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Consolidated Fuel Reprocessing Program

A LASER CUTTING SYSTEM FOR NUCLEAR FUEL DISASSEMBLY

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ABSTRACT

A significant advancement in fuel reprocessing technology has been made by utilizing a multikilowatt, carbon dioxide laser to perform cutting operations necessary to remove unprocessible hardware from reactor fuel assemblies.

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INTRODUCTION

As part of the Consolidated Fuel Reprocessing Program, the Fuel Recycle Division at the Oak Ridge National Laboratory (ORNL) is developing equipment and processes to recycle fuel from fast breeder reactors and other nuclear fuel cycles. Reprocessing the fissionable material contained in spent fuel assemblies includes, as initial steps, removing unprocessible hardware from the fuel rods and shearing the fuel rods as a bundle into short lengths. This facilitates chemical leaching of the fissionable materials from the remaining metallic waste. Ultimately, the fissionable materials are refabricated into new fuel, and the metallic wastes are consolidated and packaged for safe burial. Although some previous work has considered the use of pulsed and low-powered CO_2 lasers for cutting and welding nuclear fuel rods during postirradiation examination, the work at ORNL is the first consideration of high-powered continuous wave CO_2 laser cutting of fast breeder reactor fuel assemblies performed in the United States.

A typical fast breeder reactor fuel assembly consists of 217 fuel rods containing the fissionable materials (Fig. 1). Each 6-mm-diam rod is a stainless steel tube with a wall thickness of 0.5 mm. To allow coolant to pass through the fuel assembly in the reactor, each tube is spirally wrapped with 1.5-mm-diam spacer wire. The rod bundle is enclosed in a hexagonal duct tube with a wall thickness of 3 mm. All metallic components are type 316 stainless steel and enter the reactor 20% cold worked. However, all materials exposed to neutrons in a nuclear reactor will become

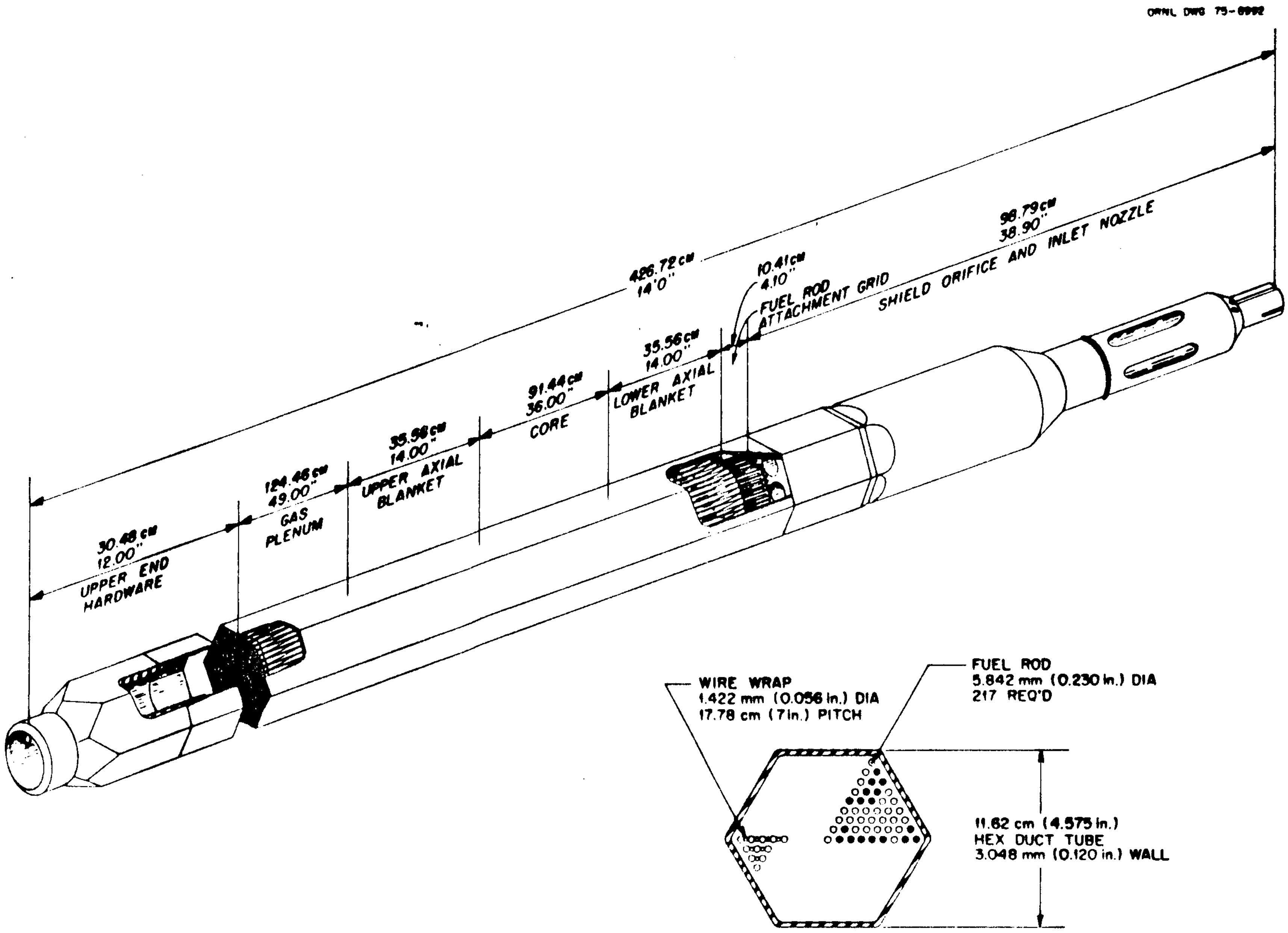

Fig. 1. Typical fast breeder fuel assembly

highly radioactive and also generate heat. This neutron activation also creates dimensional changes in the fuel assembly that cause bowing, swelling, and twisting.

The following environmental problems and system design criteria were established by ORNL to evaluate any cutting technique for removing hardware from spent fuel assemblies.

1. Due to the radioactivity generated by spent fuel assemblies, the cutting system must be operated and maintained inside a shielded hot-cell facility. The system should be of a modularized design to facilitate remote removal and replacement of any portion of the system using teleoperated servomanipulators and closed-circuit television. Alignment and maintenance of equipment in a hot-cell using hands-on methods is not permitted.
2. The amount of dross, or cut material lost to the general environment of the hot cell, should be minimized.
3. The cutting system must be capable of reliable remote operation while performing in a radiochemical environment. This environment may have an ambient temperature from 20 to 40°C, 30 to 50% relative humidity, nitrogen with less than 3% oxygen, and vapors of nitric acid, NO, and NO_2.
4. The amount of fissionable fuel (contained inside the fuel rods) vaporized or otherwise lost to the hot-cell environment should be minimized.
5. Any expendables required by the cutting system, including degradable components, gases, and fluids, should be minimized so not to add significantly to the decontamination and waste conditions already inherent in the disassembly operation.

The cutting devices that were evaluated at ORNL include the abrasive disk saw, plasma torch, band saw, electric-arc saw, milling cutters, and the laser. Several inherent characteristics of laser cutting suggest the desirability of the use of this process to cut metal in a hot cell:

1. No force is exerted on the fuel assembly by the cutting process.
2. Compared to the other metal removal techniques, the amount of material vaporized or lost as slag from the cut region is minimal, due to the small kerfs achievable with laser cutting.
3. The laser cutting process can be readily automated by suitable indexing of the beam transfer and focusing mirrors.
4. The laser itself can be located outside the hot cell, which greatly reduces the complexity of the laser cutting system in the hot cell.
5. In-cell system components which require maintenance and/or replacement can be relatively small and tolerant of the radioactive and corrosive environment.
6. The laser is a very versatile cutting method that can eliminate the need for any other cutting tool in the hot cell.

DISASSEMBLY PROCESS DESCRIPTION

The disassembly of a fast reactor fuel assembly involves three types of cutting operations—namely, circumferential, slit, and crop cutting. Circumferential cutting is accomplished by rotating the fuel assembly on its central axis while the focusing head of the laser cutting system floats in a cam-like fashion on the hex duct tube. The objective is to cut through the 3-mm-thick wall of the duct while minimizing fuel rod damage. Two circumferential cuts are required, one at each end, to remove the hex-shaped duct tube from the fuel assembly. Slit cutting is performed on a flat side of the hex duct by traversing between the previous circumferential cuts with the focusing head. Three slit cuts are required, on alternating sides, to remove the hex duct as three pieces. Again, the objective is to only cut through the wall of the duct while minimizing fuel rod damage. The objective of crop cutting is to separate the fuel rods from the fuel rod attachment grid at the lower end of the fuel assembly. This requires deep, penetrating cuts into the fuel rod endcaps. The operation is similar to circumferential cutting in that initially the fuel assembly is rotated while the focusing head floats on the hex duct tube. Following the rotation phase, the focusing head scans each flat twice, cutting as deeply as possible. This procedure is repeated until all fuel rod endcaps have been cut.

PROCESS VARIABLES

The laser cutting process variables evaluated as part of the system development are listed and illustrated in Fig. 2. Optimum values of these variables are not independent but have a strong dependence on one another. Laser power and cutting speed are closely related, especially under conditions where the depth of cut must be accurately controlled to cut through the hex duct tube

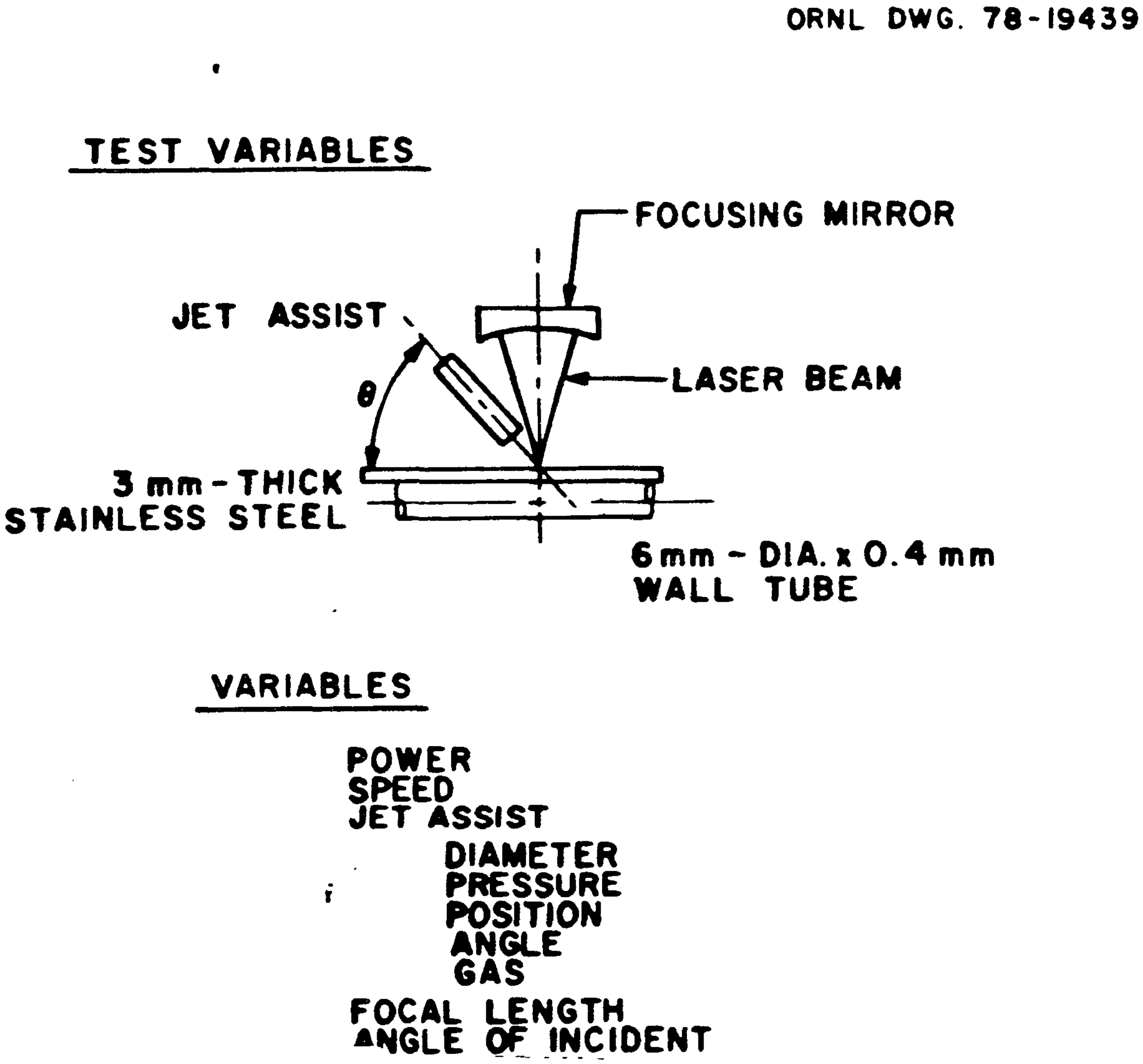

Fig. 2 Process variables

without damaging the internal fuel rods, which have a 0.4-mm wall thickness. For effective laser cutting, a gas-jet assist is normally employed to help remove vapors and molten material from the cut formed at the beam impingement point. The jet assist is a small tube positioned to angle its high-velocity gas stream at the laser beam impingement point. Laser cutting results are strongly influenced by the f-number (f-number = optical focal length ÷ unfocused beam diameter) of the laser focusing system. In general, low f-numbers result in higher intensity at the focal point but shorter depth of field. Systems with large f-numbers have a lower focal point intensity, but greater depth of field.

LASER CUTTING SYSTEM DESCRIPTION

The laser cutting system is composed of three principal subsystems: the laser generator subsystem, the beam transport subsystem, and the laser focusing subsystem. Two of these, namely the beam transport and the laser focusing subsystems, must be maintained remotely inside the hot cell.

THE LASER SUBSYSTEM

The laser employed for the development at ORNL is a closed-cycle, convectively cooled, continuous-wave, carbon dioxide laser, model TM31-9, from United Technologies (Fig. 3). The laser provides, via unstable resonator optics, an unfocused 5-cm-diam annular beam. The rated optical power is 9 kW. The measured long-term beam divergence is less than 2 milliradians, and the long-term pointing stability is less than 0.2 milliradians. In

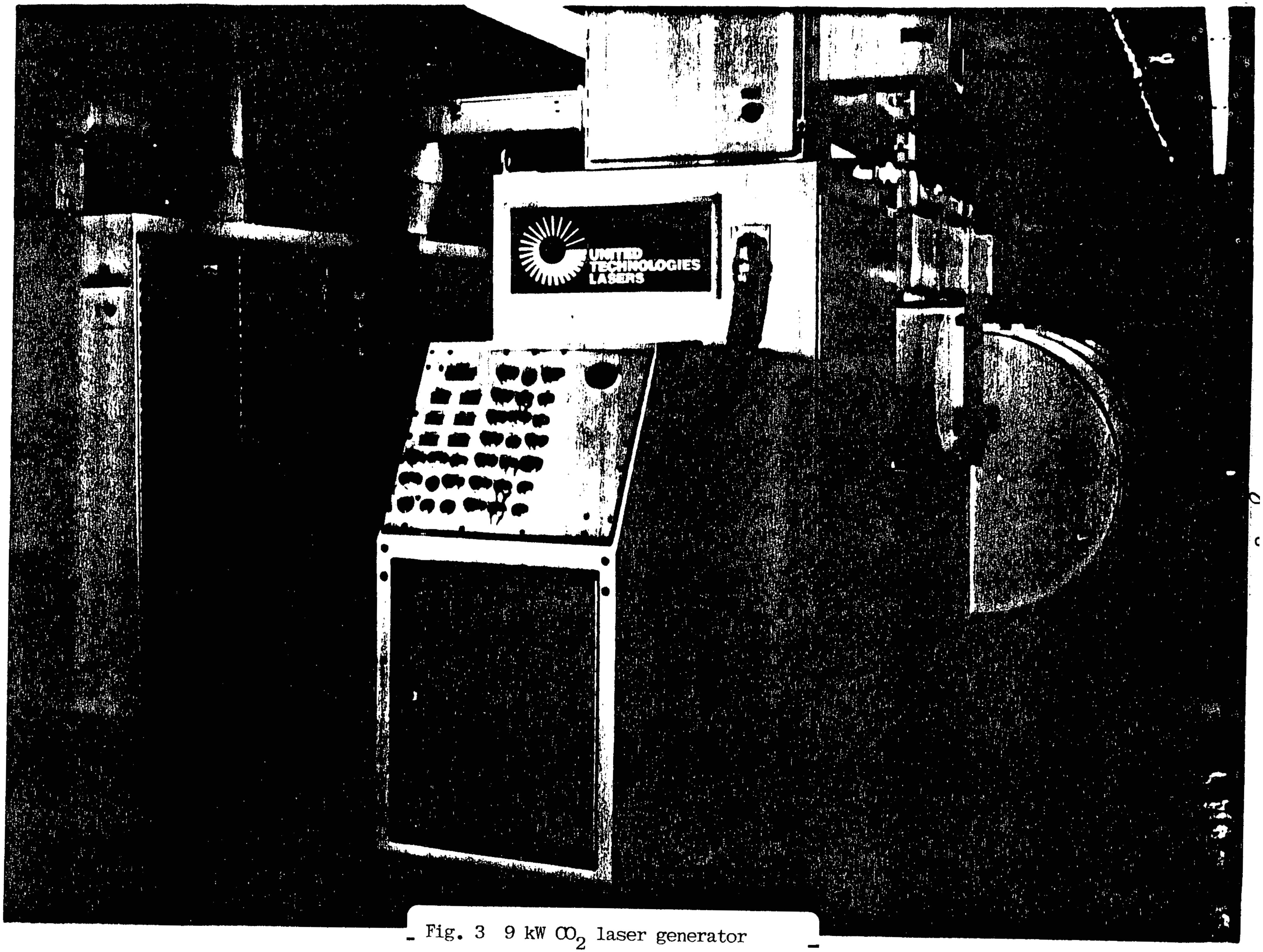

Fig. 3 9 kW CO_2 laser generator

addition to the carbon dioxide laser, there are two helium-neon lasers incorporated into the subsystem for use during optical alignment.

THE BEAM TRANSPORT SUBSYSTEM

The purpose of the laser beam transport subsystem is to transfer the laser beam from the laser subsystem, through a zinc selinide window in the hot-cell wall, to the laser cutting subsystem (Fig. 4). The hot-cell window is a special shielded design which prevents direct gamma radiation from streaming through to expose personnel or to damage the zinc selinide window. Water-cooled molybdenum mirrors on motorized mounts are incorporated in the beam transport subsystem. The total beam path is enclosed and purged with filtered air to provide safety and a dust-free beam path.

THE LASER FOCUSING SUBSYSTEM

The laser focusing head subsystem positions and focuses the laser beam on the spent fuel assembly being disassembled (Fig. 5). Ball screw drives position and control movable tables along three major axes to provide the required locations and motions of the beam focal point. Four uncooled molybdenum mirrors, mounted in the focusing head, receive, turn, and focus the laser beam onto the fuel assembly. The floating head mechanically follows the surface of the fuel assembly while maintaining the laser beam focal point-to-work surface relation. The head follows the fuel assembly surface using gimbal-type contact arms with cylinderical rollers attached to a spring-loaded table. A rotating

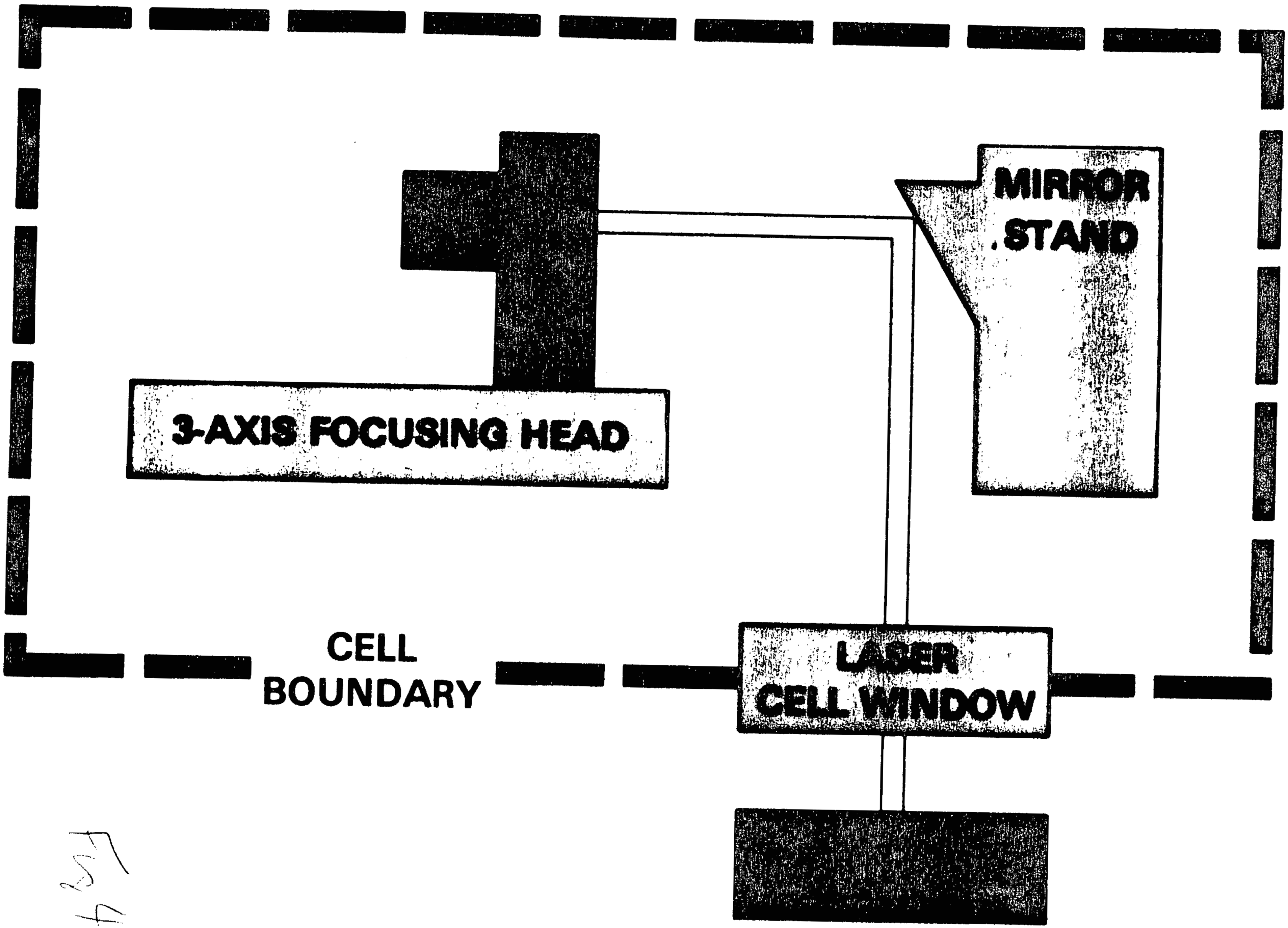

Fig 4

Fig. 4 The laser beam transport Subsystem transfers the laser beam from the the laser to the 3 AXIS focusing head.

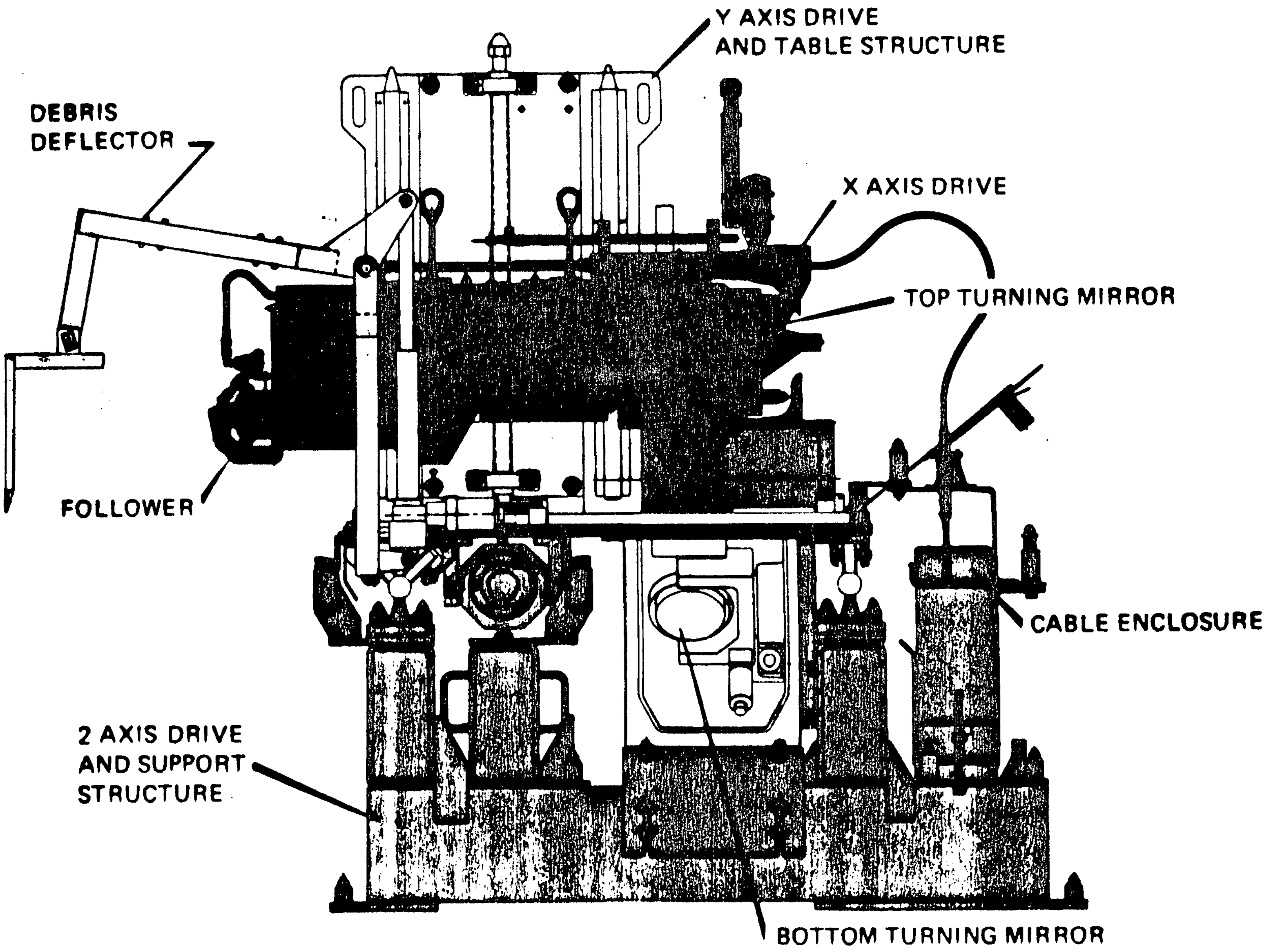

Fig. 5 Laser cutting system

head feature allows the laser focusing head to be driven parallel to the assembly for lengthwise slit cuts and then rotated for circumferential and crop cuts. A gas jet is provided to remove the molten kerf during cutting. A debris collection system consisting of a gravity settling section for large particles and a gas-jet aspirator/filter for all but submicron-sized particles is attached to the laser focusing head.

ALIGNMENT AND MAINTENANCE

To facilitate remote alignment of the laser system optics, all mirror mounts inside the hot cell are motorized and equipped with prealigned targets that can be rotated into position remotely during the alignment procedure. To align the optics, the visible HeNe laser and invisible carbon dioxide laser are first made coincident by using Lucite burn patterns in the near and far field regions outside of the hot cell. Once coincident, the HeNe laser beam is progressively used on each mirror target down the beam path until all optical components are aligned. A telescope or remote television cameras are used to observe the mirror targets during remote mirror alignment. The final alignment of the focusing mirror and the gas-assist jet is verified by remote television cameras and cutting tests.

All maintenance performed on equipment in the hot cell must be performed with an overhead crane, power manipulator, or teleoperated servomanipulator. For this reason, the entire in cell portion of the laser cutting system has been designed into modular packages

Photograph of
LASER CUTTING SYSTEM
BEING MAINTAINED
BY M2 MANIPULATOR.

Fig. 6

that can be removed and replaced remotely (Fig. 6). Other design features that facilitate remote maintenance include (1) captured fasteners, (2) hoist/crane lift fixtures, (3) positioning guides to aid reassembly, and (4) quick-disconnect electrical and tube couplings.

RESULTS AND CONCLUSIONS

The laser cutting system has been installed in a nonradioactive remote operation and maintenance test area where the system is undergoing detailed component development and remote maintenance testing (Fig. 7). The laser disassembly processes, described in this paper have been successfully demonstrated using dummy fast reactor fuel assemblies containing a porcelain substitute for actual fissionable materials (Figs. 8 through 10). Minor damage to fuel rods during laser disassembly has been observed but is considered to be acceptable for process requirements. Future work will continue at ORNL to reduce the fuel rod damage by improving the process control.

In conclusion, the laser has been successfully demonstrated to be a valuable tool for use in nuclear fuel disassembly. The most significant development required for using the laser in a hot cell is the electromechanical and optical transfer systems. The radioactive environment creates additional problems for system maintenance and alignment that most industrial laser applications do not need to consider. Other potential applications for a high-powered laser in a hot cell might include seal welding waste canisters, process piping repair, and equipment dismantling during plant decommissioning.

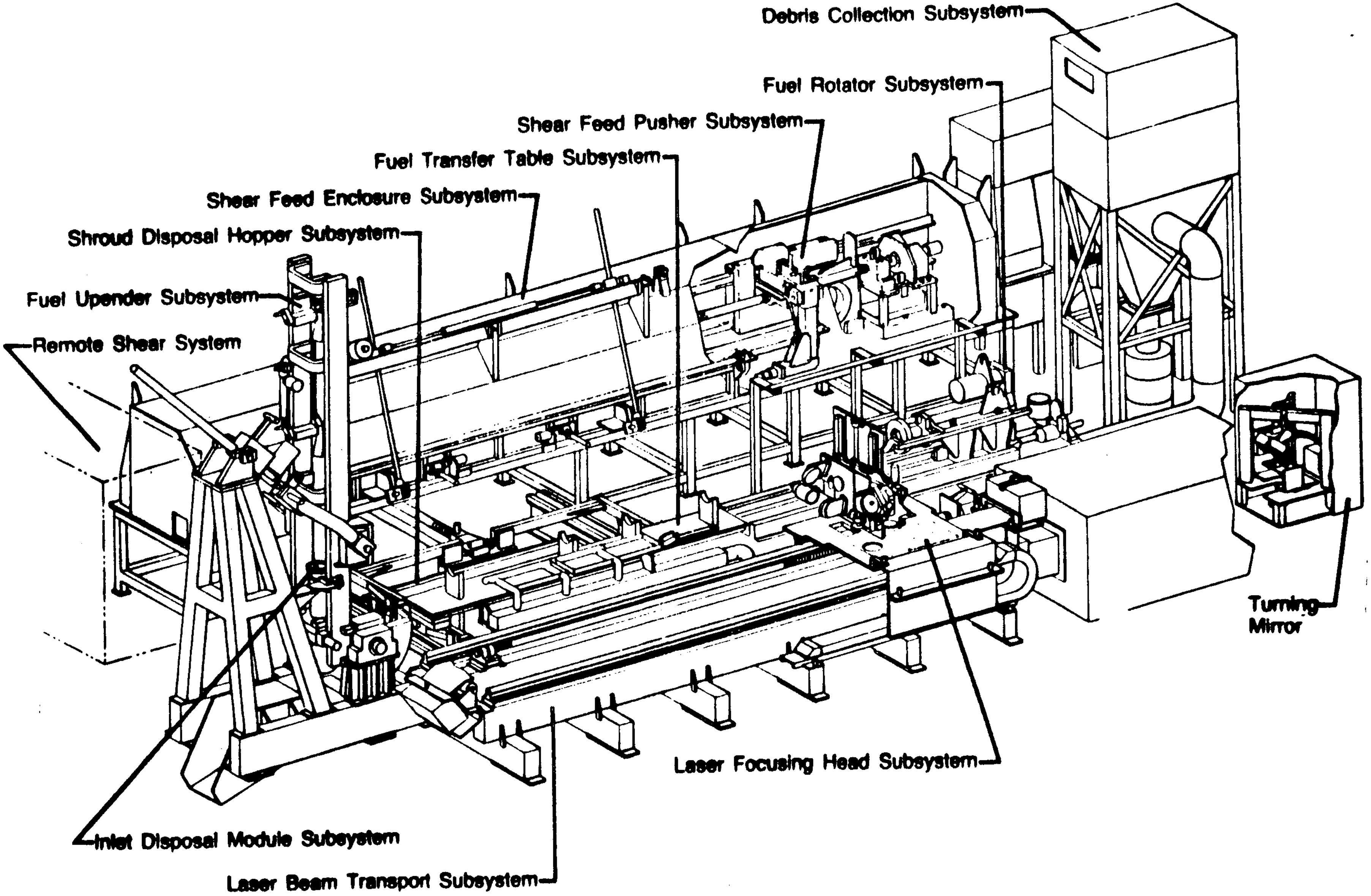

Fig. 7 The disassembly system showing the integrated laser focusing head subsystem

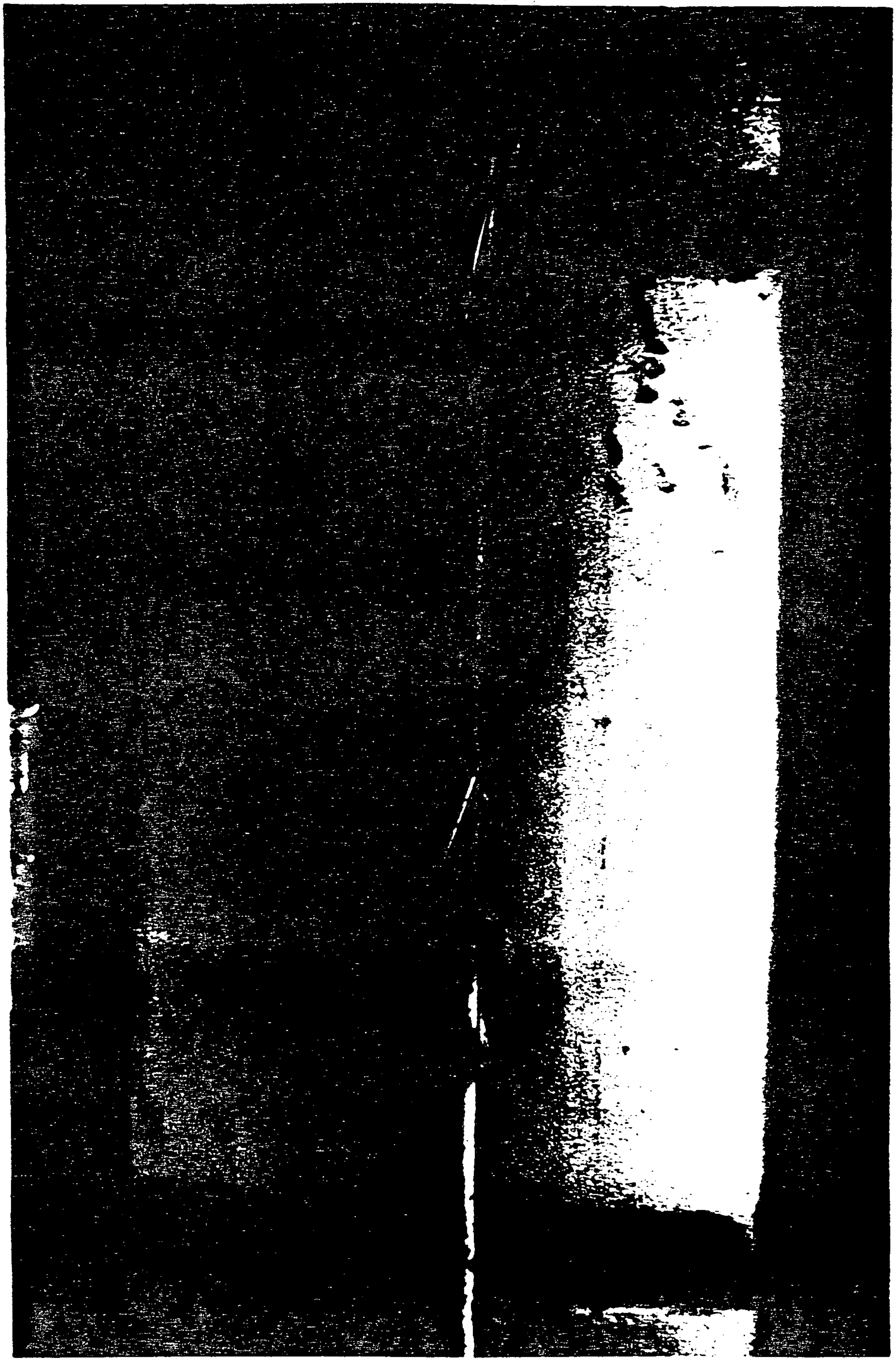

Fig. 8 Slit cutting results

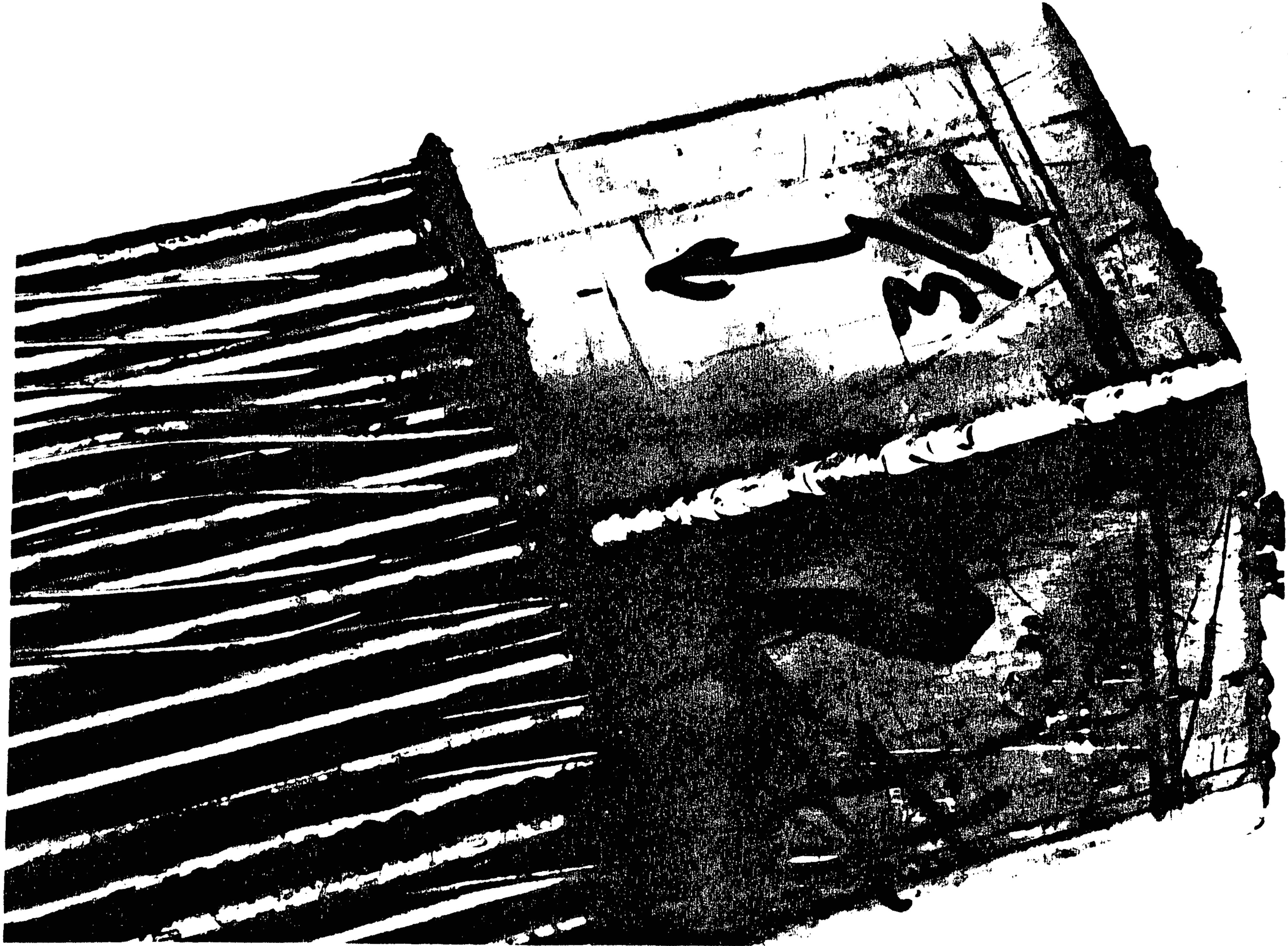

Fig. 9 Circumferential Cutting Results

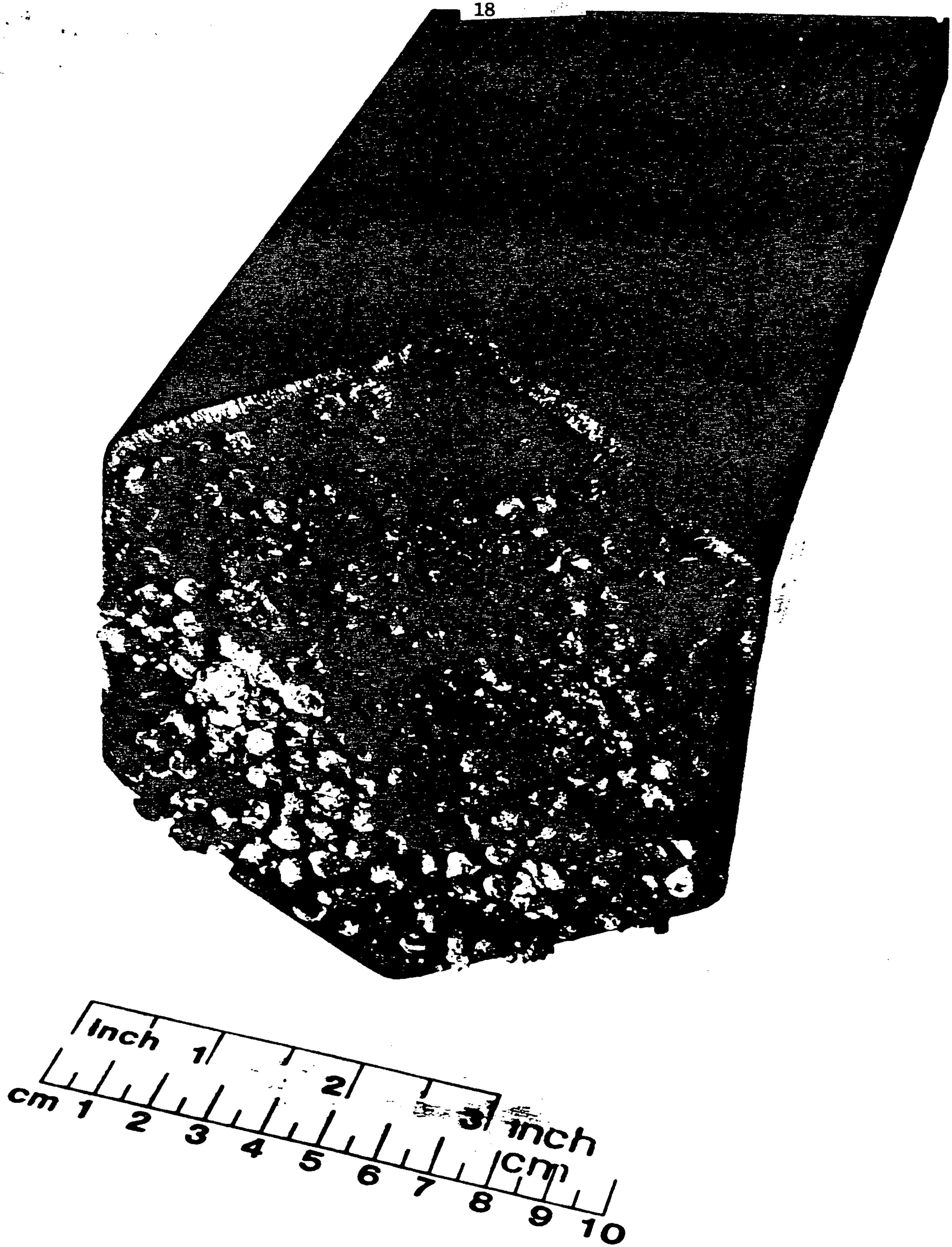

Fig. 10 Cropping results

BIOGRAPHY OF THE AUTHOR

Since joining the development staff of the Consolidated Fuel Reprocessing Program at Oak Ridge National Laboratory in 1974, Mr. Weil has worked on several mechanical systems designed to disassemble and shear nuclear reactor fuels for reprocessing. He has been responsible for several patents and has authored several reports on this development. Mr. Weil holds a B.S. degree in mechanical engineering from Virginia Polytechnic Institute and State University. He is a member of the American Nuclear Society and holds a professional engineering license in the state of Tennessee.