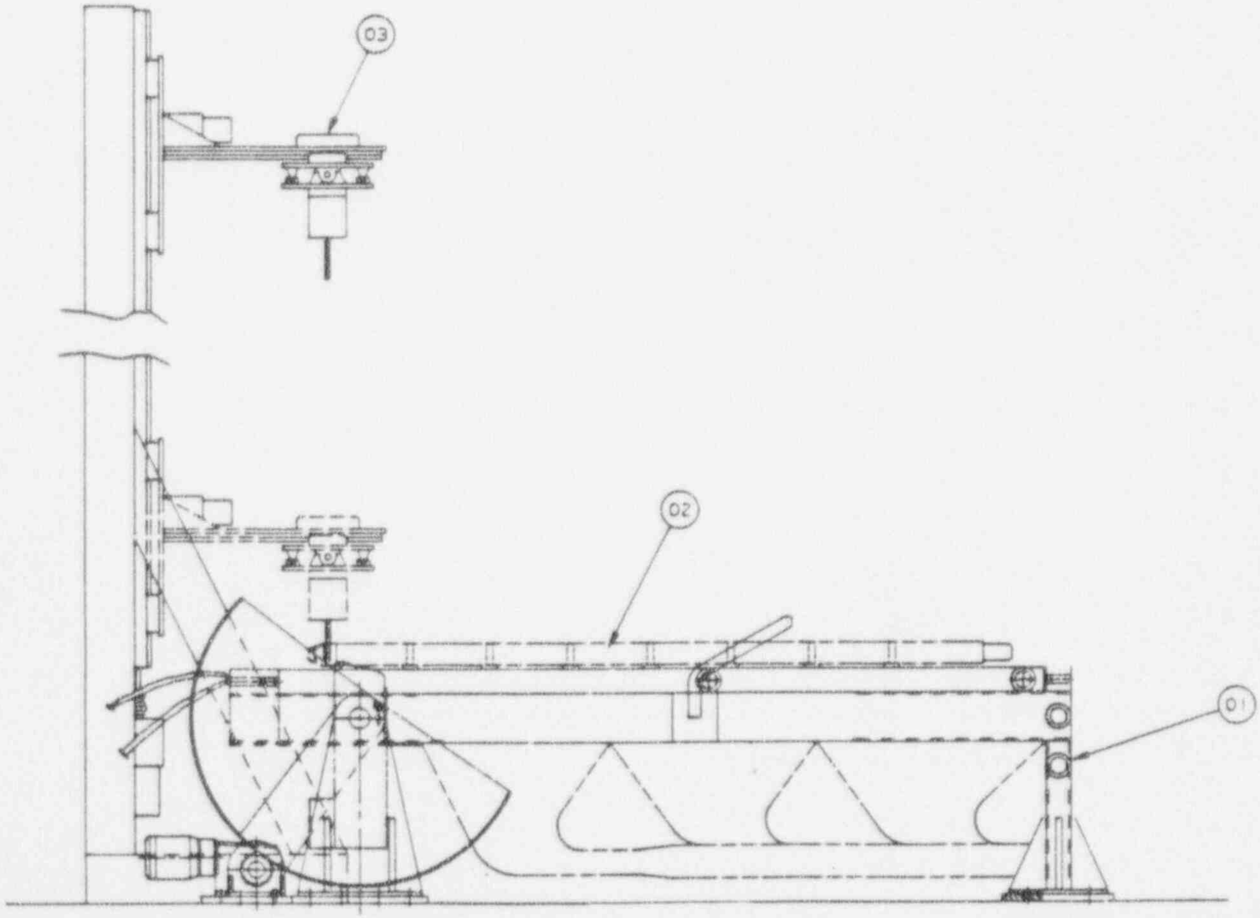
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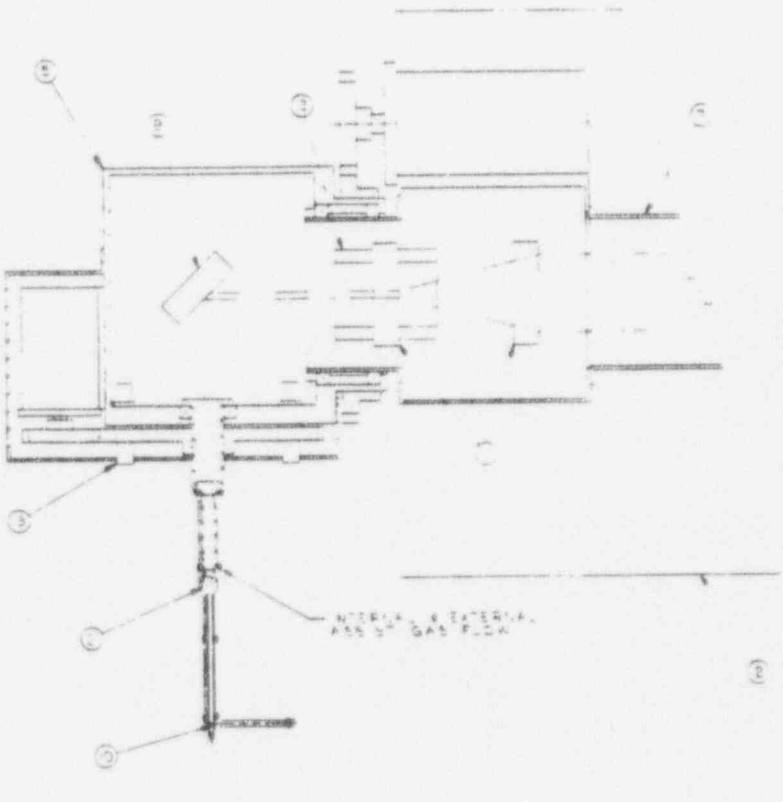
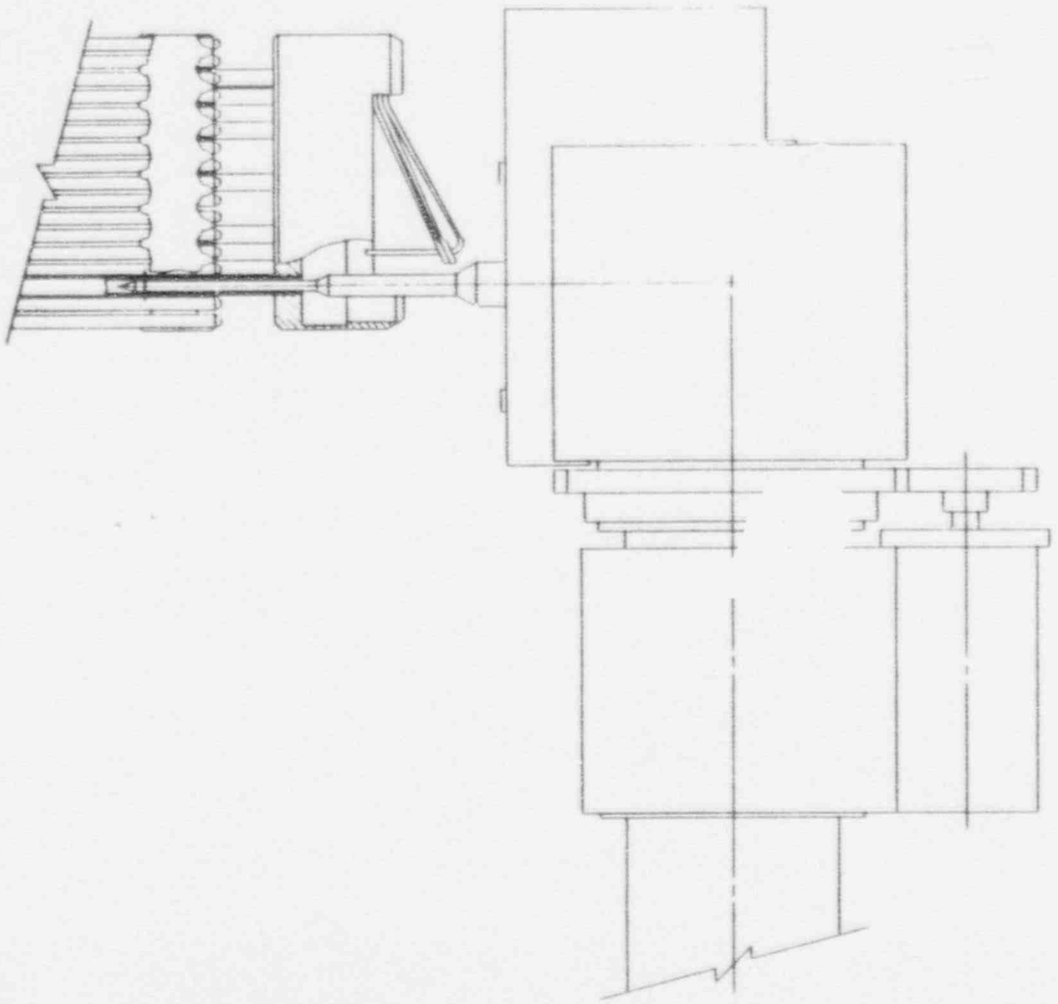
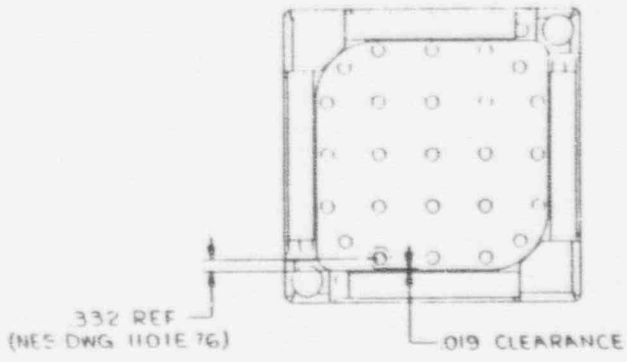
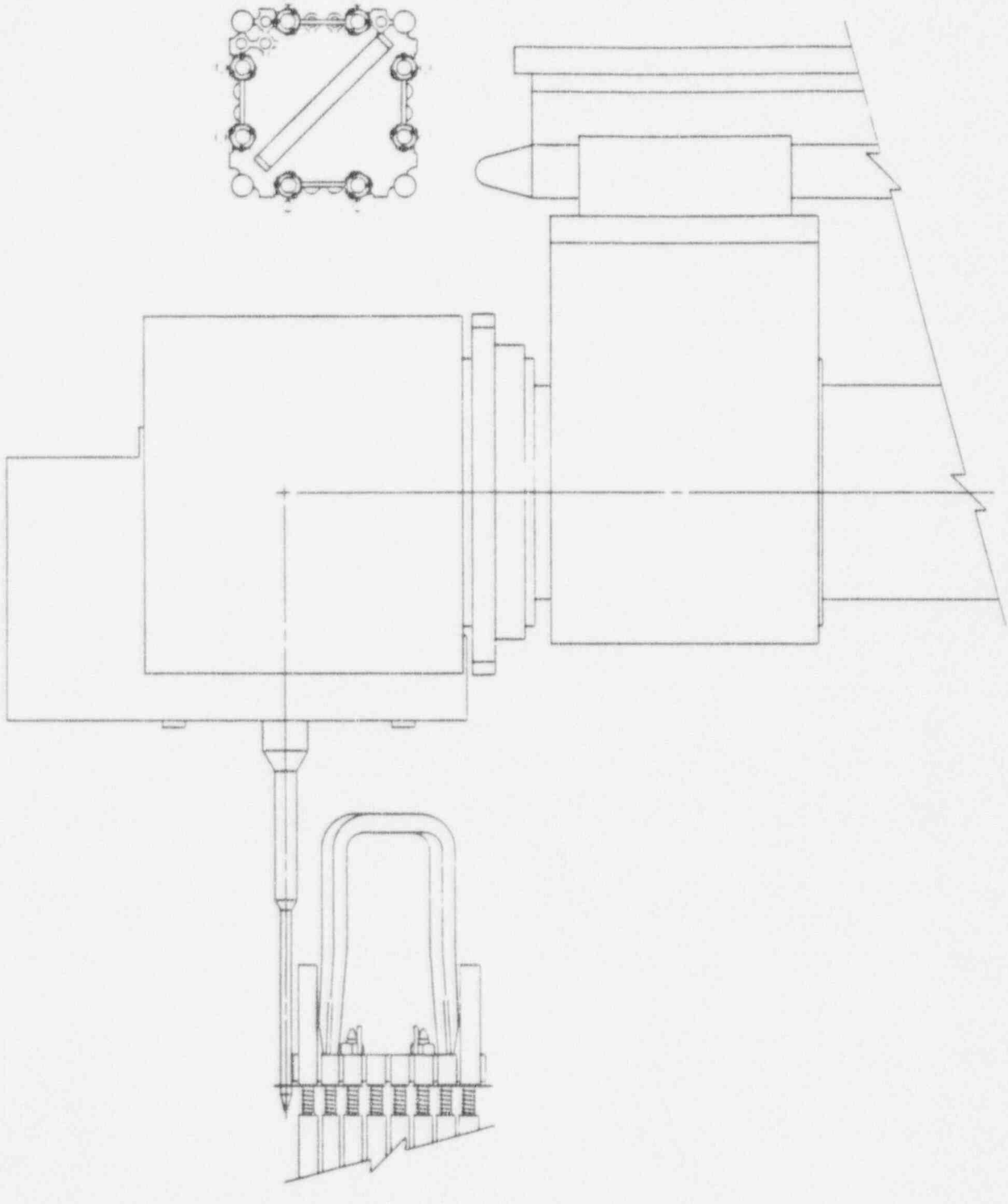

③
INTERNAL & EXTERNAL
ASSIST GAS FLOW

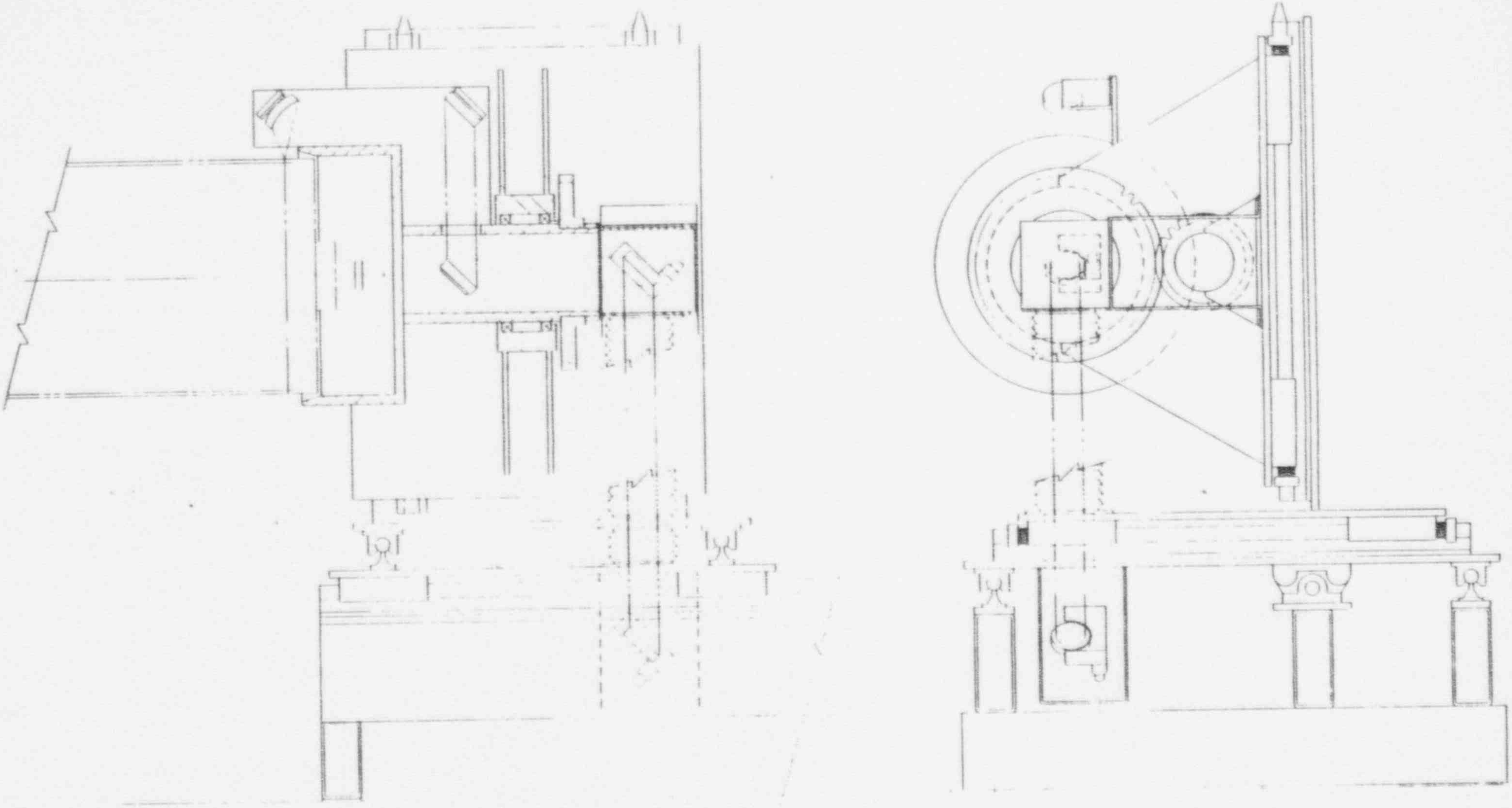
PWR



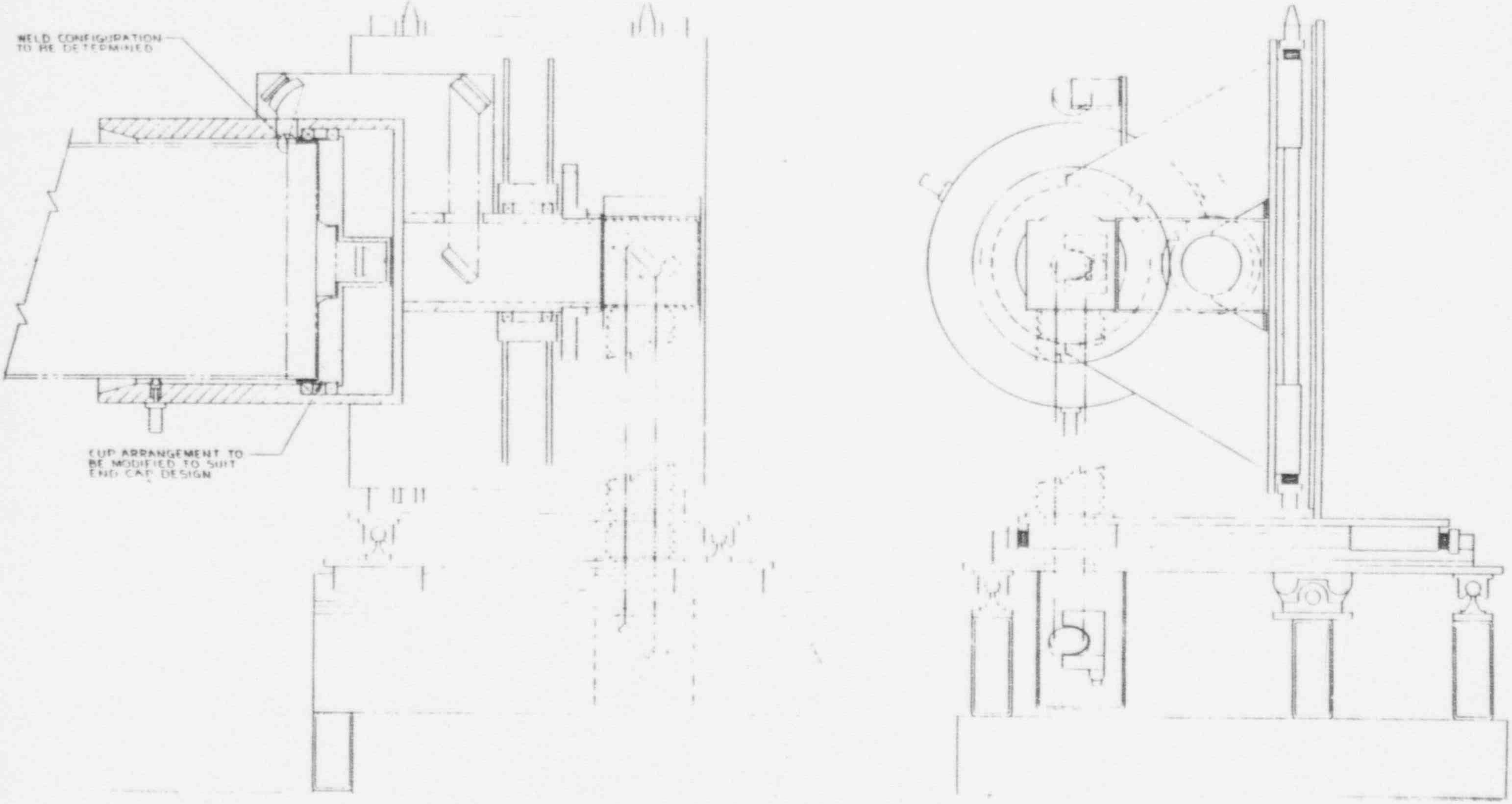




BWR



END CAP REMOVAL CONCEPT #1



END CAP WELDING CONCEPT #1